Ecological Monitoring, Research & Demonstration

Progress of Long-Term Ecological Research in China

Chinese Ecosystem Research Network

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Chinese Ecosystem Reaearch Network

August 2007, Beijing

Preface

It was witnessed the establishment of Chinese Ecosystem Research Network (CERN) by Chinese Academy of Science (CAS) in 1988, which consisted of 29 ecological field stations, 5 sub-centers and 1 synthesis center at the very beginning. In 2002, CAS expanded CERN by adding 7 stations to 36 sites in total, and set up ChinaFLUX based on CERN. In 2005, China National Ecosystem Observation and Research Network (CNEN) was launched by the Ministry of Science and Technology (MOST), selecting 33 ecological field stations from CERN and 18 ones from other sectors. Meanwhile, the Synthesis Center of CNEN is also based in the Synthesis Center of CERN.

CERN carries the mission that through long-term observation and experiment on the ecosystems of various regions and types across China, and with technological methods like simulation and modeling, GIS, by adapting multi-dimensional approaches on observation, experiment, integration and cross-scale recognition and modeling, it aims to explore the structure, function, process and changing patterns of ecosystem driven by global change and human activity, to discuss the management of ecosystem structure, patterns and process, as so to provide reliable and dynamic monitoring data, sufficient scientific support and appropriate technology for China's biological resource conservation, ecosystem management, grain production, natural resources management, environment protection and adaptation to climate changes.

Through decades of development, CERN has become the pivot of the national field station system, and the pioneer on ecosystem and global change monitoring, research and demonstration in China. In particular, in recent years, CERN plays an important role in national scientific innovation and fundamental supporting systems by initiating the researches on terrestrial ecosystem on C, N and water fluxes, biodiversity and ecosystem function, transect and control experiments on ecosystem's response to global change, as well as specialized observation and pilot platform of ecosystem restoration.

CERN serves as the supporting platform in undertaking various scientific researches at the national and regional levels. According to the rough statistics from 2001 to 2005, as the scientific platform, CERN undertook and participated 9 national 973 projects, 5 national 863 projects, 15 science innovation programs, 8 key fund projects, 17 excellent youths projects, 6 ministry key programs, and 26 CAS Excellent Young Scientists Programs, with a total research fund of RMB 218.56 million in field stations and centers. Besides, CERN also took charge of 16 key projects of National Natural Science Foundation of China, 227 General Project Funds, 49 CAS key programs, 59 international cooperation projects, with a total research fund of RMB 345.22 million yuan. Over the past five years, the scientific staffs of CERN released 7150 scientific papers, amidst which, 1322 were cited by SCI, 204 by EI, and 5043 by CSCD. In addition, 201 monographs were published, and certain high quality scientific papers appeared in publications with global influence like *Nature* and *Science*. Based on the work in the field stations, the researchers of CERN were awarded 121 science prizes, amidst which, 15 projects got the National Second-Prize of Scientific Innovation and 48 got provincial/ministerial prizes.

The scientific research of CERN focuses on China's regional ecological environment changes, the land temporal-spatial pattern of carbon & water cycle and balance, the ecosystem structure and function, process and pattern, restoration and management, as well as ecological data technology and sharing. To meet the needs of national and local economic development and eco-environmental development, the field stations of CERN also carry on a wide range research on technology development, pilot demonstration and macro-policy making. CERN makes outstanding scientific contribution to the ecosystem protection through various management and treatment on saline land in northeast plain, southern uplands, ecosystem restoration, water eutrophication and pollution, water loss and soil erosion area on Loess Plateau and desertification control.

The collected works of this book is made in accordance with the decision of CERN Scientific Committee (SC) in December 2006 and complied by the CERN field stations, Sub-centers and the synthesis centre coordinated by CERN Secretariat of SC and the Leading Group Office. It is an overall representation of main scientific researches on ecology of CERN in recent years. It briefly demonstrates the main progress made by CERN's field stations, sub-centers and the synthesis center, which would provide the ecologists and gratuates scientific staffs with some useful information.

Chinese Ecosystem Research Network

August, 2007

01

Monitoring, Modeling and Synthesis Studies of Terrestrial Ecosystems in China

Scientific Research Progress of Synthesis Research Center, CERN

Introduction of Synthesis Research Center

The Synthesis Research Center of Chinese Ecosystem Research Network (CERN) was officially established in 1990 as an organization under the Commission for Integrated Survey of Natural Resources of Chinese Academy of Sciences (CAS), which was incorporated with the Institute of Geography of CAS in 2000 and the Synthesis Research Center was reorganized at the same time.

According to the constitution of CERN, the basic functions of Synthesis Research Center are: integrating, managing and sharing the CERN's monitoring data; predicting the evolvement trends of resources, environment and ecosystems, and synthetically researching on key scientific problems at regional and national scales; publishing research results of CERN; and providing information and policy consultation for the decision-making of key problems in national economy construction. In addition, the Synthesis Research Center is also in charge of establishing criterions, standards and instructions for CERN stations in field observation, data collection, instrument calibration and data quality control.

The major research areas of Synthesis Research Center cover ecosystem primary productivity, carbon and nitrogen process, water cycling and utility, ecosystem function evaluating and management, ecosystem health and restoration, and integrated research of key scientific problems in the fields of resources and environment.

The Synthesis Research Center of CERN has managed to find a sustainable development way under the supports from government and research organizations, and has been forming an integrated service organization and ecosystem research unit, as a quaternity of International – National – CAS (Chinese Academy of Sciences) – Institute, gradually. Based on the Synthesis Research Center of CERN, the Key Laboratory of Ecosystem Network Observation and

Modeling of CAS was established in 2004, and the Synthesis Research Center of Chinese National Ecosystem Observation and Research Network was formed in 2005. This will provide a platform for researching on the ecosystem processes at national scale, and advance the roles of CERN in the national science and technology innovation system. From its establishment, the Synthesis Research Center of CERN has made remarkable success and progress on the following aspects.

1. Sharing systems of CERN's dynamic monitoring and spatialization database

Many efforts have been made to standardize the long-term monitoring technique and data management among all the CERN stations according to the ecological types of crop, forest, grass, water, desert, swamp (marsh) at each site. The guidance for long-term observation and data quality control has been published in *the Monitoring Manual of CERN*. We have submitted *the monitoring standard* to the scientific committee *of CERN*. The monitoring data from all the stations is vast. In order to effectively manage the mass data and provide better service for scientists and researchers, *the criterion of CERN data service* was made according to the classification of data users. The Synthesis Research Center has played an active role in the publication of *the National Standard of Ecological Data*. *The Standard of CERN's Long-term Monitoring Data* has also been published and the new *criterion of CERN Metadata Service* for ecological researchers is under writing.

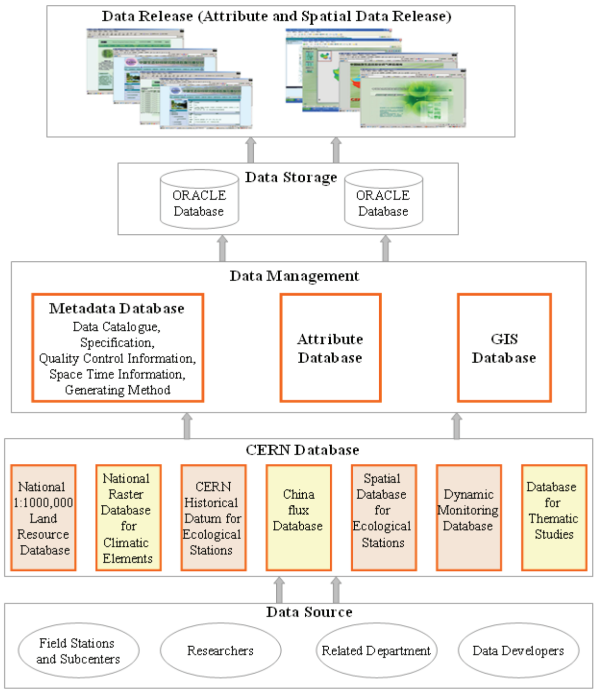

Fig. 1.1 The structure of CERN database and information management system

Data is the foundation of scientific researches. Reasonable data filling, data arrangement and quality assurance and developing new dataset by making full use of modern information technology provide assurance for data sharing. From 2001 to 2005, Synthesis Research Center has, for the first time, achieved scientific management of long-term dynamic monitoring data from the 36 field stations. At the same time, Synthesis Research Center published the *Spatial Information Atlas of CERN Field Stations* and the *Statistical Dataset for Water, Soil, Atmosphere and Biology of CERN (1998-2001)*. These publications have been cited by general scientific researchers. Meteorological data is very indispensable for researches on issues about ecology, biology, geography and agriculture and global change, and it especially plays an important role in simulating ecosystem change and ecosystem management at regional and global scales. Synthesis Research Center developed spatial information of terrestrial ecosystem in China----climatic elements database and published *Atlas of Specialization of Terrestrial Ecosystem in China----Climatic Elements* by using the basic meteorology data and national DEM data. The database consists of 1km×1km raster data covering the whole nation of more than 20 climatic elements such as radiation, temperature, precipitation, humidity, wind and climatic index and so on. With regard to scientific research data, the ChinaFLUX Database and China Forest Biomass Database were also established at Synthesis Research Center to provide data services for National 973 Program and key projects of CAS.

The Synthesis Research Center of CERN also designed the information systems for the sub-centers and each station and provided technical support to them. With the WebGIS and JSP techniques, the Synthesis Research Center had accomplished a series of data-information sharing systems to provide data service to the public, including all the metadata and observation data listed above. Users can obtain the original monitoring data, metadata and some other integrated data products by visiting CERN's data sharing website. People can directly submit the field observation data at five sites of DHS, QYZ, FQ, YC and LS and biology sub-centre to the central database server at Synthesis Research Center based on the web-database technique. A series of software referred above are to be granted with patents (Fig. 1.1).

2. Systematic observation and research on carbon, water fluxes in terrestrial ecosystem

Chinese Terrestrial Ecosystem Flux Observational Research Network (ChinaFLUX) was established in 2002 at Synthesis Research Center, with the support of the Knowledge Innovation Program of CAS and the National Key Basic Research and Development Program (973 Program) and cooperation with other institutes and some sites of CERN. Observational system of ecosystem carbon, water and energy fluxes had been set up at eight stations, combined with measurement of soil respiration at sixteen stations of CERN from 2001 to 2006. Based on Synthesis Research Center, ChinaFLUX has provides an advantageously experiment and data platform for the researchers of water/carbon cycles, ecosystem changes, global changes and global system science in China.

(1) Setting up principles and methodology of flux measurement

A series of technical problems had been solved by ChinaFLUX, which applies uniform observational techniques and methods across different sites or ecosystems types. The criterion of data quality control and evaluation was set up for the first time by synthetically analyzing long-term, continuous data of CO_2 and water flux. It realized long-term observation of CO_2, water and heat flux between vegetation and atmosphere at ecosystem scale over complex topography and unfavorable micrometeorological condition. The principles, techniques and methodology system of flux observation had been set up and the monograph '*Principles of Flux Measurement in Terrestrial Ecosystem*' had been published.

(2) Obtaining long-term observation data

Continuously long-term observation data of carbon, water and heat flux over typical terrestrial ecosystem in China had been obtained for 4~5 years. Meanwhile, ChinaFLUX researchers emphasizes on the synchronous monitoring of environmental factors of SPAC (soil-plant-atmosphere continuum), by measuring the physiological parameters, collecting site information about vegetation, soil, hydrology, meteorology and planting system at each site to insure the integrity of observation items and diversity of data use, which also forms a data foundation for integrated research on carbon and water cycles at ecosystem and transect scales.

(3) Evaluating carbon source/sink and analyzing the mechanism in typical ecosystems

Based on long-term observation of CO_2 flux between vegetation and atmosphere by ChinaFLUX, we investigated the formation and variation mechanism of carbon flux in major terrestrial ecosystems in China; analyzed the effects of climatic and environmental changes on carbon flux across different biomes and ecosystems at different time scales; and evaluated the spatial pattern of carbon source/sink of major terrestrial ecosystems in China. These studies have provided plentiful data for validating carbon cycle models, scaling up and predicting the trends of terrestrial ecosystems changes under future climate change scenarios in China. It also filled the blank of observation data and integrated research in Asia monsoon area, enriched the regional observation data of global flux measurement, and provided reliable data and knowledge for our country taking part in international negotiation about carbon emission reduction (Fig. 1.2).

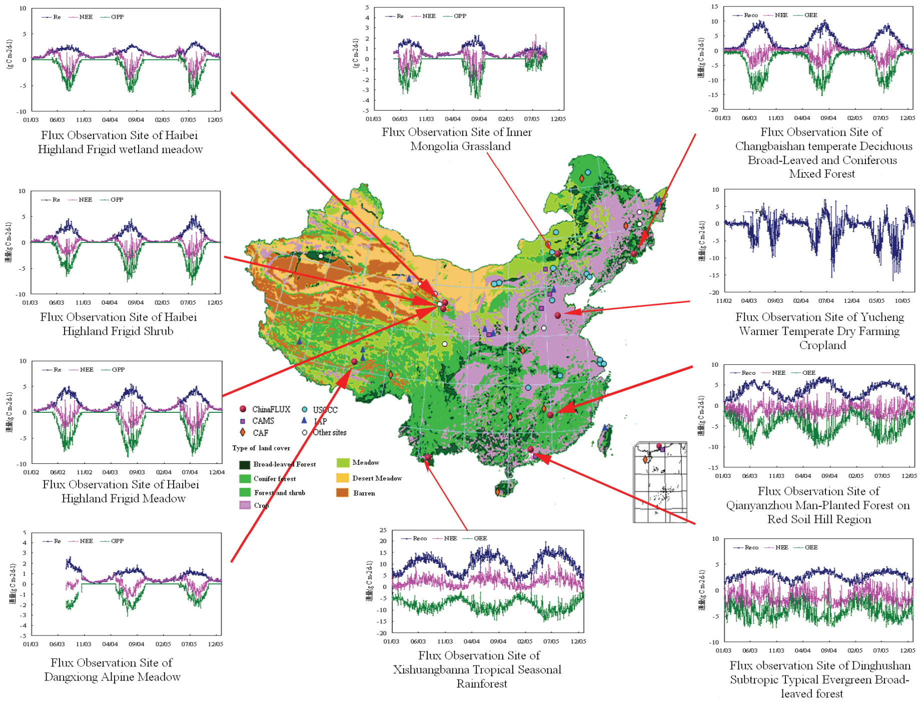

Fig. 1.2 The seasonal and interannual trends of carbon flux across ChinaFLUX sites

3. Study on the spatial and temporal pattern of carbon storage in Chinese terrestrial ecosystems

(1) Effect of land use change on the storage of organic carbon and nitrogen. Based on the Second National Soil Survey, researchers of Synthesis Research Center constructed the soil profile database and spatialized the basic soil data in Chinese terrestrial ecosystems. Based on the first and the Second National Soil Survey, the influence of land use change from 1960 to 1980 on soil carbon pool was discussed. The spatial and temporal characteristic of land use change in the Yellow River delta, the Northeast of China and the whole country was achieved by using the Landsat images in 1990s. The changes of soil carbon storage and nitrogen due to land use conversion among grassland, forest and farmland were estimated. The researchers elucidated characteristic of spatial and temporal pattern of carbon storage in soil by improving the "book keeping" method used in land use change. These studies preliminarily indicated the forest plantation in China has large potential to sequestrate carbon and provided the scientific foundation for researchers to predict the possible changes of carbon and nitrogen storage in Chinese terrestrial ecosystems in the future due to land use and cover change (LUCC).

(2) Based on the biology principle of foliage growth, a phenology model that simulates the seasonal dynamic change and geographic distribution of forest LAI was developed. The researchers demonstrated geography distribution of carbon storage in Chinese forest. Based on

transect research on Qinghai-Tibet Plateau, the relationship between NPP, aboveground and belowground biomass, LAI of natural vegetation and climatic factors could be well fitted by logistic function. The researchers validated Weber's Law in terrestrial ecosystems by using a mass of measured Data. A dynamic balance existed in the relationships between LAI, precipitation and water, nutrient content in soil and these relationships had a threshold value. The interaction between LAI and nutrient content in soil (especially nitrogen) had a great influence on the canopy photosynthesis. These relationships could help to create regional terrestrial ecosystem model.

(3) Researchers have illustrated the spatial distribution of carbon density in national forest vegetation during 1973-1977, 1978-1980, 1984-1988, 1989-1993, and 1994-1998, respectively. Based on survey data from more than 5000 forest stands, researchers have estimated the total biomass and productivity of China's forests between 1989 and 1993. Dr. Luo Tianxiang has calculated the total biomass and the potential distribution of vegetation productivity for 117 counties in Tibet, basing on nearly 100,000 records of vegetation productivity data in this region. Based on the stands records (1993 to 1998, over 150 thousands stands) of the first-class data in national forest survey dataset, the distribution of vegetation, soil and litter carbon pools have been estimated by GIS models. Three recommendable innovations from above-mentioned studies include: (i) For the first time, the time-series vegetation classification maps and carbon density distribution maps of forests in China were developed; (ii) A novel remote sensing classifying method for forest vegetation based on exponential categorization of leaf life was established; (iii) developed a new theory for spatially mapping carbon density by integrating data from different sources and controlling the gross precision. The outcomes will be an important fundament for biomass carbon pools estimations and remote-sensing-based vegetation sorting.

(4) Researchers have implemented the investigations on formative mechanisms of grassland ecosystem's productivity and developed the rule of grass re-growth decline and the model framework on environmental gradients theory of grass productivity. The integrated observations and investigations for material cycles in southern grassland ecosystems have been implemented; and characteristic rules of trophic dynamic, nutrient accumulation and allocation of grassland ecosystems have been revealed. An application model and a search system for grass production managements have been established, as well as a dataset for Chinese Grassland Transect (CGT). Furthermore, the carbon pools and their spatial patterns of China's grassland ecosystems have also been estimated.

4. Synthesis study on multi-scale modeling of terrestrial ecosystem

All experiments and measurements are based on some given scales, which are not enough to help us understand and estimate the interaction of the key factors or processes at different scales. Models enable people to estimate and evaluate the spatial pattern and change trend of the main processes of terrestrial ecosystem. With the development of RS, GIS as well as computer technology and the understanding to the structure, function and process of terrestrial ecosystem, researches on terrestrial ecosystem models progressed rapidly and has become an irreplaceable method in ecological study.

Recently, the Synthesis Research Center have improved and developed a series of ecological models based on data from multi-scale observation, including coupled models of stomatal conductance-photosynthesis- transpiration, SPAC models coupling water and carbon cycles (Such as stomatal conductance combination model at long time scale, coupled model of stomatal conductance-photosynthesis, Synthetic Model of Photosynthesis-Transpiration based on Stomatal Behavior (SMPTSB), Water Use Efficiency model based on SMPTSB (SMPTSB-WUE), SPAC water and carbon cycle model at field scale, Ecosystem Productivity Process Model for Landscape (EPPML), VIP model, AVIM model, photosynthesis model, EPS model, etc.), and phonological models of seasonal and spatial variation of LAI. With these models we simulated the processes of water and carbon cycles in different terrestrial ecosystems, which lay a good basis for further study on modeling terrestrial ecosystem water and carbon cycle, provided useful tools to carry out coupling analysis of SPAC energy and mass transfer as well as ecological process of vegetation productivity, and presented method to analyze ecosystem productivity restricted by water stress.

We estimated the spatial pattern of terrestrial ecosystem productivity and carbon cycle at regional and national scales，and its variation at different time scales by using a regional carbon cycle model. The model was an improved version of CEVSA (Carbon Exchange in the Vegetation-Soil -Atmosphere) on the basis of regionalized environmental data and parameters. Results showed that the total net primary productivity, soil respiration of terrestrial ecosystem was 2.86-3.37 and 2.89-3.21 Gt C yr^{-1} in China during the past two decades, respectively. The net ecosystem productivity (NEP) fluctuated from -0.32 to 0.25 Gt C yr^{-1}. The variation of NEP was eight times over the mean value 0.07 Gt C yr^{-1}. The results showed there was a considerable carbon sink in terrestrial ecosystem in China. Due to the increasing rate of NEP was lower than that of soil respiration, the carbon uptake capability showed a decreasing trend. Most area in China was acting as carbon balance or carbon sink. The higher carbon uptake occurred mainly in Northeast Plain, the south of Tibet and Huanghuai Plain. In Daxing'an Mountain, Xiaoxing'an Mountain, Loess Plateau, Yun-Gui Plateau, and uplands in Shandong, Zhejiang and Fujian provinces, there were carbon sources. With the increase of atmospheric CO_2 concentration, the terrestrial ecosystem changed into a carbon sink since the early of 20^{th} century. The carbon sequestration rate increased markedly in 1950s, and will reach a saturation state in the middle of 21^{st} century. Increasing precipitation and CO_2 concentration mainly resulted in the carbon sink in middle and high latitude in the north hemisphere. Global warming will weaken the carbon sequestration of terrestrial ecosystem. In addition, we applied CEVSA model to agricultural system combined with GLO-PEM (GLObal Production

Efficiency Model), and estimated the potential carbon sequestration of residue amendment and no-till in China.

The Synthesis Research Center adopted and improved several ecosystem models such as InTEC、EALCO、BEPS、GLO-PEM、TEM、CASA and CENTURY, which has accelerated the development and application of ecosystem models in China. It laid a foundation for multi-scale data-model fusion and prediction of ecosystem changes in future. (Cao et al., 2004).

5. Study on interaction between ecosystem pattern and global change on Tibet Plateau

(1) The carbon sink or source characteristics in Tibet Plateau have been primarily investigated. Soil emissions of greenhouse gases (GHGs) were measured continuously at five typical ecosystems in Tibetan Plateau using chamber method. Diurnal, seasonal and interannual variations of GHGs fluxes were described and the relationships between GHGs fluxes and environmental variables were also analyzed. The net primary productivity and ecosystem carbon budget were calculated with the harvesting method. Results indicated that the five ecosystems were all carbon sinks. Using GIS-based ecological model and remote sensing data, carbon budget at Tibetan Plateau region was evaluated. Results indicated that the whole Tibetan Plateau was apparently carbon sink.

(2) Major vegetations and soil types on Tibetan Plateau were sampled and analyzed with transect approach (along haibei-geermu-wudaoliang-lasa-linzhi transect). Combined with the "Second National Soil Survey" data, soil organic carbon storage and spatial distribution were evaluated. Meanwhile, we analyzed the spatial pattern of soil organic and community structure distribution across the altitude through an vertical transect investigation (Gonggashan vertical transect). With the isotope technique of ^{14}C, SOC accumulative rates and accumulative amount since the "Nuclear explosion" in two typical alpine ecosystems (alpine forest and alpine meadow) were quantified. Field soil samples collected at the Ruoergai swamp indicated that soil moisture had pronounced effect on organic carbon storage in swamp soil and peatland soil, and the indoor incubated experiment suggested that soil moisture was the major factor affecting the carbon and nitrogen mineralization of wetland soil.

(3) With the concept of the BIOME1 model, we simulated the distribution of major species on Tibetan Plateau at the resolution of 2.5′ × 2.5′ as PRISM model worked with. Key climatic variables or coefficients (maximum & minimum air temperature, accumulated temperature above 5℃, accumulated temperature above 0℃，Priestley-Taylor coefficient) were used as the input data of the model. The results indicated that, under warming climate, Himalayan fir, Nyingchi spruce, *Pinus densata,* griffith larch, *Quercus aquifolioides* would move to the north and west. Under the condition that temperature and precipitation rise, and CO_2 increased to

500 ppmv, the area of sub-alpine mountainous forest, alpine meadow and alpine desert would shrink, however, the area of mountainous forest, mountainous shrub-steppe, mountainous steppe and mountainous desert would extend.

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02

New Technologies and Tools for Hydro-ecological Processes of Terrestrial Ecosystems

Scientific research progress of Sub-Center for Water, CERN

Introduction of Water Sub-Center

The Water Sub-center, Chinese Ecosystem Research Network (CERN) was established to evaluate and manage the data produced by water environment long-term monitoring from the terrestrial ecosystem research stations in CERN. Water Sub-Center, CERN was also endued to study and set the index for water environment long-term monitoring, and guide and supervise the water environment monitoring of the field terrestrial ecosystem stations in CERN. Also, Water Sub-center, CERN has the duty to organize or implement some related researches based on CERN platform.

Water Sub-center, CERN is an operation unit in CERN, but is also a research group in the Institute of Geographical Sciences and Natural Resources Research, CAS. Water Sub-center, CERN focuses on the ecohydrological processes research using new techniques, such as RS, stable isotope et al.

This review will present the water environment indices that are long-term monitored by the terrestrial ecosystem stations in CERN, and the available data from the monitoring since 2000. This review will also introduce some work and program in scientific research by our staff in Water Sub-center, CERN.

1. Indices for water environment long-term monitoring of terrestrial ecosystem in CERN

CERN has been carrying out a long term ecosystem monitoring plan for monitoring and evaluating the status of ecosystem, environment and resources in China. The set and application of the long-term monitoring indices for ecosystem and environment is one of important tasks in the plan. Water Sub-center, CERN had participated in this work, and takes charge of supervising the implementation of the water environment long-term monitoring of terrestrial ecosystem in CERN.

The monitoring indices for water environment of terrestrial ecosystem are the factors that reflect and affect the water environment of terrestrial ecosystem. In CERN, for the water environment monitoring of terrestrial ecosystem, the indices are classified into two types: (1) hydrological indices, and (2) water chemical factors/indices. And also, the indices are divided into two groups, one (the first set of indices) is for regular monitoring, which must be applied by all field stations, and another (the second set of indices) is only monitored by the field stations which have the abilities. Table 2.1 shows the indices and their monitoring frequency.

Table 2.1 Indices for water environment long-term monitoring of terrestrial ecosystem in CERN

Type	Index	Monitoring Frequency
Hydrological	**First set of indices:**	
	Soil water content	Time serial observation during growth season per year
	Ground water level	
	Evaporation from water surface (E601)	
	Surface evaporation (water balance method)	
	Runoff	
	Water area for wetland	
	Irrigation for agricultural system	
	Through fall in forest	
	Soil hydraulic parameters	Once per 5-10 years
	Second set of indices:	
	Surface evaporation by Lysimeter	Automatic measurement
	Surface evaporation by eddy correlation	
Water Chemical	pH	1-4 times per year
	Ca^{2+}	
	Mg^{2+}	
	K^+	
	Na^+	
	SO_4^{2-}	
	NO_3^-	
	CO_3^{2-}	
	PO_4^-	
	Cl^-	
	Total N	
	Total P	
	COD	
	DO	
	TOC for wetland	

NO_3^-—N for soil water in agricultural system	
NH_4^-—N for soil water in agricultural system	
All for 1. flowing surface water 2. still surface water 3. groundwater 4. precipitation 5. soil water (the second set of indices)	
HDO and $H_2^{18}O$ for precipitation	Every month since 2005

2. Current data of water environment of terrestrial ecosystem in CERN

The monitoring of water environment of terrestrial ecosystem in CERN began in 1998. From 1998, water environmental data from the terrestrial ecosystem stations in CERN have been collected. However, due to ill management, much data is absent in the early monitoring years. Since 2000, water environmental data based on the monitoring indices come into being full. At present, CERN can provide whole water environmental data from 31 terrestrial ecosystem stations in CERN. The data cover the time from 2000 to 2006, and include all hydrological data and water quality data that required by the monitoring indices of water environment, such as soil water content, runoff, groundwater table, water quality, and stable water isotopes of precipitation et al.. The data also cover different ecosystem types in China, including 13 agricultural ecosystem, 9 forest ecosystem, 6 desert ecosystem, 2 grassland ecosystem, and one wetland ecosystem.

3. Main researches of Water Sub-Center, CERN

As a research team, the scientists of Water Sub-center, CERN focus their interest on the evapotranspiration processes study, especially using new techniques and methods. These new techniques and methods include the development of quantified remote sensing inversion model, the application of Large Aperture Scintillometer (LAS) and Tunable Diode Laser Absorption Spectroscopy (TDLAS) in observing moisture flux.

Inversion model of surface flux at regional scale based on remote sensing data and its application

The scientists of Water Sub-center, CERN have developed a two-layer model of crop transpiration with remote sensing data, which has been proved effective at some agro-ecological stations. A series of new algorithms have been developed, they are (ⅰ) the algorithm for separating crop canopy temperature from mixed surface (soil and canopy) temperature on the basis of multi-temporal radiometric temperature and thermal inertia; (ⅱ) an algorithm for the estimation of regional emissivity derived from the process of inversing surface temperature; (ⅲ) a static feedback algorithm which does not consider the interactions between air temperature and ground surface temperature in the calculation of air temperature from mixed surface temperature by spatial extending; and (ⅳ) an interactive feedback algorithm to extend wind speed from plot measurements to regional distribution with high resolution TM data and LUCC surface classification information. Based on this model, we have got the distribution of crop transpiration and the soil water utility efficiency (SWUE) in North China using NOAA-AVHRR data and surface measurements, which can be used to agricultural water management in this district (Zhang et al, 2003,).

We also developed a new two-layer energy-separation algorithm, which was simple and direct without resistance network parameters for each pixel. Using this algorithm, we can separate the surface temperature into vegetation temperature and soil temperature, based on which we can improve the calculation of surface flux in regional scale. The following figure shows our some results about carbon dioxide assimilation flux in North China.

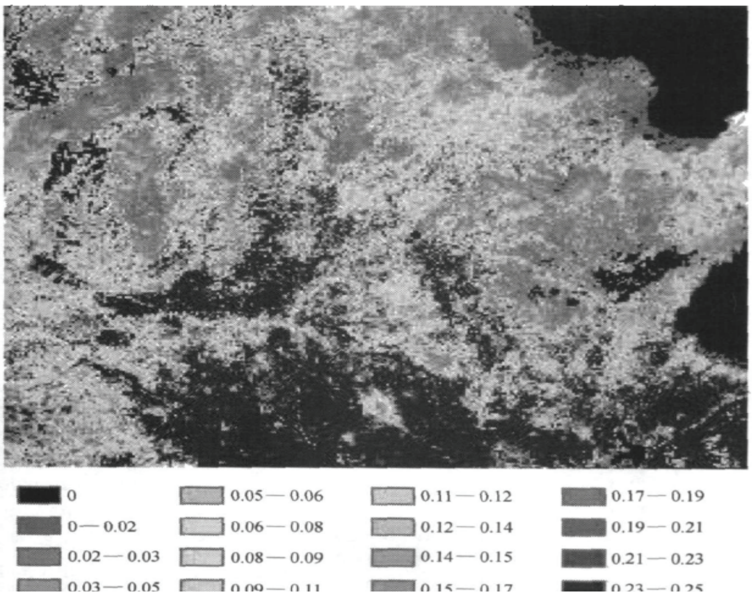


Fig. 2.1 Regional distribution image of vegetation carbon dioxide assimilation flux

Line-path heat and water flux measurement using Large Aperture Scintillometer (LAS)

The large aperture scintillometer (LAS) is an optical device used to monitor fluctuations in refractive index of the turbulent atmosphere over a relatively large area. Assuming that temperature and humidity fluctuations are perfectly correlated, the spatially averaged refractive index measured directly by a Large Aperture Scintillometer (LAS) is related to temperature structure parameter, which can be used to get the sensible heat exchange between surface and air based on Monin–Obukhov similarity theory.

This instrument was used by our research team firstly in area averaged flux observation combining satellite remote sensing information in China. The aim of this research is to build a framework for concurrent measurement between satellite and surface on a pixel scale, and is to validate the remote sensed inversion model, explore the method of scale transfer between site-scale observing data and the remote sensed information. At present, we have established the pixel scale calibrating field for remote sensed inversion model, and developed a set of operation algorithms for data processing. The following figure shows our some result on LAS application:

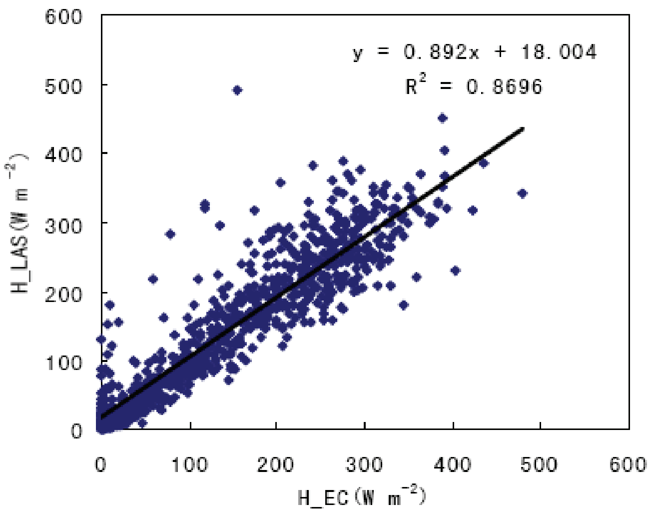


Fig. 2.2 The coparison between sensible heat flux by LAS (H_{LAS}) and by Eddy Covariance method (H_{EC}), 6:-00–18:00, 29/3-20/4, 2002.

Continuous and in situ measurement of water vapor HDO and $H_2{}^{18}O$ using Tunable Diode Laser Absorption Spectroscopy (TDLAS)

Isotopes, particularly those of oxygen, hydrogen and carbon, have been employed in Earth System science for many years. These stable isotopes can be used as detectors and illuminators of a wide variety of soil–plant–air exchanges. These include using ^{18}O plus D to quantify local and regional water recycling; exploiting measurements of ^{18}O in atmospheric CO_2 to reduce uncertainties in the relative contributions to global CO_2 of the marine and terrestrial biospheres; using ^{13}C and ^{18}O in cellulose in tree rings to improve palaeoclimate reconstructions; and determining ecosystem specific water use by combining ^{18}O plus D characterization of water sources with ^{18}O in organic matter. Stable water isotopes (HDO & $H_2{}^{18}O$) in water vapor can be a valuable factor to explore the water change between surface and atmosphere. But the traditional measurement of stable water isotopes (SWI) is labor intensive, and bias. The new instrument, Tunable Diode Laser Absorption Spectroscopy (TDLAS), is a system for in situ and continuous measurement of SWI value. Our research team has introduced the device into China from Campbell Inc., which is first device that is used to measure the in situ water vapor SWI value in China. We will firstly study the water exchange between farmland and atmosphere in North China Plain using this new device. This system is in testing process indoor and will start the field measurement soon.

The following figure shows the framework of TDLAS (Lee et al., 2005).

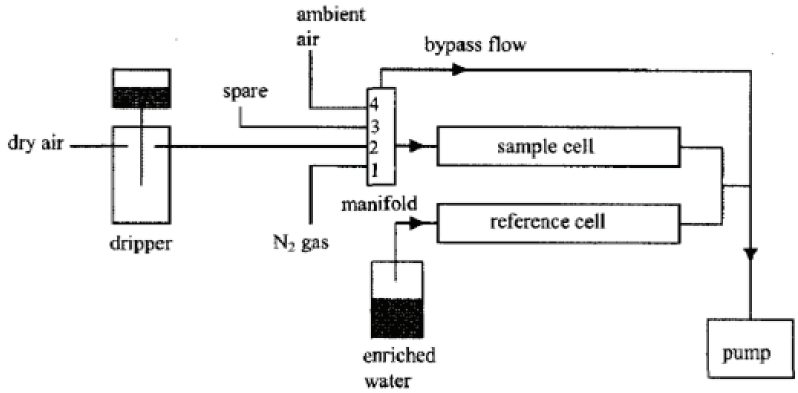
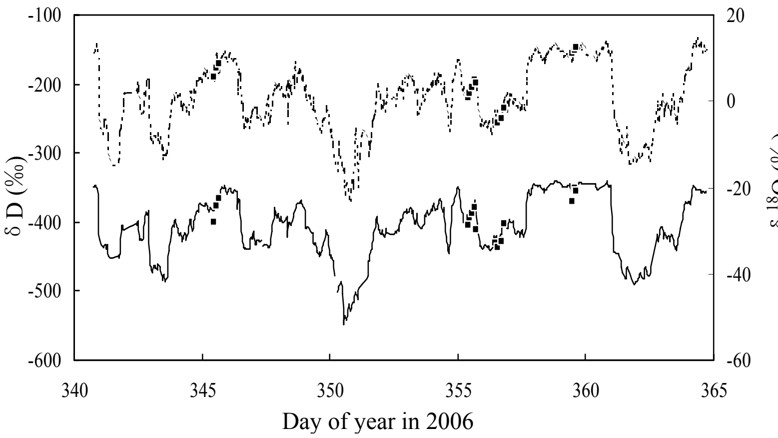


Fig. 2.3 A schematic diagram of the TDL system for water vapor isotopes. Ultra-high-purity nitrogrn gas is used for zero calibration. Flow rate through the four intakes is 0.25 L min-1 STP and is controlled by a critical orifice at the inlet. The spare intake 3 can be used to sample ambient air at a differenr height from intake 4 to give the vertical istopo gradienrt and therefore the flux istope ratio.

The following figure shows the result of comparison between TDLAS measurement and the traditional collection-analysis method based on the data of our testing experiments:



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03

Soil Quality Changes and Its Eco-Environmental Impacts

Scientific research progress of Sub-Center for Soil, CERN

Introduction of the Soil Sub-Center

The Soil Sub-Center (SSC), subordinated to the Institute of Soil Science, Chinese Academy of Sciences (CAS), was established in 1992 by Chinese Ecosystem Research Network (CERN) for the scientific study and observation of soils.

SSC undertakes the task controlling the quality of CERN long-term observation of ecological processes in soils, which covers instituting the observation criteria, developing and supplying standard material, controlling the observation quality, collecting data and compiling date base, and training the observation and analysis technician. Furthermore, SSC builds the long-term soil monitoring database of China which provides data supports for studies of pedology and eco-environment science.

Besides the mission to manage soil network observation of CERN, SSC orientates its research at sustainable development of agriculture, soil resources and eco-environment by long-term ecological research and observation network combined with modern analysis techniques, ecological models and 3S techniques. The main research directions are: (1) nutrient cycling and its environmental effect in agro-ecosystem at local, regional and national scale; (2) spatial-temporal changes of soil quality and the controlling mode; (3) establishment of soil database and decision support system providing scientific data and advices for important decision-making in ecological resources and environment at regional and national scale.

1. Standard methods and criterion for long-term soil observation and measurement

In 1996, SSC compiled CERN *standard method series on observation and analysis – soil physical and chemical analysis and soil profile description* (Liu et al., 1996) which promoted the standardization of experiment, observing and analytical method, and data processing of ecosystem network research for CERN.

Since 2001, under the leadership of the Scientific Committee of CERN, SSC organized experts from the domains of agriculture, forestry, desert, prataculture and swampology, to discuss and revise the index system and criterion of long-term ecological observation. In 2006, SSC published the series of *Protocols for Standard Long-term Observation and Measurement for Chinese Ecosystem Research Network (*Sun et al, 2006), including *Protocols for Standard Atmosphere Environmental Observation and Measurement in Terrestrial Ecosystems, Protocols for Standard Soil Observation and Measurement in Terrestrial Ecosystems, Protocols for Standard Water Environmental Observation and Measurement in Terrestrial Ecosystems, Protocols for Standard Biological Observation and Measurement in Terrestrial Ecosystems, Protocols for Standard Observation and Measurement in Aquatic Ecosystems.*

Now, SSC participates and organizes the development of *the scientific observation index system of eco-environment in the field* for national field observation and research station system.

2. China soil database and the storage warehouse for long-term soil profile samples

SSC constituted metadata criterion for long-term soil observation, designed metadata scheme for China Soil Database, participated in the establishment of national metadata standard for ecology data and as well as of CERN metadata standard for long–term ecological monitoring.

SSC established China Soil Database (CSD). CSD includes sub-database of soil spatial database at 1:1000000 and 1: 4000000 scale, soil taxonomy database, regional agro-ecological research database, Soil Species Database of China, soil quality monitoring database, NPK nutrient cycling research database. The database which has been expanded to 924M at data volume covers data about Chinese soil resources, soil survey, nutrient cycling, regional agro-ecological research, dynamical soil quality monitoring. CSD which technically emphasizes in metadata standardization and integration of many sub-databases can be queried in different sub-database by the order of provinces, soil types, and subject. At present, website of China Soil Database is accessed by 150 thousand times between 2003 and 2006 (40% IP address from abroad), and its download flow has been increased to 12300MB.

SSC established dynamic monitoring database of soil quality. The database collects soil long-term monitoring data from 31 experiment stations and includes the contents of soil nutrients, exchange capacity, total mineral element, microelement, heavy metal, readily available microelement, mechanical composition, and bulk density *et al.* The Database has a capacity of 750M and can be queried by station name, monitoring time and subject. The database provides metadata information such as plot background, collective and analytical method, and determination of standard sample.

In order to preserve soil samples collected by time series for 100 years at fixed sites, which will supply samples for long-term ecological research, SSC established sample storage warehouse in 2005 for the preservation of CERN soil profile sample. Now the warehouse contains 730 samples from 31 experiment stations of CERN.

3. Translocation and transformation of soil nutrients in agro-ecosystems of China, as well as soil microorganism processes

With the support of CAS knowledge renovation project, SSC organized a research network combined with seven CERN field research stations (Hailun, Shenyang, Luancheng, Changwu, Changshu, Yingtan and Yanting）, to study the translocation and transformation of soil nutrients in agroecosystems and put forward optimized management measures for non-point pollution control from 2001 to 2005. Based on the long-term field fertilizer experiments, social and economical investigations, and network observations, the project studied on the cycling regulation of soil nutrients and its effects to crop yield in main agricultural area of China, and put forward the measures to regulate and control the fertilization in main agricultural area of China. The project also observed the soil-water and soil-air transfer flux of nitrogen (N) and phosphorus (P) and evaluated its eco-environment effects.

The form of soil nitrogen under the long-term fertilizing in three primary agro-ecosystem soils (black soils, chao soils and blac loessial soils) was studied and got some achievements (Fig. 3.1): （1）The content of soil total N decreases with increasing annual temperature; (2) Organic manure plus mineral fertilizer can significantly increase the content of soil total N, hydrolysable organic N and ammonium N, and organic manure was better than mineral fertilizer especially to promote the content of amino acid N. The changes of soil N forms are dominantly caused by the improvement of nitrogen mineralization rate and nitrfication rate promoted by fertilization, that finally increase soil nitrification potential and crop field (Yang & Sun, 2007).

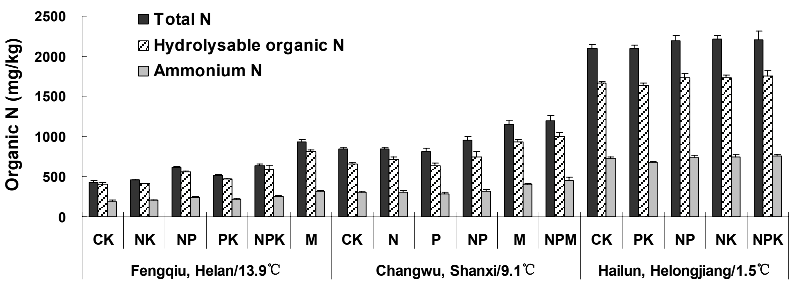

Fig. 3.1 Effects of long-term fertilization on the forms of soil organic nitrogen for chao soils (from Fengqiu), Blac loessial soils (from Changwu) and black soils (from Hailun)

The experiment of soil replacement was launched to explore the effects of climate and soil factors on soil nutrient transformation. Along the temperature gradient transect in eastern china, three dominating soils were selected (black soil from Hailun, Heilongjiang province, representative of temperate monsoon climate; chao soil from Fengqiu, Henan province, representative of warm temperate climate; red soil from Yujiang, Jiangxi province, representative of central subtropical moist monsoon climate) and in situ exchanged. The results show that the sequence of nitrifiers population and nitrification potential were: chao soil > black soil > red soil. The trend is consistent with the pH value variation (Fig. 3.2), which reveals the control of pH value to soil nitrification. The nitrification potential of three soils after replacement decreased with the decrease of annual temperature from north to south in the bloom of corn. Thus temperature and soil pH value affected together the nitrification process in soil.

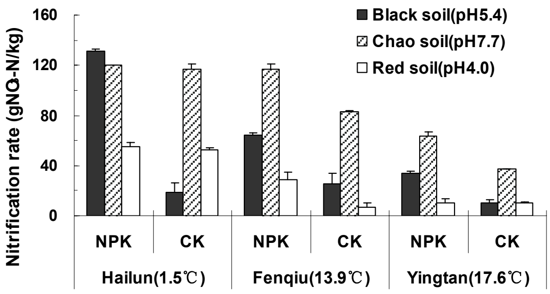

Fig. 3.2 The nitrification potential of black soil, chao soil and red soil after replacement in the bloom of corn in 2006

The microbiology mechanism of nitrification-denitrification in paddy soil was studied and a hypothesis was put forward due to the facts that the denitrifying bacteria population and its activity are not agree with the denitrification potential. The hypothesis indicated that nitrate reduction products produced by one type of partial denitrifiers could be used as electron acceptor by other type of partial denitrifiers. This mechanism of soil denitrification，here referred to as successive denitrification (Fig. 3.3), difered from the commonly accepted mechanisIn in that the former was conducted by diferent types of partial denitrifers while the later was done by complete denitrifiers. The research indicates that the partial denitritiers could cooperate in use of the substrate and play a similar role to that typical denitrifiers do. The hypothesis explains why the denitrification process is intense though the denitrobacteria is not dominant in paddy soils.

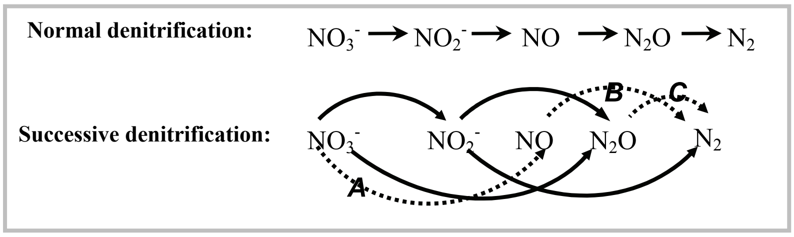

Fig. 3.3 Comparison between “Successive Denitrification” and normal denitrification

Based on the long-term field fertilizer experiment carried on paddy soils of Tai lake, the molecular ecology anaysis indicated that the soil microbial community composition and its diversity were highly similar for treatments of mineral fertilizer, organic manure plus mineral fertilizer and the control (without fertilizer), about 45% of soil microbial community composition were affected by fertilization and about 30% were independent of fertilization. The land-use change also has significant impact on the evolution of soil microbial community. In Tailake region, there is a large area of paddy field changed to the vegetable land with the urbanization. The study on the soil microorganism biodiversity by RFLP (Restriction Fragment Length Polymorphism, RFLP) analysis among there land use pattern: 1) paddy field which has been used for more than 100 years as intensive paddy field under conventional tillage (Paddy), 2) vegetable field which has been altered from the paddy field for ten years (NV, new vegetable land), 3) vegetable field which has been altered from paddy field for more than 100 years (OV, old vegetable) showed that, the ratio of RFLP type to clone number was the lowest (0.36) in OV, compared with 0.95 in Paddy and 0.84 in NV.

4. Environmental risk of nutrient balance in the main farmland ecosystem of China and countermeasures against agricultural non-point pollution.

The chemical fertilizer consume of China are first in the world. Studies on the NPK (nitrogen, N; phosphorus, P; Potassium, K) nutrients utilization and balance in farmlands at national scale from 1980 to 2004 show that the fertilizer efficiency decreased 30.8% (from 22.9 kg kg^{-1} in 1990 to 15.9 kg kg^{-1} in 2003) while the fertilizer consume kept increasing. Since 1990, the amount of surplus of soil N and P kept increasing while the deficit of K was decreasing. The chemical fertilizer consume in the more developed southeast provinces was the largest, and the surplus of N and P were also largest. The surplus of N and P were relatively less in the west and north area because of less chemical fertilizer input. The serious deficiency of K occurred in the east-south provinces and the part of north provinces (Xinjiang and Heilongjiang province), but the K contents in most farmland soils in north are relatively high and don't need the supplement of K.

According to current developing trend, by using the nonseasonal mixed autoregressive moving average model (ARIMA), it is estimated that the amount of surplus N will increased to 179 kg ha^{-1} in 2015 from 137 kg ha^{-1} in 2001. Risk evaluation maps have been made based on the critical values for the N surplus of 180 kg ha^{-1} and 100 kg ha^{-1} (Fig. 3.4). The regions of high environmental risk from fertilization in 2000 were 7 provinces of east-south China and Hubei province as well. If no control measures were carried out, 15 provinces in central and east-south China will be of high environmental risk.

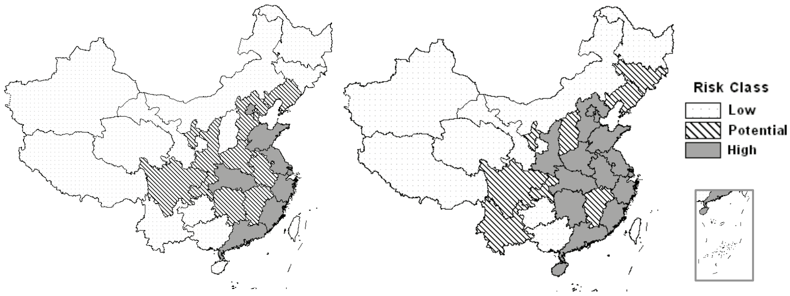

Fig. 3.4 Environmental risk led by excessive using of nitrogen fertilizer in China farmland

Non-point pollution became the main reason for the degradation of rural environment in China. The status of non-point pollution was evaluated from 3 aspects of chemical fertilizer application, pesticide application and lake eutrophication. Excessive input of chemical fertilizer and pesticide, fewer treatment of organic manure from livestock breeding, low use efficiency of fertilizer and irrigation water, inadequate extension services and deficit environmental awareness were four reasons for non-point pollution. Last the countermeasures were put forwards from policy, legislation and technology. Policy suggestions include: ensure the national food security with right level of grain self-sufficiency; overall arrange the construction of grain producing bases; promote the farmer technical organization; raise the environmental awareness in whole society. Environmental legislation suggestions include: control the discharge of organic waste; promote the recycling use of organic manure; and control the pesticides pollution. Technology systems suggestions include: monitor the farmland quality and environmental capacity; construct the high-efficient agriculture extension system; extend the mature high-efficient fertilization technology; implement basin planning and comprehensive management. The policy report for controlling agricultural nonpoint pollution in China (Zhu et al., 2006) was submitted to China Council for International Cooperation on Environment and Development (CCICED) (www.cciced.org).

5. Temporal and spatial change of regional soil quality and decision-making systems for regional optimized fertilization.

SSC estimated the soil carbon stocks of China. The total soil organic carbon and carbonate carbon in soils of China for a depth of 100 cm were estimated to be 83.8 Pg and 77.9 Pg C, respectively, and for whole soil profile was estimated to be 147.9 Pg and 234.2 Pg, respectively, with the sum of overall carbon storage 382.1 Pg (Li et al., 2007）. The temperate regions have sequestered more terrestrial carbon in soils than the tropical and subtropical regions. This study suggests that terrestrial carbon in China is mainly sequestered in soil pool instead of aboveground forest biomass. Carbon densities in soils of China vary with and are modulated by bioclimatic conditions (temperature and precipitation/evaporation) (Xie et al., 2004). In farmland ecosystem human activities such as cultivation and fertilization reduce the influence of environmental variables on soil organic carbon.

SSC researched the temporal and spatial change of soil quality and its influence factors on landscape and regional scale by using geostatistics. For red soil hilly region, SSC studied on the spatial variability of soil fertility and heavy metal pollution, and analyzed the influences of environmental variables such as soil, terrain, hydrology and cultivation. Also, based on spectroscopy analysis and multivariate statistical analysis, the relationships between visible–near-infrared reflectance spectra and soil properties (organic matter and heavy metal) were established.

Besides, SSC developed balanced fertilization models based on soil fertility for paddy field and upland soils in red soil hilly region (Yujiang county, Jiangxi province) and Yangtse Rive delta region (Yizhen city, Jiangsu province) . The fertilization decision making supporting systems at the county scale was developed by inserting MapObjects component into the Visual Basic development environment and combining the techniques of database, ComGIS, decision supporting systems. The decision supporting system can supervise the basic information of geography, soil and agricultural economy, analyze spatial variation of soil nutrients, and finally give fertilization instruction for the paddy soil and upland at the county scale based on the minimum unit of fertilization.

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04

Measurement and Analysis of Atmospheric Environment for Terrestrial Ecosystems in China

Scientific research progress of Sub-center for Atmosphere, CERN

Introduction of Sub-Center of Atmosphere

The Sub-Center of Atmosphere Science (SCAS) which the laboratory serves for is considered one of the best sub-centers of the Chinese Ecosystem Research Network (CERN) in recent years. SCAS are mainly engages in exploring the basic laws physical and chemical processes in the atmosphere and environment in East Asia. The Mission of SCAS includes Atmospheric chemical, boundary layer structure on Ecosystem, and Dynamics process of regional Ecosystem environmental Research. Global change and ozone depletion in stratosphere research are major concern for global environment study. Air pollution in a metropolitan city and city cluster is a major environment challenge for government and scientific research center. The study of SCAS is always carrying out experiments and theory research focus on the requirement of government and track the advanced research topic.

SCAS carry out many experiments research based on all kinds of funds and Innovation Program of the Chinese Academy of Sciences and other government department. There are many measurement data have been obtained by all kinds experiments research, besides perform CERN contractual obligations. The scientists of SCAS are carrying out many atmospheric chemical, atmospheric physics, and atmospheric environment research. There are many significant results have been gained base on the in situ measurement data.

1. Measurement of greenhouse gases in CERN stations

The issue of global climate change has raised concern of the whole world. Scientists generally agree that the climate change will be affected by the increase in concentration of atmospheric greenhouse gases such as carbon dioxide, methane and nitrous oxide. Having an insight of Carbon cycle not only give basic knowledge of understanding and control of the global climate change, but also concern with other natural process (water cycle, nutrient cycle etc.), human environment and social development. To further understand the problem, it is necessary to examine the carbon budget, that is, the inventory of carbon in the oceans, atmosphere and the terrene as well as the exchange between these major carbon reservoirs. As a country noted for its six typical ecosystems of forest, grassland, farmland, wetland, fresh water and marginal sea, China is an ideal experimental platform for the studies of global carbon budget. The work is most likely to make academic breakthroughs and greatly contribute to the global change studies. With the development of economy, China has been one of the world's major producers of carbon dioxide and other greenhouse gases, but is not obliged to reduce its emissions under the Kyoto Protocol. But recent data of IEA shows, China will be the largest producer of greenhouse gases instead of USA in year 2010 due to fast rate of economic development with high energy consume. For China, it is inevitable to shoulder its share of responsibility in fighting global warming in the coming years. It is urgent to got greenhouse gases flux data from terrestrial ecosystems for Chinese scientists, or else they can not provide countermeasures for greenhouse gases fixation and reduction which will disbenefit China in environmental diplomatic negotiation.

Supported by the Knowledge Innovation Program of the Chinese Academy of Sciences (CAS) "Study on Carbon budget in Terrestrial and Marginal Sea Ecosystems of China", ChinaFLUX is built in from 2001 to 2005. Now, ChinaFLUX consists of eight sites which apply micrometeorological method and sixteen sites that apply chamber/chromatography method (Wang et al., 2003). The sixteen sites which use chamber observational method cover all of the main ecosystems of China, includes six agroecosystem, four forests, two grasslands, two freshwater lakes and two wetlands, mainly measure the output of CO2, CH4 and N2O in ecosystem.

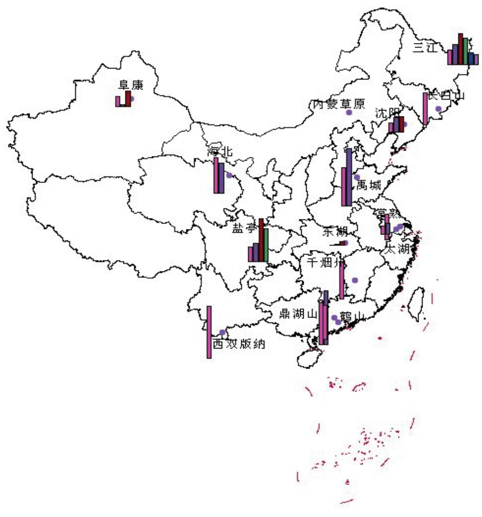

Fig. 4.1 CO_2 efflux in China typical ecosystems

Based on carbon dioxide data of twelve sites from 2002-2005, we got primary attribution of CO_2 efflux in China typical ecosystems (as Fig. 4.1 shows) and main control elements (Fig. 4.2). CO_2 efflux enhanced with the decrease of site latitude and increase of annual precipitation, it also positively correlated with the annual average soil temperature except three sites with abundant organic carbon.

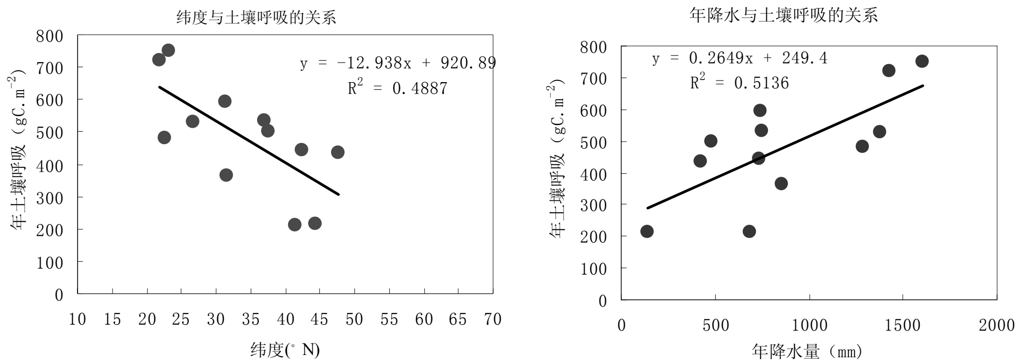

Fig. 4.2 The relation between CO_2 efflux latitude vs. annual precipitation

2. Spatio-temporal variation characteristics of Ultraviolet and Photosynthetically active radiation in China

The radiation measurement network (Fig. 4.3) has been renewed and rebuild from 2004.The observation system has been upgraded. There are many significant results about radiation over CERN have been gained base on in situ measurement data. The spatio-temporal characteristics of Ultraviolet radiation and Photosynthetically Active Radiation have been derived from the ground-based measurements taken in CERN.

Ultraviolet (UV) radiation and broadband solar radiation (R_s) measured from January, 2005 to June, 2006 at 31 stations in Chinese Ecosystem Research Network (CERN) were used to investigate the spatio-temporal characteristics of UV radiation and UV fraction (the ratio of UV radiation to R_s) in China.

In general, the spatial variation characteristics represent as an increased trendy from east to west (Fig. 4.4). There a lowest center appeared at regional in Yangtze Rive, and from this point there is an increased trendy to the north and south. The highest center appeared at Huanan region, and the second high center appeared at Huanbei region. There is an increased trend from south to north in Northeast of China.

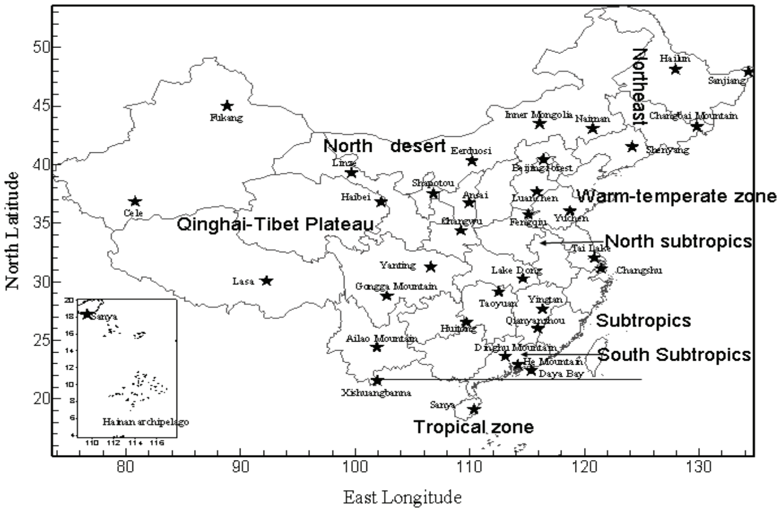

Fig. 4.3 Regional distribution of China Radiation

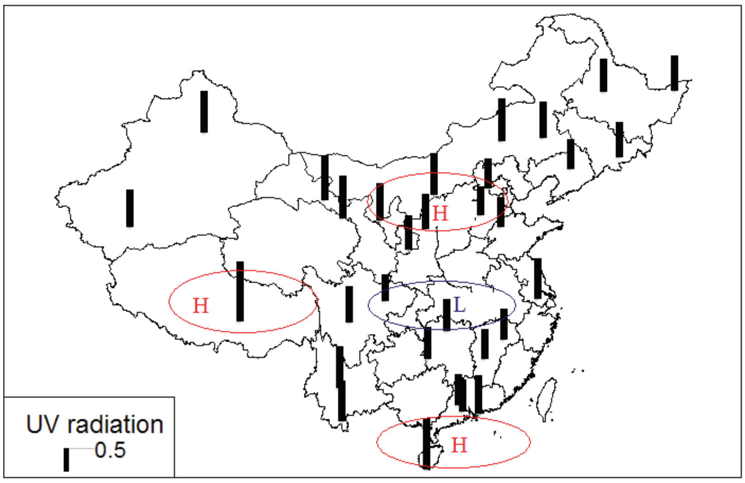

Fig. 4.4 Plots of annual mean daily values of UV. network in Chinese ecosystem research network radiation (MJ m^{-2}) in China (Hu et al., 2007)

There is a distinct seasonal variation characteristic of UV radiation in China. Results indicated that the seasonal variations of UV radiation and R_s were consistent with the solar activities, which reached their lower values during winter period, and increased throughout the spring, peaking in June or July, in most sites. The Meiyu weather system and Southwest Monsoon produced different variation characteristics of UV radiation and R_s in subtropical and tropical regions. The UV fraction values showed a similar seasonal trend as that of UV radiation, which was mainly determined by the seasonal change of the AOD (Aerosol Optical Depth) and water vapor content in atmosphere. The seasonal variations of UV fraction were much smoother in southern China due to high water vapor content over the whole year.

The spatial variation characteristics of UV radiation in China are presented as follow. In winter, the value of UV at Qinghai-Tibet Plateau is the highest in China. There is a remarkable low center appears at Warm-temperate zone due to high AOD. There is an increase trend developing from this center to the north and to the south. The high centers of eastern China appear at Tropics and North desert area, respectively. In Northeastern China, there is a lowest center at Shenyang site resulting from high AOD and high volume of fine particle especially strong in winter. In the west of China, UV decreases from south to north due to the solar activities. The spatial variation characteristics of UV radiation in autumn are similar as those in winter.

In spring, the highest UV in China appears at Qinghai-Tibet Plateau in spring also. From March, UV starts to increase in all observation sites. In the West and North desert areas of China, this increase trend is distinct. The spatial distribution characteristics of UV are same as winter's variation characteristics in the West. However, the spatial characteristics of UV in Eastern China present a different pattern. The low center appears at South subtropics due to its continuously cloudy and rainy sky conditions. From this point, the UV increases from south to North desert area, and the highest UV of East China appears at North desert area. The variation properties of UV in Northeastern China in spring are same with those in winter. This is mainly formed by high atmospheric attenuations due to the largest AOD index in Shenyang site.

In summer, there is an increased trendy from the north to the south. In the east, UV radiation distribution represents as longitude variation characteristics. The highest center is still appeared at Qinghai-Tibet Plateau, and the UV radiation in northeast China is all a high center.

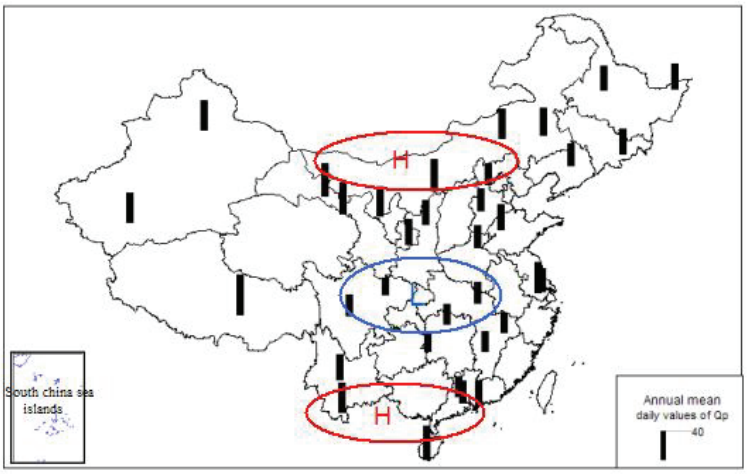

Fig. 4.5 Annual mean daily values of Q_p in China

The spatio-temporal variation characteristics Photosynthetically active radiation in China are similar as those Ultraviolet radiation in China (Fig. 4.5). There is a distinct seasonal variation characteristic of PAR fraction (the ratio of Photosynthetically active radiation to global radiation). The PAR fraction is small in winter and autumn as there is a little rainy in these season and the relative humidity in these season are lower than those in summer season. The highest PAR fraction appeared in summer (Hu et al., 2007).

These results are helpful for understanding the climatic, agricultural, and ecological processes over China, and useful for primary productivity estimation and ecosystem–atmosphere CO_2 exchange study in China.

3. Study progress of Background Atmosphere Monitoring Network of CAS

The background atmosphere monitoring network of CAS observe the greenhouse gas include CH4, CO2, N2O and ozone, research pollution long range transport, acid rain, aerosol and so on. The observed data were provided to scientist to study for that promote our deeply understand the reciprocity between ocean, atmosphere and biosphere, and forecast the future of atmosphere and earth system. All that campaign will make great effect on the environment problems in 21st century.

The CAS pilot project of the national knowledge innovation program (KIP) launch the project of CAS field station network in 2002, as the sub-project, the project of background atmosphere monitoring network commenced in July .It had been established that set up observe station in Changbai Mountain, Gongga Mountain,Dinghu mountain,Xinglong ,and Fukang separately by conference of the Chinese ecological system research network and leading group of field observation network. That would form and possess the Northeastern, southwest, East, North, northwest of China representative observation network platform. The observe parameters include of greenhouse gases (carbon dioxide, CFCs, methane, nitrous oxide, tropospheric ozone), ozone (surface, total column,),solar radiation including ultraviolet, precipitation chemistry, chemical and physical properties of aerosols including optical depth, reactive gases (carbon monoxide, sulfur dioxide, nitrogen oxides, volatile organic compounds), meteorological parameters. The goal is increase the quantity of monitoring station and the observe parameters gradually, gradually, try to reach the standard of GAW monitoring station as soon as possible in observe data quality. We equipped our monitoring network with high quality instrument and trained our observer by the standard of GAW .

The plan of the instrument and equipment had be agree by the leading group office of field observation network of CAS ， the office had organize experts demonstrate the <<The scheme that the instrument and equipment are purchased for the background atmosphere observe network>> at October 11 2002, the experts approving of adopts the atmospheric high-accuracy observe instrument ,which were internationally agreed. Total construction fund is 12,200,000 yuan, among them the institute allocates 7 million yuan, it adds up to 5,200,000 yuan from each institute.

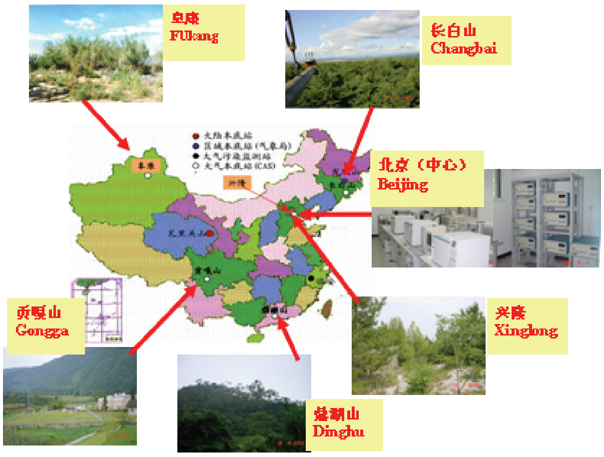

Fig. 4.6 the map of background atmosphere monitoring network of CAS

Form 2003 to 2005, we had made the arduous work in more than two years, (It were delayed and interferenced by the Gulf War and the SARS).All imported instrument and domestic equipment had been integrated, and debugged , calibrated, and the task of the sample central has perfected, , including calibrate, regulate and sample analyzed and so on, by August 2005. The job of startup of field station had been finished on schedule. Changbai Mountain station, Dinghu Mountain station, Gongga Mountain station,Xinglong station have already started ,and Fukang station have been start-up ahead of time .We has already obtained the qualified data from Gongga Mountain for nearly 1.5 years and that from Changbai Mountain for one year, and that from Dinghu Mountain for one year , and that from Xinglong half a year. At present, every station has already been operated in formal routine in an all-round way. So we can consider the second stage of construction, including increased the monitoring station and observing item; the data should be integrated and be explained with global chemical dynamics science model.

We have the following phased result already:

(1) The concentration of carbon dioxide of the Changbai Mountain is higher than that of the Gongga Mountain in atmosphere overall (Fig.4.7), because the average temperature of the whole year of the Gongga Mountain is higher than that of Changbai Mountain, and the artificial emission of CO2 in Changbai Mountain was stronger than that in Gongga Mountain. The concentration of the methane in the atmosphere in Gongga Mountain is higher than that of Changbai Mountain, because the sunshine time of Gongga Mountain is less than that of Changbai Mountain by nearly one time, and the vegetation type does benefit to detesting oxygen condition even more. The source was stronger, the sink was weaker all that make immediate cause of difference between two areas.

(2) The concentration of surface O3 of the north of China (such as Changbai Mountain, Xinglong, Fukang) were higher than that in south of China (such as Gongga Mountain, Dinghu Mountain) and the highest concentration was in spring in Gongga Mountain,Changbai Mountain and Fukang, in autumn in Dinghu Mountain and in summer in Xinglong (Fig. 4.8).

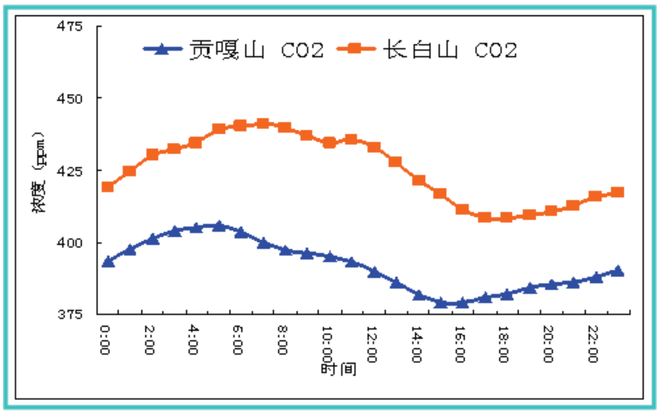

Fig. 4.7 The contrast of daily change of concentration

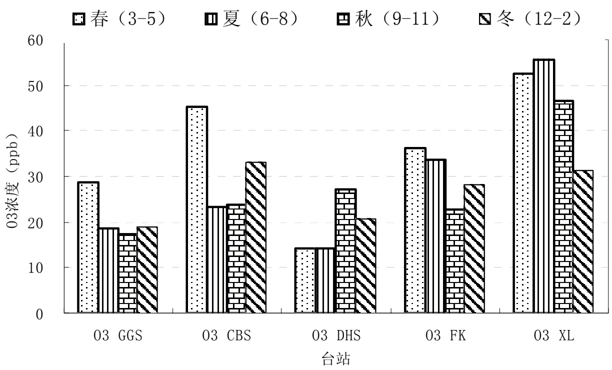

Fig. 4.8 The season change of concentration of of CO_2 between Changbai Mountain and Gongga Mountain O_3 in five stations GGS for Gongga Mountain, CBS for Gongga Mountain, DHS for Dinghu Mountain, FK for Fukang, XL for Xinglong

4. Research progress of aerosol optical properties in China

China is situated in the eastern part of Asia, on the west coast of the Pacific Ocean. It is the third largest country in the world, comprising about 6.7% of the world's total land area, and is home to 22% of the world's human population. From arid deserts to tropical forests, from the Qinghai-Tibet Plateau to immense plains and the seashore, China contains a variety of ecosystems. The vast Chinese mainland is one of the major global aerosol sources. During the past few decades, China has become one of the major players in the uncertainty of aerosol climate and radiation effects on the Earth system, due to dramatic increases in large-scale farming, urbanization and industrial activities (Xin et al., 2007). There are substantially more coal and biomass burning events and dust storms, adding more absorbing soot and organic aerosols into the Asian and Pacific atmospheres.

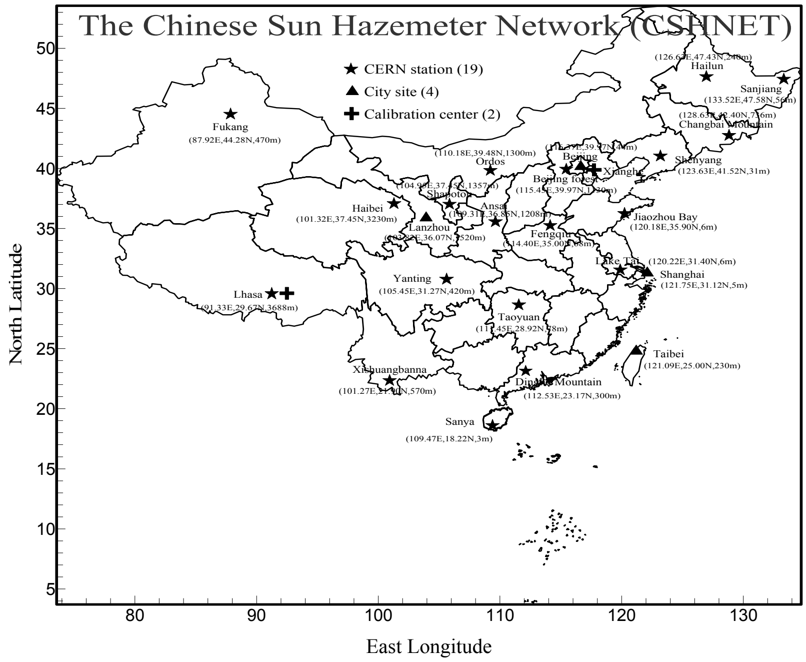

Fig. 4.9 Geographical locations of the CSHNET sites

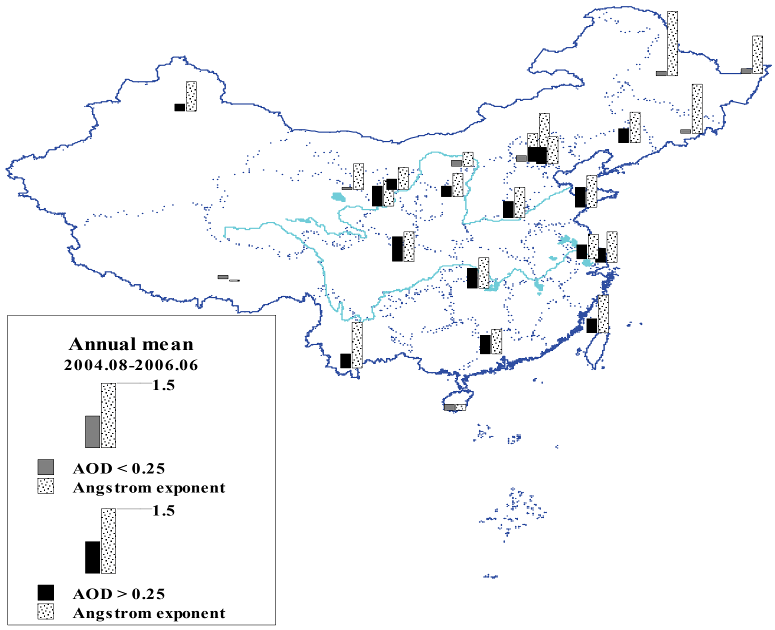

Fig.4.10 The spatial and temporal distribution of the annual mean AOD and α over China

The Chinese Sun Hazemeter Network (CSHNET) (Fig. 4.9) is the first standard network established to measure aerosol optical properties and their spatial and temporal variations throughout China, which was successfully implemented to clarify the spatial and temporal distributions of aerosol optical properties in China. The network is co-located with the Chinese

Ecosystem Research Network (CERN), which has sites located in diverse ecosystems in China. This network includes nineteen CERN stations, four urban sites, one data collection/processing center and two instrument calibration centers. The CERN stations were installed in remote areas in order to represent large-scale regional conditions of certain ecosystems; the urban sites represent typical urban environments. The sun hazemeters were manufactured by the U.S. Forestry Service and have been used in some regional aerosol experiments. Similar handheld hazemeters have been widely used for measuring aerosol properties. Measurements are taken more than 20 times a day, and the observation period is from 10AM to 2PM (local time), encompassing MODIS satellites overpass times. One calibration center is located at the Lhasa site (including other remote sites, sometime) where Langley plot calibrations are made each year. The other calibration center is located at the Xianghe site where annual calibrations of the hand-held hazemeters against the CIMEL sunphotometer are performed. The AODs, which were synchronously retrieved from hazemeters (RSD<3%) and CEMIL (RSD<5%), were coherent and comparable. Two calibration methods ensure the accuracy of the hazemeters. Data collection and quality control are conducted at Atmosphere Sub-Center of Chinese Ecosystem Research Network (SCAS-CERN) in Beijing.

Fig. 4.10 shows the seasonal variations of background aerosol optical depth (AOD) and aerosol type are investigated over Chinese various ecosystems by about two-year records (from August 2004 to June 2006) of the network. In most parts of China, seasonal cycles of AODs show a maximum in spring or summer with increasing large dust and a minimum in autumn or winter with increasing smoke and soot. The smallest annual mean AOD (0.12~0.15) was found in the Tibetan Plateau where Angstrom wave exponent (α) showed the largest range in value (-0.07~0.89). The domain aerosol is large dust. The remote northeast corner of China was the next cleanest region with AODs ranging from 0.15 to 0.20 and with the largest α (1.29~2.14), indicating the presence of fine aerosol particles. With winter coming, a mount of biomass burning and fossil fuel combustion emitted a lot of smoke and soot, which the domain aerosol exchanged from continental aerosol to smoke aerosol. The forested sites exhibited moderate values of AOD (0.15~0.47) and α (0.96~1.67). At northern forest, little particles, smoke and soot, gradually rose in autumn and winter. At tropical rain forest, AOD and α were larger in the dry season than in the humid season. The most exuberant biomass burning largely increased the emission of smoke and soot at Southeast Asia, especially in spring. A surprising finding was that the AOD measured at a few desert sites in northern China were relatively low, ranging from 0.24 to 0.37, and that α ranged from 0.52 to 0.98, presumably because of several dust-blowing episodes during the observation period. The aerosol showed large dust and continental aerosol at the region. At Fukang and Ordos, the herd and farmer burnt some biomass to emit smoke in autumn and winter. The AOD observed over agricultural areas ranges from 0.37 to 0.87; α ranges from 0.80 to 1.05. The active farming emitted a lot of soil aerosol, which the domain aerosol was continental aerosol. At north agricultural region, biomass burning remarkably emitted a lot of smoke in autumn and winter. At Sichuan Basin and south China, emission of anthropogenic sulfate aerosol was rich and hygroscopic through a year. At urban and east littoral region, aerosol pollution was severe with high AOD (0.50~0.70) and moderate α (0.80~1.48), which the pollution merged dust, industrial sulfate and smoke. In the central/eastern, southern and eastern coastal areas, the amount of fine-mode particles remains constant due to environmental regulations and economic measures reducing stalk combustion. Many sites show a mix of sulfate aerosols, mineral aerosols, and smoke aerosols throughout the year. The humidity-swelling of sulfate aerosols grow larger particles at the moist littoral. It was very clean at Sanya Bay, where annual mean AOD was only 0.20 and the domain aerosol was large sea salt (α~0.22).

As one of the most basic satellite-retrieval works, we evaluate MODIS AOD product using the network data as ground truths over different ecological regions in China (Wang et al., 2007). The evaluation results show very large differences of MODIS AOD retrieval between different ecosystems and geographic locations. The most agreement between MODIS data and CSHNET' is at farmland sites in the central southern China, where high correlation (R > 0.82) and large percentages (R2 > 72%) within the expected error lines issued by NASA are found. In temperate forest, coastal regions, and northeast and central farmlands, there appear moderate agreement with R~0.64-0.80 and 45%-73% of retrieval data falling within the expected errors. The poorest agreement is existed in the northern desert/semi-desert regions, and the remote northeast farmlands, and the Tibetan and Loess Plateau, and southern forests, where 13%-54% retrieval data falling with the expected errors. In addition, MODIS AOD retrievals are significantly overestimated in the northern deserts/semi-deserts and underestimated in the remote northeast farmlands and southern forests. The comparison results showed a lack of representative and applicability of MODIS AOD retrievals at urban areas. In high aerosol pollution, MODIS products were few. And the spatial deviation of MODIS-derived AODs was large over urban region. Overall, the comparison results show a lack of representative and applicability of MODIS AOD retrievals in China, which are attributed to complexity of surface conditions and aerosol types, and seasonal changes of surface reflectance and aerosol modes over different ecological and geographic regions. The MODIS AOD retrievals perform well over "dark-object" surface (some farmland and forest sites), while do poor over "bright-object" surface (deserts, arid regions, and plateau). MODIS has poor retrievals in the regions, where the air is clear and AOD is rather low, such as in the remote northeast corner and the Tibetan Plateau. Our analysis indicates the need for systematical modification of the MODIS algorithm over different ecosystems at different seasons in China.

Currently, the Chinese Sun Hazemeter Network (CSHNET) showed the spatial and temporal distribution of aerosol optical properties over the Chinese background region, for the first time. Compared with the network data, the applicability of MODIS AOD product was quantitatively evaluated over China. A solid study basis, important technology and rich experience are based and accumulated for establishing the high spatial resolution, high precision ground observation network and optimizing the satellite aerosol-retrieval process.

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05

Standardization of Measuring the Biological Elements in Ecosystems

Scientific research progress of Sub-centre for Biology, CERN

Introduction of Sub-Center for Biology

The Biology Center of CERN (CERN-BC) was officially established in 1993 and is affiliated to the Institute of Botany, Chinese Academy of Sciences, one of the five disciplinary centres. Its responsibilities include formulating protocols, assuring data and disciplinary research. Since 1993, the research work of CERN-BC has focused on selecting monitoring variables, formulating monitoring protocols, database establishment and research on monitoring methods..

1. Formulated and revised biological monitoring variables of CERN

According to the unified arrangement of CERN, CERN-BC took the responsibility to revise former monitoring variable systems for agricultural, forest and grassland ecosystems and to formulate new ones for desert and marsh ecosystems in 2002. In order to make sure the variable system is both scientific and workable, we do much work and make careful choices based on literature research and opinion of experts. We finished this work in 2004. During the 3 year revision period, more than 10 workshops were held, with more than 140 people being involved.

The new revision of biological monitoring variable systems have the following features: 1) Including more types of ecosystem, with ecosystem types increased from three to five; 2) Giving more consideration to both scientific and workable methods, with some variables' monitoring frequency changed, some variables deleted and some variables added according to their long-term significance; 3) Defining every variable more clearly including explicit term definition, monitoring method, monitoring frequency and time, which will be very helpful to effectively avoid misunderstanding.

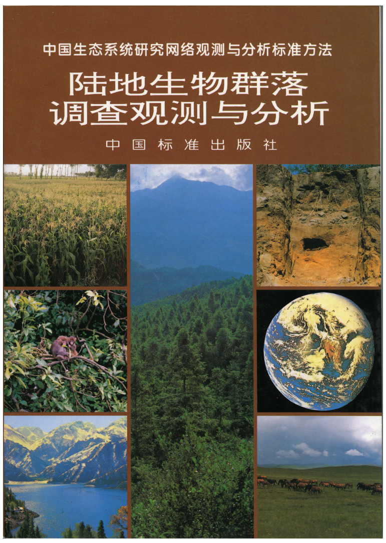
This new revision of biological monitoring variable systems was used in CERN stations in 2005. It is referred to by other similar research networks. It will publish as a part of CERN measurement variable systems.

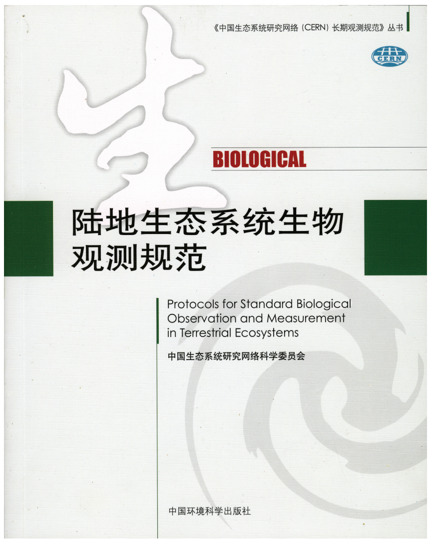
2. Formulated and writed biological monitoring protocol of CERN

CERN-BC wrote and published “Survey, Observation and Analysis of Terrestrial Bio-communities” in 1996. This book has become a most popular comprehensive reference book in biological field work. In 1998, CERN-BC took part in the writing of the following: “Handbook/Manual for Field Measurement of Agricultural Ecosystem”, “Handbook/Manual for Field Measurement of Forest Ecosystem”, “Handbook/Manual for Field Measurement of Grassland Ecosystem”, which were used by CERN stations from 1998 to 2003.

Supported by a project directed by Prof. Zhu Ouyang, the ex-secretary-general of CERN Scientific Committee, CERN-BC arranged an expert group to formulate and write the biological monitoring protocol in 2003. We finished the first draft in Feb of 2004, which was used by CERN stations in 2004 and 2005. During this period, we held several workshops and revisions. Final revision of the manuscript “Protocols for Standard Biological Observation and Measurement in Terrestrial Ecosystems” was finished and assessed in Nov. of 2005.

There are about 20 persons taking part in the writing of manuscript “Protocols for Standard Biological Observation and Measurement in Terrestrial Ecosystems”. It has about 210000 words, 125000 are contributed by CERN-BC staff. It includes four parts, which are further divided into 12 chapters, with contents on how to establish long-term plots, what to measure, how to design sample position, how to measure, when to measure, how to analyze samples in laboratories, how to record and deliver data etc. This manuscript was published in May of 2007 by Environmental Scientific Press.





3. Formulated and writed biological data protocol of CERN

CERN-BC began to formulate the biological data protocol in 2003 to make biological monitoring dataof CERN more standardized and integrated more information. By the end of 2003, we finished the primary adjustment of the data table and added some auxiliary information forms. These new data forms began to be used in data reporting of 2003.

During a probation period, we made further revisions on the protocols based on extensive feedback opinions from stations and experts as well as relevant literatures. The new protocol was finally formulated and assessed in the end of 2004, and officially used in CERN stations from 2005.

The content of new data protocol mainly contains : 1) The composition of biological data set of CERN, including station base line information, monitoring data, auxiliary data (meta data); 2) The content of station base line information and its deliver protocol; 3) The table forms of monitoring data and their deliver protocol, which includes 85 tables and about 1500 items; 4) The content of meta data and their deliver protocol.

The new data protocol supplied the explicit description on every table and even every item in tables. This ensures CERN data is more scientific and standardized. The manuscript of data protocols has about 43000 words and was published in May of 2007 as a part of “Protocols for Standard Biological Observation and Measurement in Terrestrial Ecosystems”

4. Established the biological database of CERN and constructed website of “Data and Information Sharing System of Biology Centre”

One of the core functions of CERN-BC is data assurance and accumulation. Based on approximately ten years’ accumulation of monitoring data, CERN-BC established a biological monitoring database. Meanwhile, CERN-BC collected some research data by taking advantage of the disciplinary research results of affiliated institute. Till now, CERN-BC has established 10 research databases. Based on the established databases, as well as the technical help from Synthesis Research Centre, CERN-BC established a website of “Data and Information Sharing System of Biology Centre” in 2006. The IP of this website is http://159.226.89.77:8080/cern_biocenter. It can be accessed 24 hrs. Users of this website can get the summary information of the CERN-BC database, search data, download data online etc..

5. Comparative Studies on Different Determining Methods of Underground Biomass in Grassland Ecosystems

The precise measurement or estimate of under-ground biomass is of important significance for ecosystem research. However, it always is a barrier of ecosystem research due to the difficulty of practical measurement, especially for large scale or long-term research.

The below-ground process and its measuring method are the focus research areas of CERN-BC in current and near future years. In 2005-2006, we measured the below-ground biomass in long-term fixed fields in IMGERS and HAMERS with a different method, and measured environmental resources conditions as well. We will hopefully find a good method for each fixed field which have relatively small destruction on fields and supply relatively precise data, and get some other results on below-ground process. We have some primary results as following.

（1）Compared with the traditional method —monolith method, auger method got relatively larger root biomass value. However, the two methods had a very significant correlation (Fig 1). Further analysis found that auger method was more stable with the variation coefficients between each sampling point being smaller. To take advantage of less difficult, less destructive and other factors, auger method should be promoted. Further study is needed to find out the reason of the numerical difference and the conversion value between the two methods.

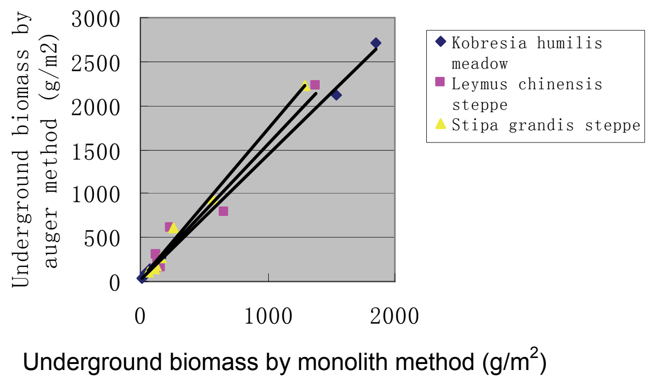


Fig. 2.1 Relative analysis of underground biomass by monolith method and auger method

（2）For auger method, the authors took 10 samples each field, and 5 drillings each sample site. We found that underground biomass values from different drilling numbers were significantly correlated. Furthermore, the absolute values were very close (Fig 2). This implied that the sutable drilling number for each sample site needn't too big.

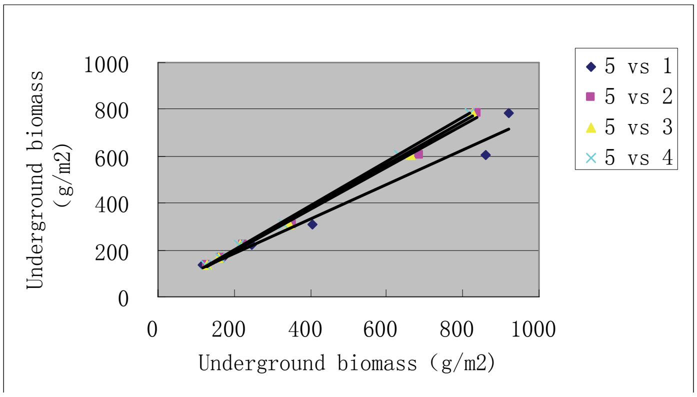


Fig. 2.2 Comparison of underground biomass in Leymus chinensis steppe measured by different numbers of augers

(3) The authors took 10 samples in each plot respectively for monolith method and auger method. By comparing the average value of sampling numbers, they found that average value become stable from 5 samples in Kobresia humilis meadow of HAMERS, and 4-5 in Leymus chinensis steppe of IMGERS, 3 in Stipa grandis steppe of IMGERS. This implied that sampling number for underground biomass in these three plots can be decreased less than usually used 10 samples, which will much benefit for researchers and plot protection.

6. Studies on the relationship of above- and below-ground biomass in grasslands

Since almost all direct measuring methods of below ground biomass always result in serious destruction on plots, the model method based on the relationship of above and below-ground biomass is the most popular method in below ground biomass estimation. However, this method is constrained by the lack of relative data resources. We studied the relationship of above and below-ground biomass in 16 types of grassland ecosystems in Inner Mongolia by direct measuring method.

The above-ground biomass of 16 communities varied between 95-500g·m-2, while below-ground biomass between 533-2590g·m-2. Most of the communities have much higher below-ground biomass compared with above-ground biomass. The root: shoot ratio varied between 1.5-11.2, with average of 5.69. It is found that root: shoot ratio is negatively related with soil moisture, soil nitrogen content, soil organic carbon, and positively related with bulk density, by single factor covariance analysis.

We analyzed the monitoring data of Inner Mongolia Grassland Ecosystem Research Station (IMGERS) and Haibei Alpine Meadow Ecosystem Research Station (HAMERS) and found that root: shoot ratio varied greatly between different year and different season. The ratio of root to shoot of Leymus chinensis steppe in IMGERS changed between 5.0~10.5, alpine

Kobresia humilis meadow grassland in HAMERS between 4.0~15.6.

Above all, root: shoot ratio of plant communities varied greatly with vegetation type, vegetation age, and environmental resource conditions. However, it should be possible to establish a model to precisely estimate below-ground biomass for long-term fixed fields.

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06

Studies on Medium-large Scale Aquatic Ecosystems

Scientific research progress of Sub-Center for Aquatic Ecosystems, CERN

Introduction of Sub-Center for Aquatic Ecosystems

Subordinated to the Institute of Hydrobiology (IHB), Chinese Academy of Sciences (CAS), the Aquatic Ecosystems Sub-Center (AESC) was established in 1995 by Chinese Ecosystem Research Network (CERN). AESC took the research group of systems ecology and watershed ecology of IHB as its backbone that mainly dealt with medium and large scale researches on aquatic ecosystems, and undertook many national projects and key projects from CAS. The primary tasks for this organization include: 1) Being responsible for establishing observation and measurement protocols and methods for dynamic monitoring systems of the structure and function of aquatic ecosystems, and also setting standard apparatus and samples to regularly calibrate the equipments used by subordinate monitoring stations. 2) Being responsible for compiling, quality analyzing and credibility assessing routine monitoring data collected from subordinate monitoring stations; submitting the compiled data to synthesis center of CERN on time, and submitting monitoring data assessment report as well, so as to provide information on assessing monitoring station by CERN and competent authority. 3) Being responsible for establishing, maintaining the aquatic ecological information system, and collecting, compiling scientific data and information on medium-large scale water ecosystems, and providing these information through website, in order to share data and information among monitoring stations. 4) Conducting comparative researches on medium-large scale water ecosystems.

AESC persists to carry out long-term ecological monitoring on typical water bodies, and develops the regional limnological methods on medium-large scale. At the same time, with emphasis on facing the national demand, AESC will focus attentions on typical water bodies to build assessment methods of ecosystem services and ecosystem health for Chinese aquatic ecosystems, exploring the sustainable management strategies for the key waters and watershed ecosystems.

1. Studies on ecological organization and comparative limnology of lake groups

239 lakes near the middle and lower reaches of Yangtze River (mainly locate in Jianghan Plain) were selected to study ecological organization and comparative limnology. Among these lakes, class 0 numbered 21, class 1 numbered 39, class 2 numbered 157, class 3 numbered 22 (Class 0 is isolated lake without any water channel linking them, class 1 are lakes directly connected with river, class 2 is a sub lake of a large water system, and class 3 is the sub lake of that of class 2, etc.)

The research on relationship between four morphological parameters of lakes and lake class showed that there were significant correlations between the lake class and lakes area, shoreline length and shoreline development index, except water depths. As far as the lake area is concerned, class 1 lakes were mainly distributed around beaches along the Yangtze River. They were characterized mainly by a large area. Lakes of class 0 often situated in inner plain, the area of which was often less than 10 km2. Lakes of class 2 and class 3 were sub lakes of lakes class 1, and the average areas of which was slightly greater than lakes class 0. Still there were a few class 2 lakes with greater areas. Ordered by the degree of connection with the Yangtze River, from class 1 to class 3 than to class 0, we found that the lakes were larger with more direct connection with the Yangtze River.

According to the relationships between the 16 physiochemical parameters and lake class, we found that there were only 6 parameters (conductivity, alkalinity, DO, Cl^-, Ca^{2+}, SiO_2) showed significant difference among lake classes. Conductivities were significantly higher in lakes of class 2 than in others, while alkalinities were higher in lakes of class 0. Concentration of nutrients (NO_3-N, TN, TP) were different in certain degree in different lake classes. And water transparency, pH, hardness, COD, NO_2-N, NO_3-N, PO_4-P did not show significant difference among lake classes.

The richness of macroinveterbrates and lake classes showed significant correlation. Total richness, richness of Oligochaete, Chironomidae, and Mollusca were all maximum in class 1 and minimum in class 0, and there were no significant differences in richness of macroinveterbrates between lakes belonging to class 2 and 3. The density and biomass of total macroinveterbrates, Oligochaete, aquatic insects, and biomass of Mollusca also showed no significant correlations with lake class.

The above results indicate that the Yangtze River had significant influence on developments of lake groups situated in Jianghan Plain.

2. Evaluation theories and methods of freshwater ecosystem services

In our point, water resources should include water quantity, water quality, water energy and aquatic organisms. Based on these four factors, the services provided by freshwater ecosystem can be summarized as follows:

(1) Water supply. It is the most elementary function of this kind of ecosystem. According to the quality of different waters, water can be used to drink, industry and irrigation etc. The value is determined by both water quantity and water quality.

(2) Water energy. Waterpower is a conversion of this function, and many freshwater ecosystem such as rivers and reservoirs have this function. As to the water current in natural river courses, its theoretical hydrologic capacity and water-head drop are proportioned to the water volume passing through.

(3) Aquatic organisms. Aquatic organisms are the main part of water system providing ecosystem services, they have many ecological functions. The service that we currently know mainly includes: 1) organic matter production provided by the primary producer such as algae, hydrophyte, etc. 2) fixing CO_2 and releasing O_2 by primary producers; 3) nutrients storing and circulating; 4) maintaining biodiversity and the evolution process; 5) absorbing, decomposing and indicating the pollutants; 6) providing fishery products, etc.

(4) Environmental benefit. This kind of ecological service mainly involves: flood detention; climate control; water purification; leisure entertainment; esthetics; education; aquatic sports; spirit and cultural value; shipping function, etc.

Table 6.1 The values of ecosystem service of Bao'an Lake, Dianchi Lake and Donghu Lake

Service functions	Unit price	Value ($\times 10^6$yuan RMB)		
		Baoan Lake	Dianchi Lake	Donghu Lake
Water supply	1.00 yuan/ m^3	12.1	141	0
Organic matter production	3200 yuan/t	15.1	24.02	10.2
Water conservation	0.67yuan/ m^3	109.3	455	42.7
Water resource storage	0.67yuan/ m^3	80.4	783	61.5
Water purification		0.52	7.10	0.36

We studied the ecosystem service of Bao'an Lake and its indirect economic values on the basis of ecological function analysis and some economic methods. The results showed that the order of economic value (in RMB) was water conservation and water supply > organic matter production> CO_2 fixation> O_2 release , nutrient recycling> SO_2 degradation. Based on the collection of existing data, the ecosystem service values of Donghu Lake and Dianchi Lake were estimated as follows (table 6.1).

In comparative research on medium-large scale aquatic ecosystems, the AESC information acquisition of lakes, reservoirs and wetlands consummated day after day. Now we had the preliminary achievement in the study on lakes changes in Hubei Province (Fig. 6.1).

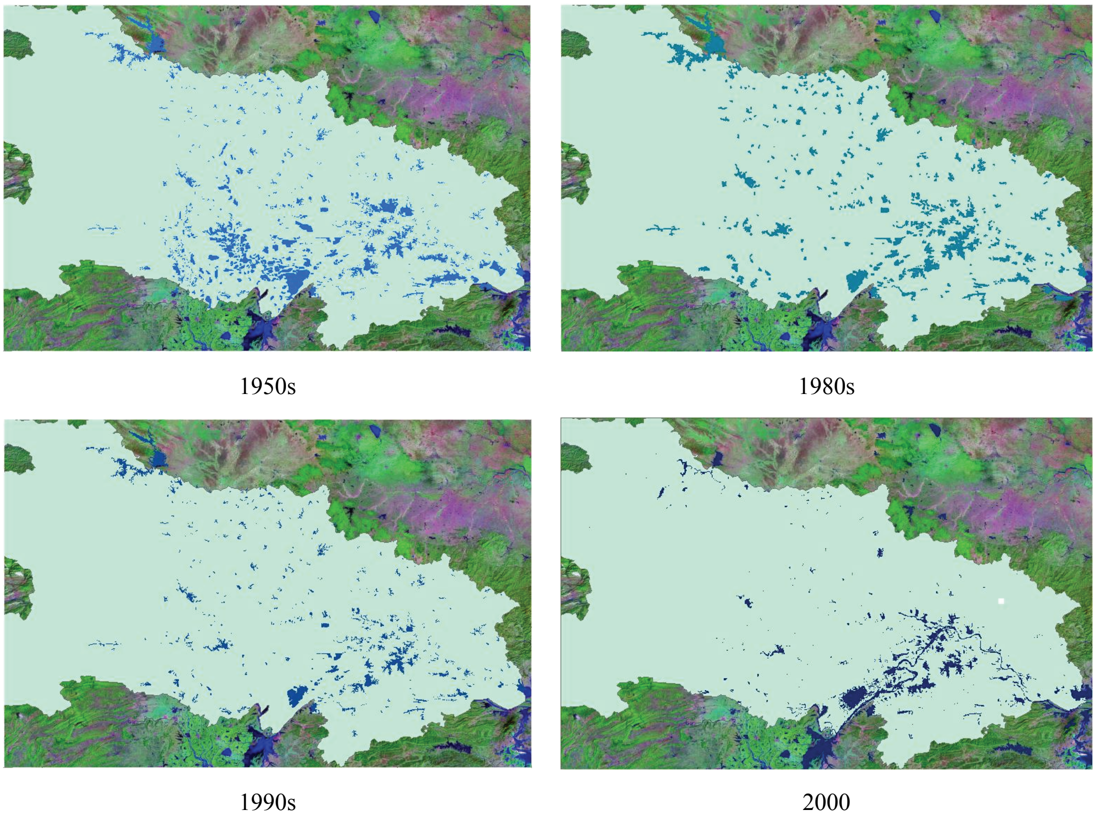

Fig. 6.1 Maps of lake alterations in Hubei Province from 1950s to 2000

According to historical data and GIS analysis, there were 1332 lakes with the area larger than 100 acres in the initial stage of P.R.C. with the total area of 8528.2 km^2 when in middle water level, in which there were 322 lakes with the area lager than 5000 acres and with the area of 7640.6 km^2 (accounting for 89.6% of the total lake area of Hubei Province) and volume of 130.5×10^8 m^3, available regulation volume of 115.4×10^8 m^3 (which could regulate 12.2% of total surface runoff of Hubei Province). Come down to 2000, there were only 103 lakes in the region. The direct effects resulting from the loss of lakes included remarked reduce in regulation capability (available regulation volume reduction to 130.7×10^8 m^3), water storage quantity (reduced from 145.7×10^8 m^3 to 67.4×10^8 m^3), function of soil and water conservation and habitats for wild lives, etc.

The evaluation results of economic values of ecosystem services provided by lakes in Hubei Province indicated that the direct service was worth 261.7×10^8 Yuan and indirect service was worth 66.7×10^8 Yuan, in which the values of fishery products accounted for 79.4% of total value of direct service. It was obvious that people excessively exploited the fishery production of lakes, and which was disadvantageous for sustainable development of lake ecosystems. As to the study of values of flood regulation and water storage, the result showed that there were 56.6×10^8 Yuan and 52.4×10^8 Yuan loss respectively owing to the loss of lakes, and the lost lakes provided 50.01×10^8 Yuan land value. So, returning land to lake should be the prime work for Hubei Province in lake management.

It is difficult to calculate economic value of biodiversity maintenance. According to experience of management and execution of wild life, we built the wildlife judicial price method (JVM). This method is based on the wild lives' values standard provided by administration and the penalty for illegal hunting, with concern in their seasonal migration as well to evaluate their market values. According to this method, the value of waterfowls in wetland of Hubei Province was 2.57×10^8 Yuan with the average value of 161 Yuan per waterfowl, in which the value of national key protected waterfowls was 2.02×10^8 Yuan with average value of 31.60 Yuan per waterfowl, and the economic value of national protected waterfowls was 0.55×10^8 Yuan with average value of 35 Yuan per waterfowl.

3. Evaluation of freshwater ecosystem health

Trophic Status Index (TSI) was used to evaluate the ecological condition of 243 Chinese inland waters. The result displayed that there were 6.17% lakes in the condition of oligotrophic (mean TSI: 30.69), 58.02% of Meso-trophic (mean TSI: 46.75), and 35.80% of eutrophic (mean TSI: 61.17) (Table 6.2, Fig. 6.2)

Table 6.2 Coverage area of different TSI value waters in China Mainland

Trophic status	TSI	% of mainland area
Oligotrophic	<37	32.3
Meso-trophic	37~53	38.6
Eutrophic	>53	29.1
(hyper-eutrophic)	(>65)	8.3

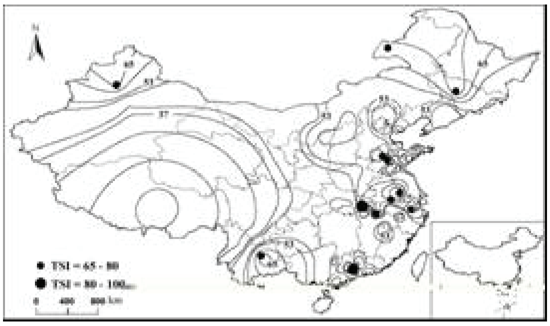

Fig. 6.2 Distribution pattern of trophic state of inland waters in China Mainland.

Ecological health of 23 lakes in the Jianghan Plain were assessed with the method of Lake Bioassessment Integrity Index (LBII). The result indicated that there were 4 lakes in the good state of health (LBII<21, QiaoDun Lake, East Liangzihu Lake, Sanshan Lake, Wutong Lake), 9 Lakes in the general state (21<LBII<31, Baoan Lake, West Liangzi Lake, Niushan Lake, etc.), 9 lakes in the bad state(32<LBII<48, Honglian Lake, Guozheng Lake, Huanghu Lake, etc.), and one in very bad state(LBII>48, Shuiguohu Lake). The trends of LBII and TSI among studied lakes were compared, and their relationship can be expressed as: LBII＝6.229＋0.491TSI ($r=0.81$, $p<0.001$) which means assessment methods based on biological integrity and trophic status can get similar result.

Based on the basic thought of IBIs, 13 indices were selected from pH, salinity, nitrogen metabolism, aerobic situation, humic degree, nutrition condition, morphological characteristics and toleration to pollution to conduct the research on ecosystem health of the Xiangxi River. Variance analysis demonstrated that the indices of ACID, FRESH, HIGH-O, EUTRA, MOBILE are significantly different among different environment condition groups (p value of which was: <0.0001, <0.0001, 0.0001, 0.0178, 0.0001). After having assessed the 49 sampling sites in the Xiangxi River system, we concluded that the whole state of ecosystem health of the Xiangxi River was good, among which the sites in the condition of “good” and “excellent” accounted for 36.8%, sites with “general” condition accounted for 36.7%, and the sites in “bad” condition accounted for 24.6%.

Benthic-Index of Biotic Integrity (B-IBI) composed of EPT taxa, Ephemeroptera taxa, Trichoptera taxa; Trichoptera%, EPT%, Chironomidae%; BI value, and gatherers%, was used to assess ecological condition of Xiangxi River. The result showed that sites influenced by pollution were worst in ecological condition (mean B-IBI: 11). Sites affected by hydropower stations and towns were bad (mean B-IBI: 37). The sites located in Guanmenshan and Jiuchong National Natural Reserve were healthy.

4. Studies on river ecology and watershed management – a case study on Xiangxi River

Till now, 327 benthic algae taxa were (mostly identified to species and variety levels) were found in the mainstream of the Xiangxi River, including 274 Bacillariophyta, 32 Chlorophyta, 18 Cyanophyta, two Xanthophyta and one pyrrophyta. The Diatoms Cocconeis placentula, Achnanthes linearis, Diatoma vulgare dominated the system, with relative abundance of 33.3%, 18.8%, and 6.4%, respectively. In the Xiangxi River system, 355 taxa of macroinvertebrates including Polychaeta, Mollusca, Crustacea, Echinodermata were identified, among which there were 10 classes, 15 orders, 79 families, 234 genera, and 355 species. Baetis spp., Ceratopsyche sp. and Degusia sp. dominated the system, relative abundances of which were 24.4%, 5.6% and 5.3%.

The trend of densities of various kinds of functional feeding groups of invertebrates along stream orders were: densities of collectors increased along with increase of stream order; while scraper showed reverse trend. Density of shredders increased with stream order firstly and then decreased. Density of predator did not show significant difference among stream orders.

Study on the effects of hydropower stations on river ecosystems showed that macroinvertebrates was influenced significantly, whereas algae community seemed to be not very sensitive. Hydropower stations have obvious influences on downstream biological communities.

5. Studies on eutrophication and control strategies of the Three Gorges Reservoir

The concentration of TN, TP were very high in waters of the Three Gorges Reservoir (TGR) and several bays, which already exceeded the threshold value of eutrophication. Although the concentrations of main nutrients in waters decreased slightly after impounding, eutrophication became so evident owing to the decrease of current velocity. Compared to the mainstream, concentration of Chla were higher in bays. The study concluded that algal bloom are more likely to occur in spring in bays. The typical blooming species include Peridiniopsis spp., Cyclotella caspia、Asterionella formosa, and Rhodomonas lacustris, etc.

To get a general information of eutrophication in the Three Gorges Reservoir, we assessed the trophic state of 22 bays and the Three Gorges Reservoir itself in spring, 2005. The results showed that 5 bays (22.7 %) were in meso-trophic condition, and 17 bays (77.3 %) were in eutrophic condition (among which 10 bays in hyper-trophic condition, i.e., 45.5 %). The water quality of the Three Gorges Reservoir itself, however, was still in good condition (meso-trophic) (with TSI of 41.60 and 41.19 in Chongqing and Hubei branch, respectively).

There are 40 rivers with watershed area larger than $100km^2$ in TGR region. Study showed that relationship between chlorophyll a and watershed parameters (annual discharge (D) and catchment area (A)) of bays in the Three Gorges Reservoir was significant negative:

Chla=-55.494 ln(D) + 239.64, R2=0.8652.   Chla=-51.795 ln(A) + 423.51, R2=0.7465

It implied that, generally, the smaller of the bay (or its annual discharge), the higher of chlorophyll a concentration, i.e. the easier of forming algal bloom in spring.

Based on the monitoring and researching, we discussed and proposed several strategies to control or mitigate eutrophication phenomena in the Three Gorges Reservoir: 1) pollution control; 2) completed survey; 3) mechanism study and 4) eco-hydraulic regulation. The main influence factors of reservoir eutrophication can be divided into three kinds, nutritional factors (N, P etc.), environmental factors (water temperature, solar radiation, transparency etc.) and hydrological factors. The research suggested that the area, volume, water depth, shoreline development, runoff coefficient, water level, runoff and water flow velocity are closely related with eutrophication. So it is necessary to strengthen the research on the effects of the meteorological, hydrological processes on the spatial patterns of algal and other biological communities. Based on flow field model of the reservoir, ecological factor fields should be superposed. According to hydrological and ecological characteristics of the TGR and its main bays at different times, combined with flood prevention, power generating, downstream managements and water environmental protection, sound ecological regulation can likely be proposed. It may be an efficient countermeasure for controlling or restraining algal blooming in the TRG region.

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07

Agro-ecosystem and its Process in the Black-soil Farmland

Scientific research progress of Hailun Agricultural Ecological Station

Introduction of Hailun Agricultural Ecological Station

Hailun Agricultural Ecology Experimental Station (HAEES), Chinese Academy of Science, located in Hailun City (478269 N and 1268389 E), the center of the black soil belt, in northeast China. Its research work focuses on the black soil agricultural ecosystem. The soil is a fine-silty, mixed, superactive, mesic Typic Argiboroll referred to as “black soil” in China. Soil nutrient contents in the black soil top layer (0–0.2 m) are 0.056 kg kg-1 organic matter; 0.0026 kg kg kg-1 total N, pH of 6.80; and its wilting-point gravimetric water content is 11.2%. The black soil is mainly found in Heilongjiang and Jilin Provinces in Northeast China and covers more than 10 million hectares. The soil is noted for its high organic matter content of 0.02 to 0.06 kg kg-1 dry soil. Before cultivation, soil organic matter contents ranged from 0.10 to 0.12 kg kg-1 dry soil. The main crops planted are soybeans (Glycine max L.), corn (Zea mays L.), and spring wheat (Triticum aestivum L.). HAEES is located in the North Temperate Zone and continental monsoon area. This region is cold and arid in the winter, and hot and rainy in the summer, with heavy rainfall and high temperatures in the same season. The annual average air temperature is 1.5℃, ranging from typical mean maximum temperature of 32℃ in the summer to a typical mean minimum temperature of -23.7℃ in the winter. The annual mean rainfall is about 500 mm. The average air temperature and rainfall during the growing season (1 May to 30 Sept.) is 18.1℃ and 423 mm, respectively.

HAEES was found in 1978, and became one experimental station of Chinese ecosystem research network (CERN). Two aims were focused on long-term monitoring and research of the black soil agricultural system. The main results were showed as followed:

1. Long-term monitoring on water, fertilizer, atmosphere and heat

The agricultural ecosystems were long-term monitoring by a weather station, a field microweather station, a water balance monitoring field and synthetical monitoring field.

(1) Precipitation dynamic in last four decades

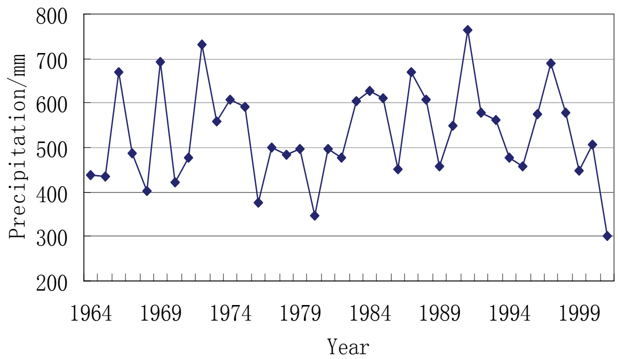


Fig. 7.1 Annual mean precipitations in Hailun experimental station from 1964 to 2001

(2) Air temperature dynamic in last two decades

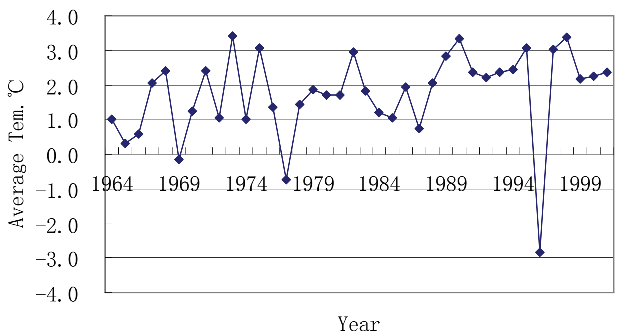


Fig. 7.2 Annual average temperatures in Hailun experimental station from 1964 to 2001

2. Study on the black soil agricultural ecosystem and its process

The black soil agricultural ecosystem and its process was studied by long-term field experiments and field experiment. Twelve long-term field experiments, including fertilizer application, soil tillage, soil water management, crop continued planting, etc, were built. The longest long-term field experiment has been doing twenty-two years.

(1) Vertical variability of soil water content in the black arable field

According to the observation and analysis, soil water content vertically distribution was divided into four main types: (1) significantly varying zone, from the depth of 0 to 40 cm (variation rate is 14-32 % gravimetric unit), maximum change range - 18%; (2) weakly varying zone, from the depth of 40 to110 cm (amplitude change was 24%-32 %, maximum change - 8%) (3) slightly varying zone from the depth of 110-260 cm. (amplitude change - 28-32 % maximum change range - 4 %) (4) not varying zone, under the depth of 270 cm.

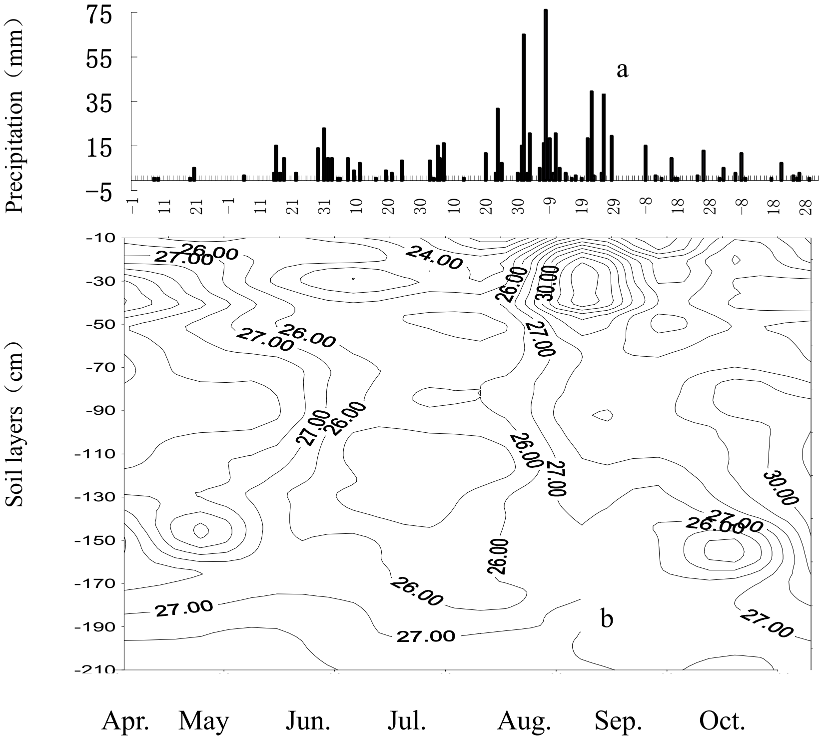


Fig. 7.3 The black soil water characteristic in above normal rainfall year (Apr.-Oct. 1997) a: Precipitation, b: The isoline of soil water content

(2) Soil water movement regularities in different seasons

The movement of the black soil water were divided into four periods according to the results from the measurements and the analysis as follows : thawing stage in spring, dry stage in summer, wet stage in fall and freezing stage in winter. The soil water appeared different dynamics at the four stages.

(3) Effects of different soil tillage systems on soil water

The bulk density and soil water of the black farmland under five different tillage systems by long-term experiment was determined. The moldboard plough and rotary tillage had the lowest bulk density in ridge, and lower water capacity than other treatments. No-till had the highest bulk density and lower saturated water content that will be apt to accumulate water on soil surface. No-till had a more 2-4 percent soil water content in ridge and furrow than those of others from April to June, so it was beneficial to relieve the spring drought. Reduced tillage had a lower bulk density and higher water capacity in summer, a more 4 percent water content in furrow more than those of others, which could hold much rainfall during the rainy season.

Hence, Reduced tillage was an effective soil water management in northeast of China.

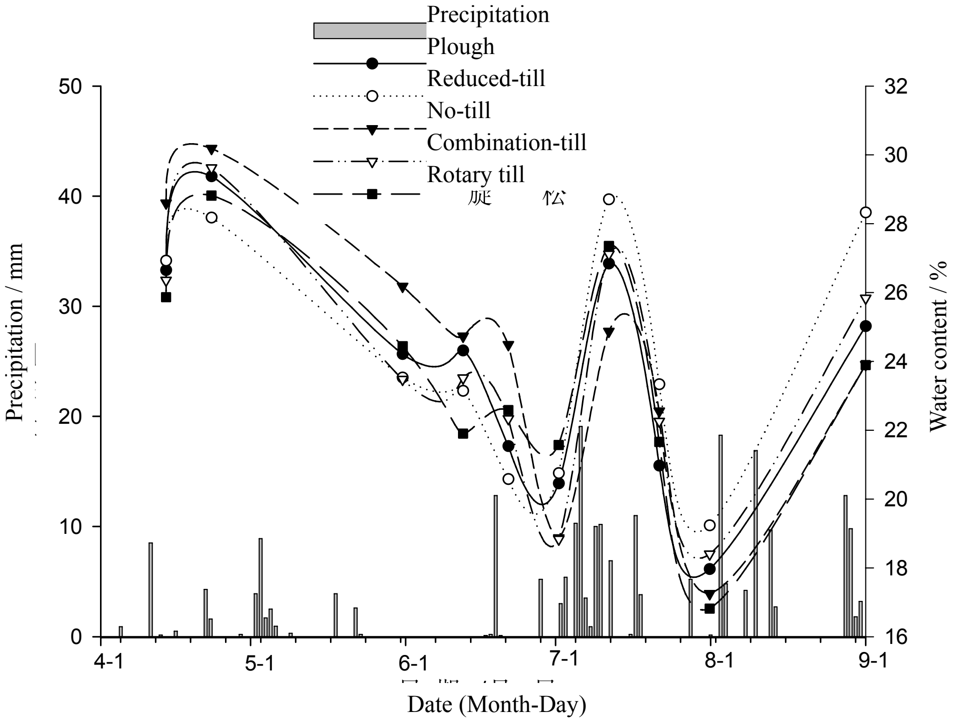


Fig. 7.4 Soil water dynamic under different tillage systems at 0～20cm depth in furrow

(4) Effects of soil erosion on corn dry matter accumulation and yield

Water and soil run off is a threat to agricultural production. Present studies investigated the effects of artificial topsoil removal on corn dry matter accumulation and yield in a black soil field with 6°slope and 30 cm topsoil layer. Dry matter accumulation was not affected when 10 cm topsoil was removed, and significant reduction was observed while topsoil removal exceeded 10 cm. Seed yield was only reduced at 1.9 % and 4.7 % by 5 cm and 10 cm removal respectively, while 34.6% and 95.7% reduction was observed in 20 cm and 30 cm removal treatment. It indicated that soil erosion will result in a sever yield reduction in soybean, and manure application could alleviate the yield loss

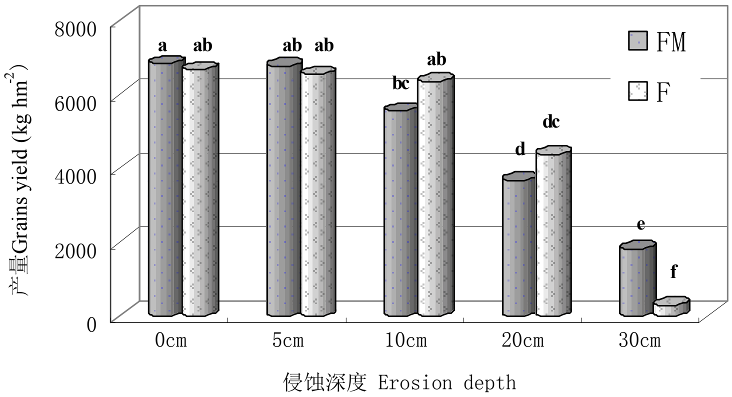


Fig. 7.5 Effect of artificial topsoil removal on corn yield (FM, chemical fertilizer with manure application; F, chemical fertilizer application)

(5) Effects of soil organic matter content on crop productivities

Soil organic matter content is one of the important soil fertility indicators. The relationship between the black soil organic matter content and corn productivity was studied by a soil removal field experiment, which five different organic matter content-18.1 g·kg-1(Lishu),31.1 g·kg-1(Dehui),54.6 g·kg-1(Hailun),103.9 g·kg-1(Bei'an),60.6 g·kg-1(Nemjiang) soils in the black soil belt of northeast, China, were collected and moved to Hailun city, Heilongjiang province and Dehui city, Jilin province, respectively. Results showed: the soil with higher SOM, have a higher soil water content and lower bulk density under Hailun's climate conditions; the soil with 60 g kg-1-SOM, but not 110 g kg-1 had the highest soil Temperature in day time and the highest natural soil productivity under Hailun's and Dehui's climate conditions; there was a higher yield increase rate from chemical fertilizer application in warm location (Dehui) than that in cold location (Hailun) despite of the variation in SOM.

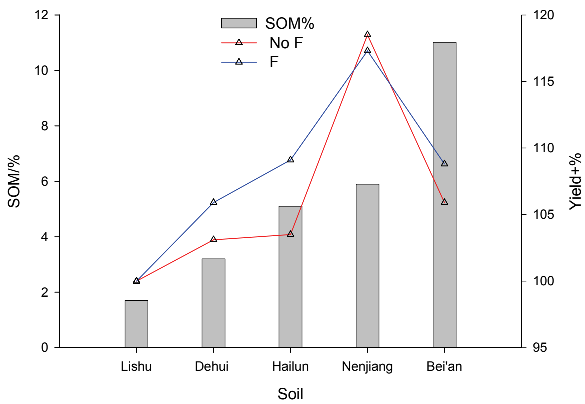


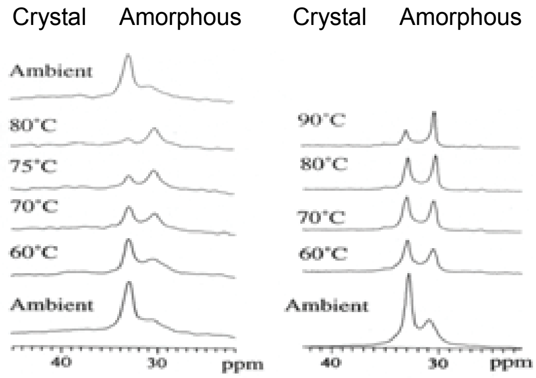
Fig. 7.6 The relationship between corn yield and soil organic content (F, chemical fertilizer application)

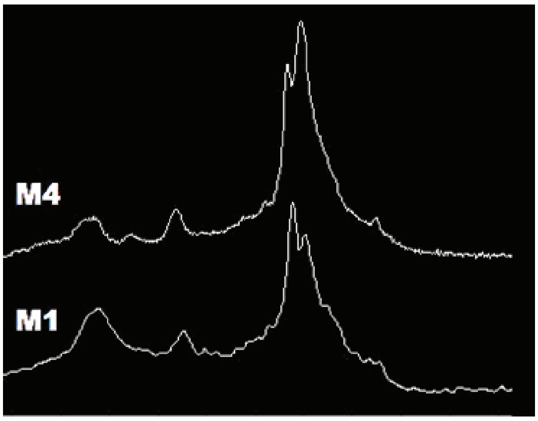
(6) Soil organic matter evolvement with cultivation

The soil organic carbon (SOC) contents were measured in the black soil. The result showed SOC decreased greatly in the first fifty year after reclamation.

(7) Crystal and amorphous fattiness carbon was found in the black soil

Crystal and amorphous fattiness carbon was found in the black soil. Organic contaminations could be adsorbed tightly by Crystal fattiness carbon, which impacted their movements; Amorphous fattiness carbon was hard decomposed, and could fixed CO_2 which affected the carbon global cycle.





(8) Spatial distribution of soil organic matter content in the black soil belt

The spatial variability of soil organic matter (SOM) content across the entire black soil area in Northeast China was determined by geostatistics analysis methods, and the spatial distribution SOM content was interpolated by ordinary Kriging.

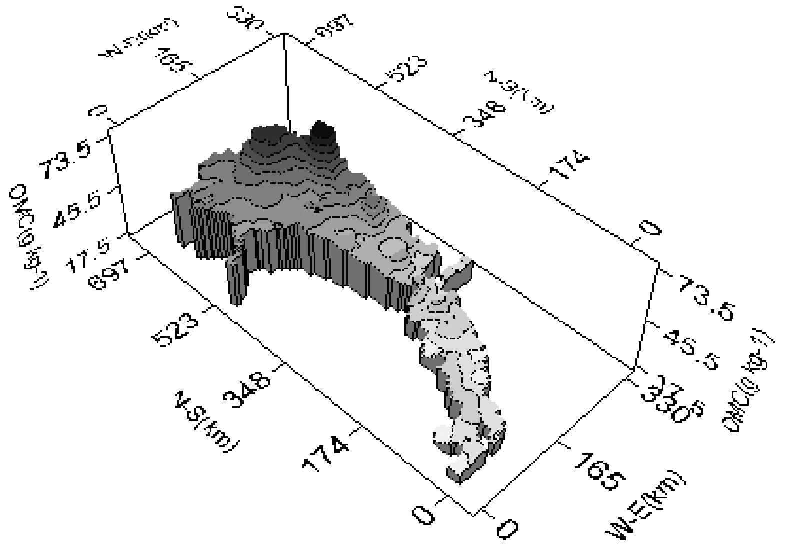


Fig. 7.7 Distributions of organic matter content of the black soil in northeast China. The point 43°.14′.000″ N and 124°.5′.000″ W (approximately south of Caijia town, Lishu county, Jilin province) was defined as a reference.

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08

Ecological Research in Agro-ecosystems of Liaohe Plain over the Last Two Decades

Scientific research progress of Shenyang Experimental Station of Ecology

Introduction of Shenyang Experimental Station of Ecology

The Shenyang experimental station of ecology was founded in 1987, and it was authorized by the Chinese Academy of Science as a key station of CERN in 1992, and then as one of the open stations for field research in 1997. Moreover, it became a National field research station in agro-ecosystem research in 2005. By exploring unceasingly, the Shenyang experimental station of ecology has gradually established its scientific research goal and monitoring duty for meteorology, water, soil and crops, aiming at the demand in agriculture and environment in the specific region, characterized as a high density industry area surrounded by many large cities. Hence, the main issues in this region is considered as sustainable use of agricultural resources, remediation of the contaminated agricultural soil (land), and construction of rural environment. In this context, the research at the station is mainly focused on C and nutrient cycling in plant-soil systems, agroecology and pollution ecology at different scales. Long-term monitoring and located researches are the key approaches at the station aiming at providing temporal dynamics of the agroecosystem there. The application of new technology in agriculture and environmental sciences is also an objective of the station. In addition, the station serves as a platform and window for international cooperative research..

1. Nitrogen ecological process in soil and nitrogen transformation control

The research of nitrogen transformation and cycling is an important part of the ecological processes of nutrients; and also is one of frontier research projects in the area of terrestrial ecological systems. The research of the nitrogen nutrients in the soil ecological processes and the control of the nitrogen transformation both have vital significance in the areas of ecology environment and the agriculture. In the theoretical research of nitrogen transformation, we firstly put forward the concept of the soil effective nitrogen transition pool. We discovered the transformable way of soil inorganic nitrogen by the stable isotope tracing technique, for example, inorganic nitrogen in soil may transform to some kind of organic nitrogen quickly after fertilized, and this new forms of organic nitrogen can be associated to soil mineral - organic complex or the surface of aggregate, which have high activity and the cycling rate. Therefore under certain kind of conditions, this kind of organic nitrogen can release available nitrogen by depolymerization and mineralization, and thus it transforms and cycles unceasingly, constituting a transition pool of nitrogen for plant growth. (Fig. 8.1). The proposed concept of the transition pool will provide a new idea for the studies of soil nitrogen transformation and cycling aiming at increase the N use efficiency of nitrogen fertilizer and thus, it will also become a new research direction in the field of soil science and plant nutrition.

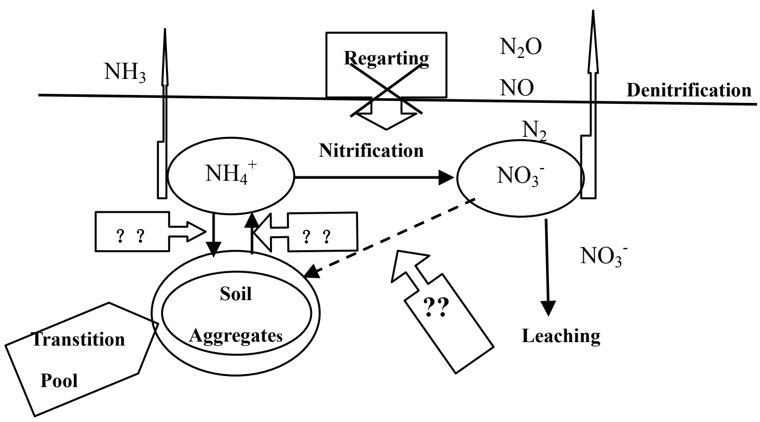

Fig. 8.1 Model of soil N transition pool

In addition, we studied the controlling of soil nitrogen transformation in a different way, i.e. the hydrolisis and nitrification processes of the nitrogen fertilizer can be regulated (urea) based on the principle of soil enzymes. In the simulation and field experiment, urease inhibitor, hydroquinone (HQ) as well as the combination of HQ and nitrification inhibitors (calcium carbide (ECC)) and the dicyandiamide (DCD) are correlated closely to affect the hydrolysis and transformation of urea and thus, they can control the processes of soil nitrogen transformation, of, which the mechanism lies in the optimization of soil enzyme activity. Foe instance, HQ+DCD can reduce soil urease activity significantly, but increase the activity of the soil nitrate, nitrite and oxyammonia reductases. On the bases of the new techiniques, a series of new fertilizers have been developed and the new fertilizers have the function of slow release feature and high efficiency. Thereafter, we cooperated with manufacturers to produce the new fertilizers, slow release and persistent effect urea by means of multiple chemical additive systems and the the production has passed the official appraisal. The work has been highly praised by Chairman Lu Yongxiang of CAS in A Report of “New concentrated fertilizer development and industrial production” in the 117th issue "the Institute of Applied Ecology of Shenyang 863 plans that “Please pay more attention to the industrial production of the new concentrated fertilizer. Afterwards, on October 24, 2003, a technical transfer contract was signed between the Institute of Shenyang Applied Ecology of the Chinese Academy of Science and Jinxi Natural Gas Chemical Industry Corporation in Liaoning province for producing the slow release urea. This research provides a model of the combination of theory and the practice.

2. Moisture ecological process and water saving technology in farmland ecosystems

Based on the study of water ecological process and cycling in farmland ecosystem, this study was focused on the water saving technology, which was suited for the characteristic of farmland ecosystem in the semi-arid region of northeast, and the increasing used rate and efficiency of water. This study has promoted the use efficiency of agro-water resource and the sustainable development of the region economy. The main contribution of the technical innovation is the recommendation of the strategy for the sustainable use of water resources, and the characterization of water movement and water ecological process in the farmland ecosystem of the semi-arid region of northeast.

Based on the study of water movement rule, ecological process, capacity and flux of water pools, and mechanism of regulation in the farmland ecosystem of the semi-arid region of northeast, we integrated the innovation of the technological system of agro-water saving in this region. This has provided the scientific basis for regulating water cycling of farmland ecosystem. With the selection of drought-resistant species, we studied the technology of flow irrigation in well irrigation areas, the saving water technology of infiltrates fills, winter irrigation, chemical regulation, and protective cultivation, and then we established integrated agricultural technology systems for water saving in the semi-arid region of northeast. The achievement provided a technical support for sustainable use of agriculture water resources in the northeast area. By a long-term localization experiment, we had clarified the basic rule and developed some technological regulations and patterns of water-fertilizer management.

3. Ecological chemistry of contamination and the theory and technology of contaminated soil phyto-remediation

Depended on the Shenyang ecological station and the Key Laboratory of Terrestrial Ecological Process, Chinese Academy of Science, we have studied the ecological chemistry of the typical inorganic and organic contamination entirely and systemically. We have attained the achievement in the basis theory of pollution ecological chemistry, ecological toxicology of chemical contamination and ecological effect of complex pollution, action of pollution ecological chemistry and analytical method of pollution.

(1) Ecological toxicology of chemical contamination and ecological effect of complex pollution

The study was focused on the following aspects: (1) the ecological toxicological effect of heavy metals and active X-3B red dyes on the germination of crops (wheat, soybean), vegetables seed (tomato, radish) and root elongation suppression, as well as the poisonous effect on earthworm; (2) the influence of the Cd-Pb compound pollution on crop ecology and the quality of agricultural product; (3) the influence of the soil Cr pollution on the bioavailability of F and the phytotoxicity of plants; (4) the interaction and the mechanism of active X-3B red - methylamine phosphorus and active X-3B red - Cd in soil - plant system; (5) the effect of heavy metals on biological tolerance; (6) diagnosis and early warning of ecological toxicology of soil compound pollution; and (7) the study of Cd- benzene toxicity and [a] pi, the phenol - methylamine phosphorus in the sea water - animal system of the land -sea surface. It was showed that the effect of compound pollution ecology is not only correlated to chemical contamination or chemical properties of pollution elements, but also to the different existence concentration and biological species, especially ecosystem type and site biology.

(2) Chemical behavior, process and analycal methods of pollution ecology

Migration behaviors of active X-3B red dye in water –soil - crops system: Through the simulated determination of adsorption isotherms, adsorption and desorption rate and the influencing factor, we studied the adsorption-desorption action of this organic dye in 4 soil types (cinnamon soil, brown soil, paddy soil and laterite) of a coastal area; Using simulation method of soil column leaching, we studied leaching behavior and movement to the ground water of the active X-3B red in the soil environment; after the flooded experiment of the polluted soil, we studied whether active X-3B in the soil induces the chemical pollution to the surface water or not; in addition, we discussed the influence factors for the agricultural, environmental and chemical behavior of active X-3B red. We used the method of micro universe water cultivation, in which nereis diversicolor is used as an indicator, and calculated the biologically concentrated factor (BCF) of active X-3B red dye; using the method of pot experiment, we have studied the distribution of this dye in crops (including soybean, paddy rice, wheat and radish); combining the method of pot experiment and chemical extraction with soil enzyme dynamics, the effect of this dye on the absorption of Fe to crops (paddy rice, soybean and watermelon) and its biochemistry mechanism were studied. Based on the movement model of active X-3B red in water - agricultural soil – crops, the optimum ecological condition was calculated for the degradation of the dye compound.

(3) Mechanism and techniques of phyto-remediation for heavy metal

contaminated soil

In recent years, taking the heavy metal, cadmium and super accumulation plant screening as the main feature, we have studied the method of the super accumulation plant screening, phyto–remediation mechanism, and phyto–remediation industrialization. The main results were as following: We established for the method of screening heavy metal enrichment/accumulation plants, and through pot and the mining sampling experiments, we discovered and confirmed Rorippa globoga and Solanum nigrum L. are the cadmium super accumulation plants (Fig. 8.2, Fig. 8.3). We also found that it is possible to find the super accumulation plants for heavy metals in the unpolluted ecological areas, so this is a significant breakthrough in the mechanism of phyto-remediation for heavy metal contaminated soil. In addition, the remediation capability of super accumulation plants was studied by the measures of fertilization and replantation.

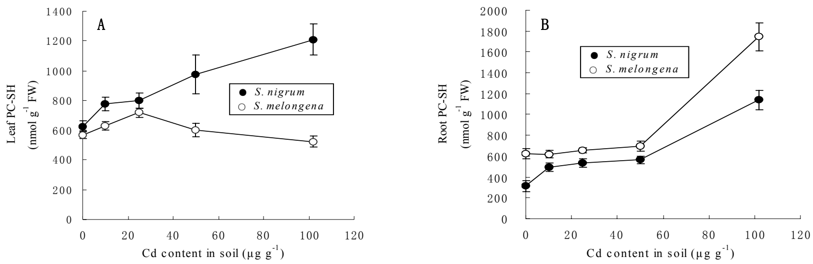

Fig. 8.2 PCs quantity of Solanum nigrum L. and eggplant in leaf (A), root (B) under different cadmium processing

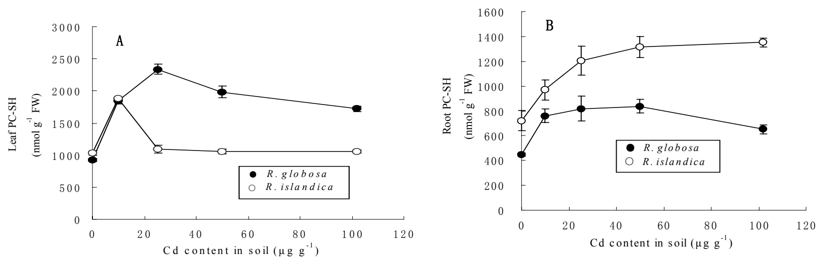

Fig. 8.3 PCs quantity of Rorippa globoga and nasturtium in leaf (A), root (B) under different cadmium processing

4. Microbiological mechanism and reduction measures of farmland greenhouse gas emissions

We illuminated the interrelation of N_2O and CH_4 emissions and its mechanism of microbiology on the basis of Shenyang station as representative farmland ecosystem for the main research region and the platform; the main research content was the technology that the management of farmland water and fertilizer, which increased crops output and reduced the greenhouse gas emissions. We put forward the emission reduction technology by clarifying the interrelation between N_2O and CH_4 emissions and its mechanism of microbiology.

A. The closed chamber method was used to measure emissions correlation between N_2O and CH_4 in northeast rice paddy (Fig. 8.4), and its mechanism of microbiology was clarified. The result indicated that there was a trade-off relationship between the emission of N_2O and CH_4 in the glebe rhizosphere and rice paddy; In the rice paddy, there was population fluctuation in the 6 kinds of bacteria and the change of enzyme activity, but this two kind of gas emissions was regulated by the microorganism quantity and enzyme activity together.

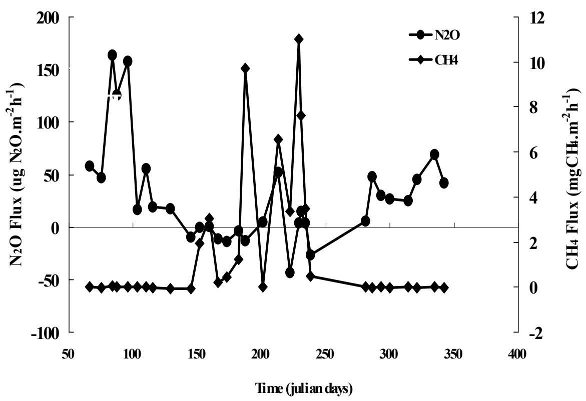

Fig. 8.4 A trade-off relationship between N_2O and CH_4 emission from rice field

B. The significance of soil moisture to the production and emission of N_2O was clarified. In the condition of dry climate and the low soil moisture, N_2O mainly come from the nitrification of nitrifying bacteria; after rainfall, the soil moisture content was high, then N_2O mainly come from the denitrification process of denitrification fungus; in condition of the farmland medium water content, N_2O which was produced by soil nitration and denitrification was equal to each other. In farmland, the produced N_2O was mainly controlled by the soil moisture and soil nitrate reductases activity, and nitrite reductases activity will change with soil moisture. These results were published in Chemosphere (SCI source publication) in 2000.

C. After determining N_2O emission in cornfield on the whole year, it was discovered that there was an obvious seasonal variation for N_2O emissions, and the mainly emission was in crops growing season. Moreover, compared with ordinary ammonium bicarbonate and the urea, the persistent effect ammonium bicarbonate and the slow released urea could reduce the emissions of N_2O obviously, and this also can increase the corn output. In addition, there was high content of ammonia and nitrate in the later period of corn growth after fertilizing the persistent effect and the slow released fertilizer and this phenomenon indicated that these fertilizer could released to soil slowly and provide nutrients to crop for a long time which enabled the crops to absorb the enough nitrogen. At the same time, this function also reduced the emission of N_2O. Therefore, there are obvious benefits of economy and the environment for applying these fertilizers.

5. Rice allelopathy and its ecological control on weeds in paddy

It is a key of the breeding of allelopathic rice cultivars to evaluate and screen few accessions with allelopathic traits from numerous rice accessions and individual plants. Rice varieties and individual plants with allelopathic traits demonstrated their allelopathic effects by producing and releasing specific secondary metabolites into environment. Therefore, using specific secondary metabolites as markers, the allelopathic potentials of rice varieties and individual plants could be evaluated by HPLC. The allelopathic potentials of 5000 rice accessions and some individual plants of F3 and F4 were evaluated by this method in 1 a. If these accessions and plants were evaluated by the traditional method in the field, it would take more than 10a, furthermore, the breeding process of allelopathic rice cultivars would be directed and monitered by this method. There have been more than 30 determined varieties or accessions which belong to different origin, genotype and phenotype. Isolation and structural identification of specific secondary metabolites was done by LC/MS coupling 1H and 13C NMR. It revealed that allelochemicals of rice tissue were glucosides of resorcinol, flavone and hydroxamic acid, and were not well-known phenolic and fatty acids in previous studies.

Interestingly, the concentrations of the allelochemicals released from the allelopathic rice seedlings in soil increased dramatically when they were surrounded with Echinochloa crus-galli. These results imply that allelopathic rice seedlings can sense certain allelochemicals released by E. crus-galli into the soil, and respond by increased production of allelochemicals inhibitory to E. crus-galli. This study suggests that rice residues of both allelopathic and non-allelopathic varieties release similar concentrations and types of allelochemicals to inhibit successive plants. In contrast, living rice plants of certain allelopathic varieties appear to be able to detect the presence of interspecific neighbors and respond by increased allelochemicals. The results not only enable us to comprehend plant-plant interactions, moreover, but play a great role in rice production and weed control in paddy.

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09

Experiment and Research on Agro-ecology

Research progress over the past three decades in Yucheng Integrated Experimental Station

Introduction of Yucheng Integrated Agricultural Experimental Station

Yucheng Comprehensive Experimental Station (YCES) is located at the hinterland of Huang-Huai-Hai Plain, also called North China Plain, which is largest alluvial plain in eastern Asia within temperate semi-humid monsoon climate zone, fluvi-aquic soil (Fluvisol or cambisal) and saline fluvi-aquic soil as its major soil types with the silt loam top surface. Historically, natural disasters such as drought, waterlogging, wind erosion and alkali-saline hazards hit this area frequently. Although this area has fragile ecological environment due to the rainfalls with high temperatures occurring at same months (June to September), it is a major agricultural region with considerable agricultural potential. The agricultural ecosystem in vicinity of this station consist, mainly, of crop growth (wheat, corn, and vegetables), stock raising (cattle, poultry, and pig), and aquiculture, with representative of agricultural production regions in the Huang-Huai-Hai Plain.

The mission at YCES is to conduct long-term studies, observations and demonstrations by long-term experimental data collections. The YCES mainly focuses on 1)the experimental studies on transfer and conversion of energy and matter on the global surface, development of modeling and methodology of scaling up and down by the aim at rational use of natural resources and regional sustainable development; 2) innovation of experimental methodology and improvement and development of experimental instruments and facilities; 3) study of structure and function of agroecosytem by combining geography, ecology and agronomy on theory, methodology and measurement in order to optimize management in agroecosytem and demonstrate the suited techniques. By the long-term efforts over the past three decades, YCES has held the advantages on the research fields of mechanism of water and energy in agroecosystem, crop growth presses, and technique of experimental remote sensing, technique of water-saving farming, demonstration of agricultural experimental areas.

YCES was first founded in 1979 and later was listed as one of first group opening experimental stations by CAS in 1989 and one of first group pilot key national experimental stations by MOST in 1999. Since the foundation, YCES has achieved a lot on the research work and data collection in the fixed research fields of evaporation from farmland, crop water consumption, water transform in agoecosystem, application of experimental remote sensing, and demonstration of agricultural techniques. Totally more than 300 research articles have been published by the scientists working at the station exclusive of fifteen monographs, and five volume of data collection. YCES has been awarded special grade prize and second grade prize of China National Science and Technology progress and special grade prize and first grade prize of CAS Science and Technology progress, agricultural prize of Third World Academy, second grade prize of CAS Natural Science, achievement prizes by MOST , National Development and Reform Commission and Ministry of Finance of P.R. China, for conducting the National Key Technology R&D projects during 1991-1996 and moreover with additional nine prizes issued by CAS, ministries and commissions of P. R. China.

1. Hydrological modeling

Hydrological modeling has been one of the most important research areas at Yucheng Comprehensive Experimental Station since its foundation in 1979. The model development has been involved in all aspects of water cycling processes from field scale to watershed scale, and from hydrological science to multidisciplinary study of hydrology and ecology. Table 9.1 gives an overview of the advancement in hydrological modeling in the last three decades.

Table 9.1 Overview of the hydrological modeling study at the YCES in the last three decades

Models	Type	Year	Authors
Evapotranspiration	field	1980-90s	Hong, J. L.; Xie, X. Q.; Chen, J. M.; Zhang, R. H.
Root water uptake model	field	1990s	Luo, Y.
Photosynthesis-transpiration-stomata resistance model	leaf-canopy	1990s	Yu, Q.
SPAC system	field	1980-90s	Yang, B. J.; Sui, H. J.; Wang, Q.; Wu, Q. L.; Luo, Y.
CERES-Wheat, Maize, and Cotton2K models	field	1990-2000s	Luo, Y.; Ouyang, Z.
Distributed eco-hydrological model	watershed	2000's	Luo, Y.

Multidisciplinary efforts have been made in study the evapotranspiration process. Scientists from agrohydrology, agrometeorology, climate, remote sensing, plant physiology, ecology, soil physics, and etc. have used evaporators, approaches of water balance, aerodynamics, heat balance, remote sensing, eddy correlation and etc. to observe the evapotranspiration process. Based on the experimental study, they have established the mathematical models of estimating regional evapotranspiration. Combining the meteorological data and the evaporative approach, they have established the compensatory model of estimating the potential and actual evapotranspiration over large scale. Based on the observations of the surface water evaporation at this site and also in the Nansihu Lakes that is located not very far away from the station, Hong et al. (1985) had developed a formula for estimating the surface water evaporation, which was adapted as a standard approach by the national meteorological department. On basis of field observation, Xie (1988) modified the aerodynamic resistance in the evapotranspiration formula of Brown and Rosenberg. The modification improved the formula in its overestimation. Li et al. improved the zero flux plane approach to estimate the evapotranspiration over crop field.

With regard to crop root development and its relationship to irrigation, and the root water uptake modeling, quite a few scientists have made their efforts both in field and experiment. Luo et al. (2003) have evaluated the widely used macroscopic root water uptake models (Molz–Remson, Feddes, and Selim–Iskandar) using the lysimeter data, and modified the Feddes model with the root length density as following,

$$S = \frac{\alpha(\psi)R(z)}{\int_0^{Lr}\alpha(\psi)R(z)dz}T_r \tag{1}$$

Compared to the observations, the modified Feddes model significantly improved the prediction accuracy, reducing the average deviation from 13.6% to 5.6%.

Wu (1993) established a two-dimensional numerical model for the saturated-unsaturated infiltration from within a single ring under a steady head to study the theory of using the pressure infiltrometer to determine the hydraulic conductivity of soil. Wang (1991) derived an analytical solution of the change of soil moisture profile over time under infiltration condition influenced by different tillage practices, such as mulching, furrow, and deep plowing.

In soil-plant-atmosphere continuum system modeling, Yang (1988) constructed a coupled soil water and heat transfer model to study the tillage effects on soil temperature and moisture of the seed bed based on Philip-de Vries equations in order to study effects of tillage practices on soil water and temperature. The effects of the ridge and furrow dimensions and orientations to sowing were investigated numerically with this model. Similarly, Sui (1989) researched the soil water movement and heat transfer over soil profile under varieties of surface cover conditions, such as transparent, semi transparent plastic films, straw mulching, and etc. Also, infiltration was studied under mulching conditions. The models of Yang (1988) and Sui (1989) did not take into account of the crops. The soil water regime in a crop root zone is critical to crop growth. To better characterize the dynamic variability of soil water regime, Luo et al. (2007) developed a stochastic model of soil water storage (SWS) by treating the evapotranspiration (ET) as an explicit random process, which is a set of two first-order temporal stochastic differential equations. The Fokker–Planck equation of the probability density function (PDF) of SWS was derived from the stochastic differential equations and solved numerically. These numerical solution results compare favorably with two years of SWS measurements. This indicates that the stochastic model can be a useful tool for irrigation scheduling and the associated risk assessment.

Wu (1993) also constructed a model to provide a physical base to simulate water movement and heat transfer in SPAC. The coupled vapor and heat flux equations were based on the framework of Shuttleworth and Choudhury. The one-dimensional partial-differential equations were employed to describe the coupled water and heat movement in soil. Wu (1993) presented a technique in decoupling the canopy heat and vapor fluxes in this model and simplified the iteration processes of the numerical solution.

To study the relationships among crop photosynthesis, transpiration, and stomata resistance in the SPAC system, Yu in the late 90s and early 2000s improved the famous stomata conductance model, the Ball-Berry model, by considering that the stomata conductance and gross photosynthetic rate increase initially from 0 in response to light increase. Therefore, the B-B model can be modified as

$$g_s = m \cdot \frac{P_n}{(C_s - \Gamma) \cdot (1 + D_s / D_0)} \tag{2}$$

With the improvement, the model could describe the responses of stomatal conductance to light intensity below light compensation point. The integrated model of photosynthesis, transpiration and stomata conductance was established by generalizing the relationships between physical and physiological processes on the leaf. After the model integrated photosynthesis, transpiration, stomata conductance and leaf energy balance, the description of the effect of environment factors on the midday depression of photosynthesis and transpiration was achieved.

Luo et al. (2001) established a crop – soil system (CropS) model to simulate the coupled photosynthetic and evapotranspiration processes under water stress conditions. The CropS model simulates the soil water dynamics, soil evaporation and crop transpiration, crop water uptake by root, canopy resistance-photosynthesis-CO2 flux.

The SPAC modeling study has been extended to the crop growth modeling study since the start of 2000s at YCES. Crop growth models have become an important part of the eco-hydrological modeling study. Extensive field experiments have been carried out since then to lay a foundation for the model study. CERES-Wheat and Maize and the COTTON2K models are extensively studied. The suitability of those models to local crop, soil, groundwater, climate, and agricultural practices has been evaluated systematically (Luo, Ouyang). The COTTON2K model was improved in the LAI development to fit for the local management practices. Those models were employed to analyze the response of crop water use, yield, and water use efficiency to irrigation practices and climate variability in the irrigation districts of the Yellow River Basin or in Huang-Huai-Hai Plain.

The Yellow River is the second largest river in China. The basin covers nine Provinces: Qinghai, Sichuan, Gansu, Ningxia, Inner Mongolia, Shanxi, Shaanxi, Henan and Shandong. Water use is mainly dedicated to agriculture of wide spread irrigation districts in the basin. Farming systems within irrigation districts of the Yellow River basin have been developed on diverting the Yellow River water for many centuries and have contributed tremendously to China's food output and social welfare. Irrigation districts spread out widely in the basin, Figure 1. According to the data of 1995, the total irrigation area was 712.6×104ha, of which 346.5×104ha was in the upper and middle reaches, and 366.0×104ha in the lower reaches. According to the Water Resources Bulletins of Yellow River basin, agriculture uses 80-90% of the total water resources of the basin, 90% of which was used to irrigate crops. An integrated water management has been becoming an ever increasingly important issue of sustainable development of the irrigation districts.

The hydrological models are very powerful tools for the integrated water and land management at watershed scale. However, there are not any models that meet with features of the irrigation districts and ready for use. So, Luo (2007s) developed a distributed eco-hydrological simulator (DEHYDROS, Fig. 9.1) for the irrigation districts of the Yellow River Basin, and applied it in Hetao irrigation district, Inner Mongolia, China. The DEHYDROS model was developed from the watershed hydrological model SWAT2000 (Soil Water Assessment Tool), the groundwater model MODFLOW96 (A Modular Three-Dimensional Finite-Difference Groundwater Flow Model), the surface/groundwater modeling package SWATMOD99, and the wheat and maize crop models of CERES (Crop Environment Resources Synthesis) model family.

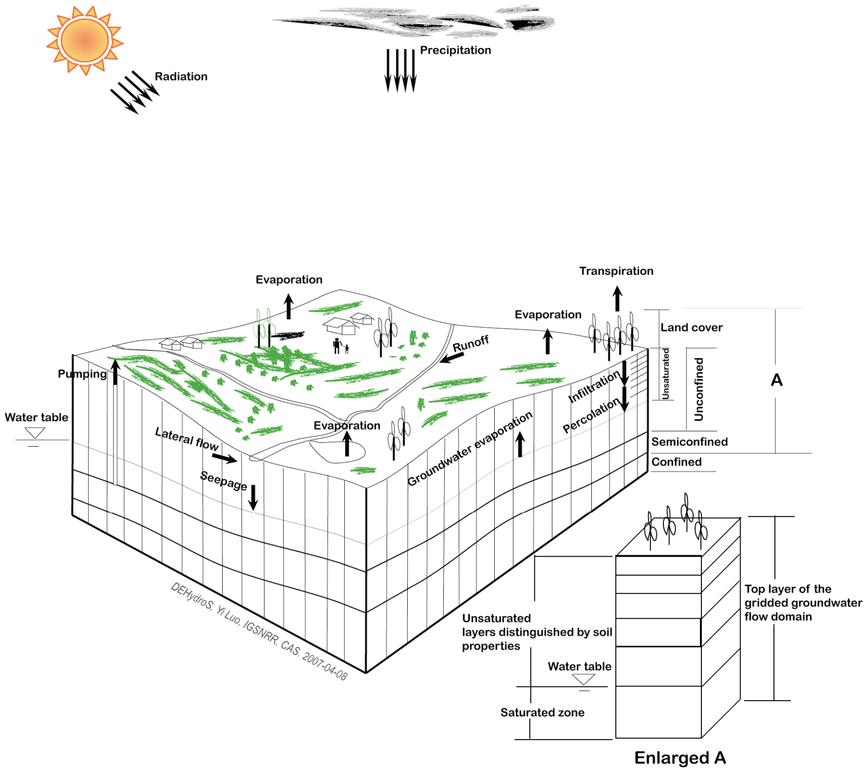

Fig. 9.1 Sketch description of DEHYDROS model

The application of DEHYDROS in Hetao Irrigation District provided a detailed simulation of seasonal groundwater table fluctuation, recharge to and evaporation from the shallow groundwater, and the annual water budget over the entire district. These results indicate the necessity of two-way coupling of the unsaturated-saturated processes when groundwater level is shallow, and the feasibility of making comprehensive use of surface, soil and ground water information in providing a more physically-based assessment of regional hydrological dynamics. Meanwhile, scenarios simulation revealed that annual diversion of 4 billion cubic meters in Hetao Irrigation District was a critical value that maintains the crop yield and water used efficiency both at a reasonable level (Fig. 9.2).

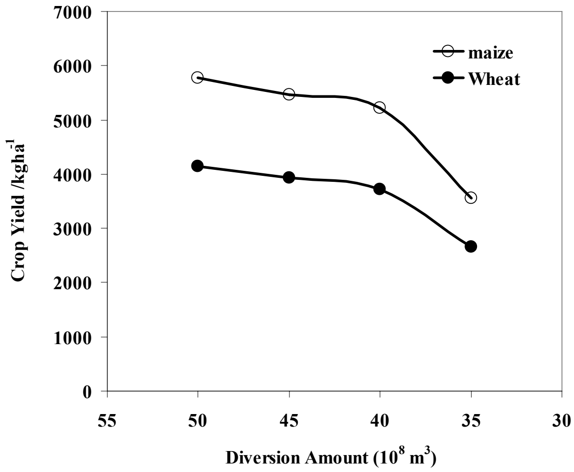

Fig. 9.2 Yields of wheat and Corn under different amount of water diverting from the Yellow River, HID, Inner Mongilia, China

2. Experimental remote sensing

Experimental remote sensing research has achieved great progresses in the last three decades. A 30m high tower was build up as a platform for installing the remote sensors. Synchronized with detailed ground truth observation and with the multidisciplinary efforts of remote sensing, micrometeorology, ecology, soil physics, and other methods have been developed or improved to retrieve information through the thermal infrared information. Chen (1988) developed an improved evapotranspiration model using the remotely sensed plant canopy temperature by introducing the excess resistance concept and gave the theoretical formulation of the excess resistance. Great progresses have been achieved in remote sensing soil moisture, evapotranspiration, crop yield, etc. Zhang et al. have improved the theoretical models of crop water stress index of Jackson Price and Idso, the thermal inertia model of soil, and crop yield prediction since 1980s. Sun et al. (2007) have evaluated and improved MOD16 algorithm of NASA for surface resistance, and applied the improved method in estimating the regional evapotranspiration in North China Plain from the MODIS information.

3. Nutrient cycling

A long-term permanent plot experiment has been conducted since Oct, 1989 at YCES. Field treatments included five different treatments, i.e., unfertilized (control), NP, NK, PK and NPK. A randomized complete block design with four replications was installed. Each plot has a size of 6m×5m. Fertilizer treatments were applied to the same plots each season in a continuous winter wheat/summer corn double-cropping system. Soil available nutrient, nutrient of crop, and crop yield were collected and analyzed for each year. The natural productivity of representative soil in local area was analyzed. The long-term experiment provided rich data for field nutrient balance (Fig. 9.3).

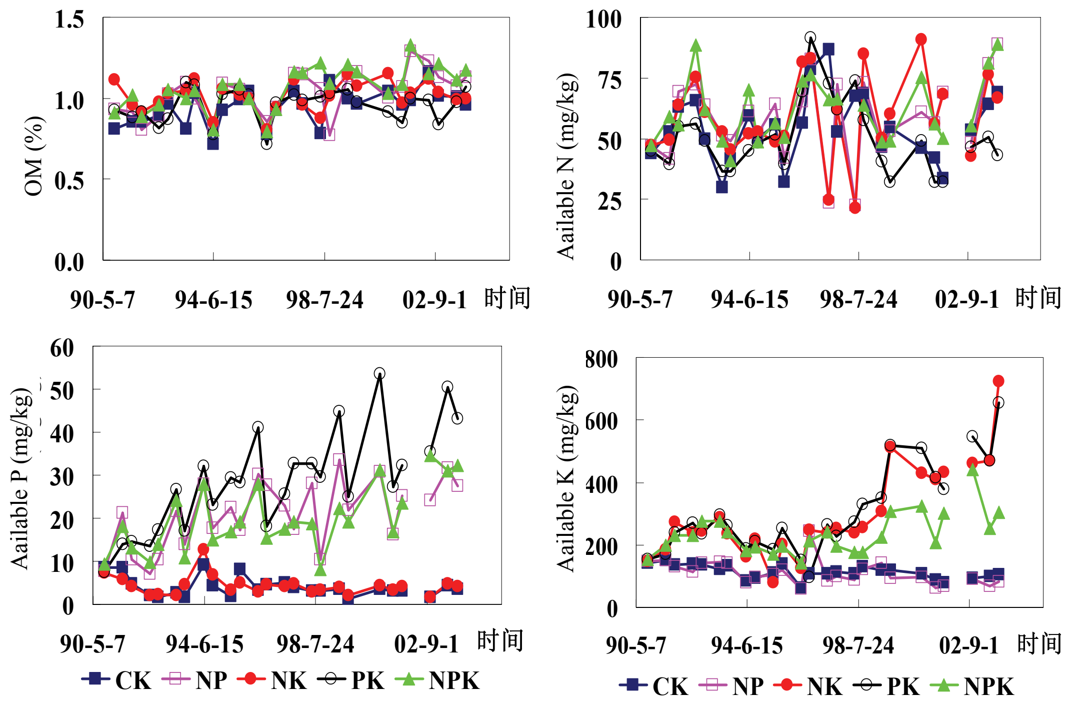

Fig. 9.3. The dynamics of main soil nutrients from 1990 to 2002

Based on the analysis of the spatial variability of soil texture, bulk density and organic matter content, the spatial variability of hydraulic parameters, solute transport parameter and transformation parameter were considered in a process-based model (HYDRUS-1D). It was assumed that the field was composed of a number of non-interacting one-dimensional columns. The spatial variability of N transformation and transport due to variation of soil properties was analyzed (Fig. 9.4). Two scenarios for N leaching below root zone were compared, i.e., considering the spatial variability of N mineralization rate or not. The simulation experiments provide a basis for analysis on the risk of N leaching, which aims at groundwater quality assessment at field scale.

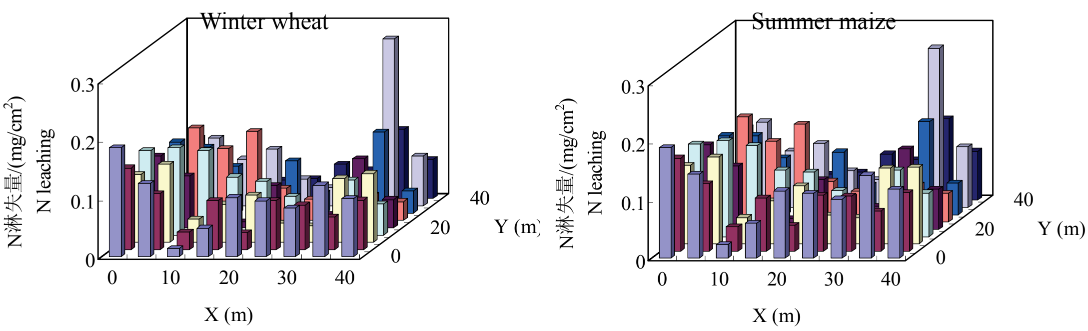

Fig. 9.4 N leaching amount during the growing state of winter wheat and summer corn

4. Regional agricultural integrated research

Since 1983, YCES has started to conduct the National Key Technology R&D programs over the National Sixth Five Year Plan to National Ninth Five Year Plan period. Three suited techniques on ameliorations of heavy saline and alkali soils, wind erosion lands and waterlogging depressions were developed successfully, three type experimental bases were set up and outputs with academic values and application foreground had been achieved, which was praised by international and domestic scholars at the related fields.

During different developmental stages for the Yucheng Experimental Area, YCES had offered the suited techniques for the integrated amelioration of saline-alkali soils and improvement of middle-low productive croplands and agricultural sustainable development in Huang-Huai-Hai Plain. In 1960s, before YCES was established, the Researchers from CAS developed the techniques for amelioration of saline-alkali soils by irrigating cropland and draining water both through using wells; in 1970s, with scientists from other institutes of CAS, YCES co-developed integrated amelioration techniques of saline-alkali soils, called " well, channel, leveling, fertilization, forest and change" which means that to use well to irrigate and drain cropland, to use channel to drain flood, to level cropland, to fertilize cropland, to forest around cropland and finally to get the cropping system changed; in 1980s YCES developed suited techniques on amelioration of heavy saline and alkali soils, wind erosion lands and waterlogging depressions; in 1990s YCES developed the techniques for keeping ecological stability in reclaimed area and developing stock raising in agricultural region.

Around the YCES three types of experimental bases with different characteristics were established, which include the experimental base for waterlogging depressions reclamation by constructing fish-pool terrace land eco-engineering, experimental base for seasonal wind erosion lands reclamation by planting cash trees, and experimental base for amelioration of heavy saline and alkali soils by controlling water-salt movement. More specifically, in each base there were different models to be developed to ameliorate different lands. They consist of the model to ameliorate waterlogging depressions in semi-humid region by employing fish-pool terrace eco-engineering techniques, the model to reclaim wind erosion lands by planting arbor, shrub, and grass with panting cash tree together to establish wind erosion-proof forest system, and the model to reclaim heavy saline and alkali soils by controlling water-salt movement with intensive irrigation to leach salts down and keep the stability with crop straw mulch. through the above measures more suited techniques were developed, which indeed enriched the "well, channel, leveling, fertilization, forest and change" techniques, and demonstration sites and technical ways were developed in Huang-Huai-Hai Plain, which led the larger area amelioration and agricultural development in the Plain. Only in Yucheng County there were 6667 ha of barren lands reclaimed and 36667 ha of middle-low croplands improved respectively (Fig. 9.5).

Fig. 9.5 Compared pictures before and after ameliorating heavy saline and alkali soils in Beiqiu experimental site, Yucheng County

YECS developed high efficient development model of stock rising in agricultural area.In order to boom stock raising and investigate high efficient development models of stock rising in agricultural area, since 2001, YCES has developed a high efficient model called “Four Unifications and One Separation” model which means farm household to raise separately and community to use techniques for management unitedly, to use silage feed unitedly, to protect epidemic disease unitedly, and to collect the products for selling unitedly. The above breeding pattern has made great progress on high efficient rising of milk cow and live pig. The models consist of planting-breeding-processing resource cycling model, high efficient feed optimized techniques in stock rising in agricultural area, high efficient techniques of using the corn stubble as feeds, and planting models of high yield with high quality of forages.

5. Development of experimental equipments and facilities

Great achievements in developing new techniques, instruments, and facilities for SPAC system experiment have been made at YCES, such as the automatic sensor level shift Bowen Ratio system, the large scale weighing lysimeter, the automatic observation system of temperature profile in canopy, IAG-II neutron probe, the eddy correlation system, and the observation site of evaporation pans. These equipments and facilities have contributed greatly to the research in micro-meteorology, water cycling, soil physics, and experimental remote sensing.

Especially, the innovative design of the weighing lysimeter has gained a sensitivity of 60g (equivalent 0.02mm water in depth over the surface area 3.14 m^2) against the total weight of 32.7-35.99 tons. The technology of the design and manufacturing of the lysimeter has been applied in more than ten experimental stations within the Chinese Ecological Research Network, which has been playing important role in water cycling study at those stations (Fig. 9.6).

Fig. 9. 6. The weighing lysimeter (left) and the biggest evaporation tank (20M^2 in area) at the evaporation observation site (right) of YCES

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10

Theories and Practices of Increasing the Productivity and Stability of Agro-ecosystems in Huang-Huai-Hai Plains, China

Scientific research progress of Fengqiu Agricultural Ecological Station

Introduction of Fengqiu Agricultural Ecological Station

The Experimental Station of Agroecology in Fengqiu, CAS (ab. Fengqiu Station) is located in Fengqiu county (35°01'N, 114°32'E), Henan Province, the centre of Huang-Huai-Hai plain (HHH-plain: Yellow River, Huai River, Hai River) of China, where climate is semi-arid and sub-humid warm-temperate with monsoon, and average annual precipitation and evaporation are 615mm and 1875mm, respectively, and annual average temperature 13.9℃. It is adjacent to wetland of the Yellow River bank in the south and North China Plain in the north, where major soil type is fluvo-aquic soil, the most wide-spread soil type in the HHH-plain, accompanied with a small proportion of saline-alkaline soil, aeolian sandy soil and marshy soil, and main natural vegetation is secondary arbors, bushes, grasses and marshy, aquatic plants. Since some typical ecosystems in HHH-plain, such as intensive agro-ecosystem with high yield, low productivity agro-ecosystem in problem soils, lowland ecosystem in Yellow River bank can be found in the station region, Fengqiu Station is an ideal field research base for agricultural natural resources, ecology, environment in HHH-plain. Therefore, sustainable agriculture, as a target of the station is main topic, three aspects are concentrated on:

(1) Long-term on-site monitoring of agricultural resources, ecology and environment to accumulate basic data, investigating and predicting the evolvement of resources , ecology and environment in HHH-Plain under intensive practices.

(2) Systematic studying on structures, functions and productivities in different agro-ecosystems, and material, particularly nutrient cycling and energy transformation in and between sub-ecosystems, such as water, soil, atmosphere and plant to develop best management.

(3) Establishing of cycle agriculture and developing of relative new techniques for saving of

water, fertilizer, land, energy to optimize agro-ecosystems and build demonstration areas for HHH-Plain.

Through hard work in last 50 years, especially in last two decades, the station got very successful and great achievements.

1. Evolvement trend of fluvo-aquic soil quality under long-term intensive agriculture in HHH-Plain

Fluvo-aquic soil is widely distributed in HHH-Plain, previously it is a poor fertile soil with nutrient deficiency, particularly nitrogen (N) and phosphorus (P) deficiencies except potassium (K) due to light texture, low organic matter, higher soluble salts and calcareousness. In the last 2 decades productivity potential of fluvo-aquic soil was enhanced by intensive practice, such as huge nutrient input, expanding of effective irrigation area and increase in irrigation water amount by pumping groundwater through wells, which resulted in the HHH-Plain became the highest yield area in China. However, a question has been concerned, i.e. how does the long-term intensive practice influence on fluvo-aquic soil quality? Focusing on this sensitive problem which relates to agricultural sustainability in HHH-Plain, researchers from Fengqiu Station conducted long-term experiments for monitoring and observing the change of fluvo-aquic soil quality at different scales (such as simulation studies in lysimeters, long-term field experiment, gridding soil survey in 8 typical counties selected from HHH-Plain), and the objective revealed long-term effect of intensive practice on soil quality.

The results from laboratory and field experiments indicated that there was not only high nitrification potential but favorable environment for ammonia volatilization in fluvo-aquic soil. Therefore gaseous loss and leaching of nitrogen were two important processes in decreasing the use efficiency of nitrogen fertilizer in fluvo-aquic soil. On the other hand, large amount of phosphoric fertilizer was applied and immobilized at Ca-P form in fluvo-aquic soil with calcareous property. Since P slowly releases from Ca-P, accumulated P can be re-used by plants, and prone to increase available P level in fluvo-aquic soil. The results also showed that potassium was abundant in fluvo-aquic soil, but after 10 year intensive cropping soil available potassium was decreasing because the removed potassium amount through harvesting exceeded soil capacity for releasing K when fertilization without K. The results from long-term monitoring of transport of water and salts in fluvo-aquic soil indicated that the salts moved into the layer under root zone or deeper through irrigation washing process in HHH-Plain when great groundwater was exploited for flooding irrigation in the last 20 years. This irrigation approach was positive on preventing secondary salinization but negative on sustainable utility of water resources and nutrient conservation in HHH-Plain. Long-term experiment demonstrated that certain amount of nitrate leached into groundwater every year and polluted the groundwater. Soil organic matter, as an important index of soil fertility quality and ecosystem stability was elevated, and high yield also sustained even under long-term application of chemical fertilizers (NPK), which was demonstrated by both the long-term nutrient experiment and the long-term on-site monitoring in two county region: Fengqiu and Yanjin. The reason is that soil organic matter was promoted by high yield with huge crop biomass, the soil productivity increased in accord with elevation of soil organic matter (Fig. 10.1).

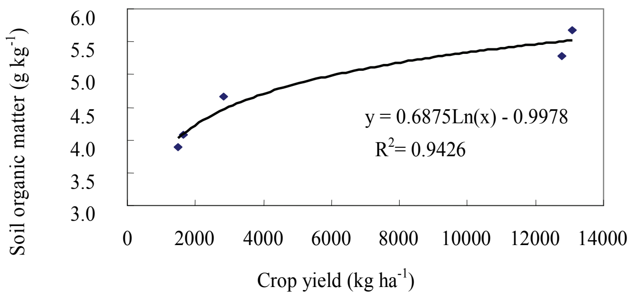

Fig. 10.1 Relationship between soil organic matter content and crop yield in fluvo-aquic soil

Gridding survey was done to identify what regional soil quality changes. One thousand seven hundred fifty-five soil samples were collected from 7 typical counties, i.e. Yuanyang, Fengqiu, Yanjin, Changyuan, Jizhou, Pingyuan, Yucheng, which were distributed in 3 provinces (Henan, Hebei, Shandong) of HHH-Plain. Twenty-three items were analyzed each sample. Some data, such as the second national soil survey in 1979-1983, soil environmental background investigation was collected too. The results showed that after 20-year intensive cropping, salinity was hardly found in root zone, soil organic matter and available phosphorus gradually increased, but soil available potassium was decreasing (Table 10.1). The average residues of DDT in surface soil were much less after 20 year degradation, and only 3% samples exceeded the national standard for soil environment (50 ug·kg-1). The average residues of hexachlorocyolohexane (C6H6Cl6) were far lower than the standard (50 ug·kg-1), and 97% CHC was degraded compared to the residues 20 year ago. The heavy metal contents in fluvo-aquic soil (especially Cd, Cr, Pb, Cu, Zn and so on) weren't beyond the standard, but all of them had an accumulative effect to different extents except Cr compared with the data 20 year ago, for example, in surface soil in Fengqiu increase of Cd and Pb was more than 80%, and Cu and Zn more than 60%, only Cr wasn't significant. The identification of pollution sources indicated that long-term fertilization, particularly phosphoric fertilizer application would lead to accumulation of heavy metals（As, Hg, Cd, Pb so on）in soil besides the effect of the macro-environment, such as dry and wet falls from atomsphere.

2. Heavy fertilization's long-term influence on sustainable productivity in farmland ecosystem

Fertilization is very important to enhance grain production in fluvo-aquic soil. However, it is wondered whether long- term large input of nutrients, especially chemical nutrients affects the

Table 10. 1 Change of organic matter, P and K in surface soil in typical counties of HHH-Plain under 20 year intensive cropping

County	Year	Organic matter ($g·kg^{-1}$)	Available P ($mg·kg^{-1}$)	Available K ($mg·kg^{-1}$)
Jizhou	1981	7.64 (n=740)	5.15 (n=920)	124.61(n=430)
	2003(n=107)	12.65	7.75	125.04
	increased by(%)	65.58	50.49	0.35
Pingyuan	1983(n=unclear)	9.10	3.06	124.52
	2003(n=82)	14.03	8.42	93.83
	increased by (%)	54.18	175.61	-24.65
Yucheng	1983	7.90 (n=509)	2.14(n-unclear)	65.58（n=271）
	2003(n=97)	14.72	11.75	110.63
	increased by (%)	86.33	449.44	68.69
Yuanyang	1983(n=872)	7.82	4.32	128.18
	2003(n=139)	12.48	7.19	106.02
	increased by (%)	59.59	66.41	-17.29
Yanjin	1983(n=764)	6.54	6.27	116.50
	2003(n=109)	11.88	5.46	68.22
	increased by (%)	81.65	-12.88	-41.44
Fengqiu	1983(n=1078)	7.83	3.16	147.90
	2003(n=134)	13.14	7.96	83.1
	increased by (%)	67.82	151.57	-43.81
Changyuan	1983(n=470)	8.88	5.63	175.16
	2003(n=105)	13.44	5.56	96.36
	increased by (%)	51.35	-1.24	-44.99

Notice: Nutrient data of the second national soil survey were cited from the statistics tables of the second soil survey in Hebei province, Pingyuan county soil, Yucheng county soil, Yuanyang county soil, Yanjin county soil, Fengqiu county soil, Changyuan county soil, all of them were summarized from the second soil survey in 1979-1983.

Sustainability and stability of the farmland ecosystem with high yield. Based on long-term experiment for 17 years, we systemically studied the influence of various exogenous nutrient treatments (NPK, NP, NK, PK, 1/2MN-half organic manure N plus half chemical fertilizer N, OM-organic manure, and CK-control without fertilizer) with equivalent N application rate on sustainability and stability of wheat-maize cropping system with high yield. Some important results follow as:

(1) Fertilization's long-term influence on the yield of wheat-maize cropping system

The highest and most stable winter wheat and maize yields were obtained in the treatment with application of chemical N fertilizer at rate of 150 kg hm-2 per crop season with P and K fertilizer (NPK). The 14-years averages of winter wheat and maize were 5261 kg hm-2 and 7633 kg hm-2, respectively. At the same application rates of N, P, and K as those in NPK, the average yields of winter wheat and maize in the treatment that half N from organic manure (1/2MN) were slightly but significantly lower than those in NPK, and at the treatment that all N was from organic manure (OM), the winter wheat and maize yields were unstable and the average yields were 22% and 16% lower than those in NPK, respectively, but increased significantly with time ($p<0.05$). In the NP treatment the maize yields were equivalent to those in NPK, but the wheat yields were lower and lower compared with those in NPK after ten years. The yields in PK treatment without N and NK treatment without P did not show significant differences from the check (CK). The average N use efficiencies of wheat and maize were 60% and 61% in NPK, 51% and 56% in 1/2OM, and 34% and 43% in OM, respectively. We can conclude from the results that sustainable production with high yield in fluvo-aquic soil can be kept when chemical fertilizers with NPK balance were applied in long-term, which is against traditional concept: the organic manure treatment could enhance the sustainable production of farmland ecosystem.

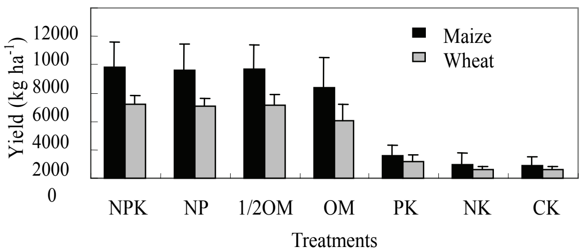

Fig. 10.2 14-year average yields of wheat and maize under different nutrient treatments

(2) Mechanism of continuous stability of farmland production under long-term chemical fertilizer application

What reasons result in long-term high yields in chemical NPK fertilizers treatment? Following these maybe could support the conclusion: Firstly, the relatively high pH of fluvo-aquic soil effectively buffered the acidification process from chemical fertilizer application. The pH value of NPK treatment slightly declined from 8.4 to 8.0, and NP from 8.4 to 7.9 after 16-year chemical fertilizer application, and became more suitable for crop growth. Secondly, the increase in crop biomass and soil organic carbon and organic nitrogen contents effectively improved the soil fertility and soil structure. It was found that both in the chemical fertilizers treatments (NPK, NP) and in organic manure treatments (OM, 1/2MN) soil organic matter and total nitrogen significantly increased with time, the increase rank followed OM > 1/2OMN > NPK > NP. It is because the application of chemical fertilizers enhanced the C and N immobilization in soil resulted from large amount of root exudates and residues with high crop biomass. Thirdly, the bacterial community structure in soil didn’t affected by long-term different fertilizations and underground bio-transformation system kept stable. The results from long-term experiments showed that long-term fertilization greatly increased soil microbial biomass C and dehydrogenase activity, except that the P-deficiency fertilization had no significant effect. Organic manure had a significantly greater ($P<0.05$) impact on the biomass C and the activity, compared with mineral fertilizers. Microbial metabolic activity (dehydrogenase activity per microbial biomass C) was significantly higher ($P<0.05$) under balanced fertilization than under nutrient-deficiency fertilization. General bacterial community structure was analyzed by PCR-denaturing gradient gel electrophoresis (DGGE) targeting eubacterial 16S rRNA gene. Mineral fertilization did not affect the DGGE banding pattern, while specific DGGE band was observed in organic manure-fertilized soils. Phylogenetic analysis showed that the change of bacterial community in organic manure-fertilized soil might not be because of the direct influence of the bacteria in the compost, but because of the promoting effect of the compost on the growth of an indigenous Bacillus sp. in the soil. Fourthly, the enhancement of nitrification potential induced by chemical N fertilizer could effectively reduce the toxicity of ammonia on soil microorganisms, and maintained the stability of soil microorganism community.

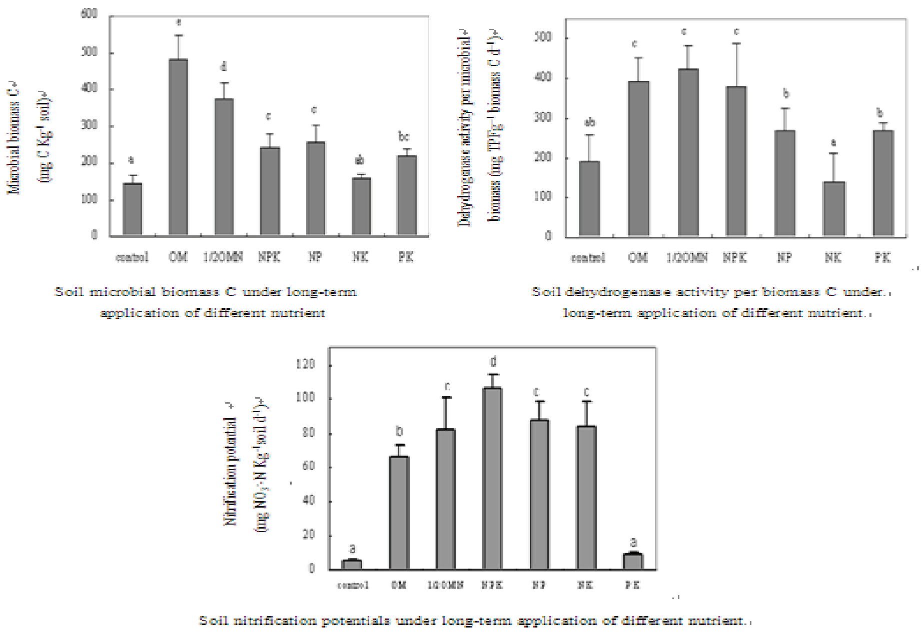

Fig10.3 Soil microbial mass C, dehydrogenase activity and nitration potential under long-term different fertilizations

3. Environmental impact of intensive agro-ecosystem

(1) CO_2 emission in agro-ecosystem

The results from long-term field experiment, on-site observation and regional investigation all indicated that the organic matter in the fluvo-aquic soil was increasing in both chemical fertilizers and organic manure. We conclude that agro-ecosystems in HHH-Plain is as a carbon sink. For instance, soil carbon immobilization increased by 27% in balanced fertilization of NPK (150 N kg ha-1 per crop season) for 14years, and most of the increased soil carbon was the heavy fraction which is difficult to mineralization. Of course, the soil carbon immobilization can be promoted by organic manure application, but the proportion of the light fraction of organic carbon increased evidently.

The field monitoring indicated that CO_2 emission in Agro-ecosystem was related to soil organic matter content and crop biomass. In maize seasons CO_2 emmision was mainly related to maize biomass, while mainly related to soil organic matter content in wheat seasons. During maize seasons, 2.94Mg organic-C ha-1 was mineralized in Fluvo-aquic soil, which accounted for 8% of total soil organic carbon in 0~40cm layer. In NPK treatment the mineralization of organic carbon could be compensated by crop root exudates and residues of plants. The maize growth evidently increased soil CO_2 emission, that was mainly attributed to the rhizosphere respiration, from which the contribution to CO_2 emission was 46~50% during the whole maize seasons. Application of N fertilizer effectively decreased soil respiration by 10%, and also lowered diel variation range of soil respiration.

(2) N_2O emission in agro-ecosystem

N2O emission in fluvo-aquic soil was mostly caused by nitrification. In maize–wheat cropping system N_2O emission was seasonally various, which was deeply influenced by soil water regime in maize seasons and an optimum moisture for the emission was 45～60% (water-filled pore space-WFPS), while in wheat seasons, N_2O emission mainly by soil temperature. The N_2O emission factor from N fertilizer at application rate of 150 kg N ha-1 per season was 0.61～0.77% annually, and 1.05~1.34% and 0.24～0.26% in the maize seasons and wheat seasons, respectively, therefore, most of N_2O was emitted in summer seasons. The N_2O emission factor was enlarged by increase in N application rate. Long-term application of organic manure significantly elevated the potential of N_2O emission, but a large amount of N2O emission wasn't observed in field, and it is probably because low transforming rate of NH4+ from mineralization of organic manure restrained N_2O formation.

(3) NO_3-N leaching

Long-term monitoring showed that at an application rate of 150 kg N ha^{-1} (balanced with P, K), little NO_3-N leached into deep soil layer and groundwater, and the environmental impact from N fertilizer was slight, too. However, more than the application rate would lead to NO_3-N leaching. The results from 3 year field monitoring indicated that when total nitrogen input reached 230～290 kg N ha^{-1} per season 4.8~18.0％ of N fertilizer leached into deep soil layer and groundwater.

4. Smart soil moisture monitoring system

Water resources shortage is limiting agricultural sustainability in HHH-Plain, it is necessary to develop water-saving technology. We developed key portion of smart soil moisture monitoring system for precision irrigation, including the new sensors for monitoring field water regime (soil moisture, rainfall, air humidity, groundwater table); the China Telecom-based remote monitoring controllers; the multi-channel equipment for data collecting and smart irrigation control; relative software, supported by 16 patents and 3 registered software copyrights which were developed by the scientists from the station. By integration of technologies a series of smart soil moisture monitoring and irrigation system were developed: (1) (SMM-model) smart network systems for regional soil moisture monitoring; (2) (SP-model) remote systems for collecting of farmland water information and controlling of irrigation equipment; (3) Management framework (software), based on Web-GIS for data collecting from the monitoring network. These systems may automatically monitor, collect and manage field digital information such as soil moisture, groundwater table, evaporation, relative humidity, air temperature, soil temperature, irrigation system pipe flux and pressure, and use the information to predict the amount of irrigation by decision-making system, delivery auto-control signals to the irrigation system, and irrigate precisely.

The most important advantages in those systems are: (1) new resistance moisture sensors, made by ourselves were equipped in the systems, those sensors can measure accurately and precisely across a wide range of moisture conditions, thereby extending the measurement capabilities of currently available sensors; (2) Modern communication technology was used in the systems to expand monitoring scale; (3) irrigation decision-making system was coupled in the systems to optimize irrigation schedules and auto-operate irrigation systems based on collected moisture information.

At present, the smart soil moisture monitoring systems were adopted in some demonstration areas for water-saving in Henan, Hebei, Xinjiang, Inner Mongolia, Jiangsu, Fujian province etc..

5. Development of the distributed hydrology model for agricultural basin hydrological cycle (DHM-ABHC) and the water nitrogen management model (WNMM)

(1) Distributed hydrology model for agricultural basin hydrological cycle (DHM-ABHC)

A physically-based distributed hydrology model was built for hydrological cycle of Tianranwenyanqu basin (2514 km2) in which the Fengqiu Station located. The model advantages include: (1) An infiltration model (GALS) based on the Green-Ampt methods for layered soil under unsteady rainfall infiltration event was derived. In the GALS, infiltration capacity, ponding time and cumulative infiltration were calculated. The soil profile was subdivided into several layers according to soil texture and initial soil moisture distribution. Comparisons of the developed model with an infiltration model named Gampt and a rainfall-infiltration experiment were conducted and good agreements were achieved. (2) A kinematic wave overland flow model based on a digital drainage network was developed and it uses topography and land use data to simulate runoff and overland flow routing. The Xinanjiang model was used to simulate the runoff yielding in each grid cell, and the kinematic wave approach was then applied to a ranked raster system defined according to flow vectors computed by the D-8 algorithm for overland flow routing. The calibration and validation results showed that this model worked well. (3) a new approach, using multiple map information such as river, lake, dam or watershed boundary network as input in addition to the DEM, was developed. The map was digitized and stored by a raster matrix in this method. Two elevation-distance functions was used to adjust the DEM according to the rater map information. This new approach allows for an accurate fit between the map and the modeled drainage structure.

The most of parameters in DHM-ABHC model are physically measurable in the field or derived from their physical meaning, at least in principle. The model is able to simulate hydrological processes, which include: (1) evaporation and evapotranspiration form vegetation, water and naked soil surface, (2) layered soil infiltration and soil water redistribution, (3) surface runoff include overland flow and channel flow, (4) groundwater flow, (5) interface recharge between unsaturated soil, channel and groundwater. The DHM-ABHC model was applied into Tianranwenyanqu basin with an area 2514 km2 lies to north bank of Yellow River in Henan province, where the water balance is not only affected by meteorology factors as precipitation but also influenced by recharge and water diversion from Yellow River. The model simulated hydrological cycle for Tianranwenyanqu basin. One year long was spent for model warm-up and parameters calibration to reduce the effect by the arbitrary initial conditions. The results showed that the model was capable of simulating all hydrological processes especially with high efficiency at routing surface water and the efficiency coefficients exceed 0.85 and the forecasted runoff errors are all limited by about ±10%.

(2) Water and nitrogen management model (WNMM)

Collaborated with Australian scientists, a spatially referenced biophysical model, WNMM was developed and shown to simulate dynamic soilwatermovement and soil–crop carbon (C) and nitrogen (N) cycling under a given agricultural management, for the purpose of identifying optimal strategies for managing water and fertiliser N under intensive cropping systems (mainly wheat–maize) in the North China Plain. A uniform data structure, ARC GRID ASCII format, was used both in GIS and WNMM for achieving a close Model-GIS coupling. A significant part of WNMM adopts and modifies concepts and components from widely used models, with a focus on soil N transformations. WNMM simulates the key processes of water dynamics in the surface and subsurface of soils: including evapotranspiration, canopy interception, water movement and groundwater fluctuations; heat transfer and solute transport; crop growth; C and N cycling in the soil–crop system; and agricultural management practices (crop rotation, irrigation, fertiliser application, harvest and tillage). The model runs on a daily time step at any desired scale and is driven by lumped variables (meteorological and crop biological data) in text data format, and spatial variables (soil and agricultural management) in ARC GRID ASCII format. In particular, WNMM simulates all key N transformations in agricultural fields, including mineralization of fresh crop residue N and soil organic N, formation of soil organic N, immobilisation in biomass, nitrification, ammonia (NH_3) volatilisation, denitrification and nitrous oxide (N_2O) emissions.

A sensitivity analysis showed that WNMM was sensitive to changes in meteorological variables, soil hydraulic properties, land use and agricultural management. WNMM has been successfully applied in Fengqiu County, Henan Province and Luancheng County, Hebei Province, China at site and regional scales. At the site scale, WNMM simulated well soil water content, crop growth and yield, NH3 volatilisation and soil NO3–N concentration. There was uncertainty in simulating soil denitrification and N2O emissions. At county scale, WNMM simulation of crop yield in Fengqiu County and Luancheng County.

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11

Ecological Processes and Efficient Use of Resources in the Farmland on the North China Plain

Scientific research progress of Luancheng Agricultural Ecological Station

> Introduction of Luancheng Agricultural Ecological Station
>
> Luancheng station, established in 1981, is one of the field stations of the Chinese Ecosystem Research Network (CERN) and a member of Global Terrestrial Observation System (GTOS). The station is also a demonstration base for modern agricultural technologies in Hebei province. In 2005, the station became one of the stations of the China National Ecosystem Observation and Research Network (CEORN).
>
> Luancheng Station is located in Luancheng county of Hebei province (37°53' N, 114°41'E and elevation at 50.1 m), represents the typical high production area in the northern part of the North China Plain(NCP). The rapid declining groundwater table has become the main problem that threatens the sustainable agricultural development in this area.
>
> The main ecosystem issues in this area are that the severe groundwater overdraft problem, the farmland non-point source pollution and the low efficiency in farmland water& fertilizer utilization.
>
> The researches conducted at the station focus on the long-term investigations of farmland ecosystem, water and nutrients transfer and regulation mechanisms, modern water-saving technologies, molecular breeding, precision agriculture and regional sustainable agro-ecosystem demonstration models etc..

1. Advances and main achievements on water and energy processes of agro-ecosystem at Luancheng Station

Luancheng Station has firstly conducted the experimental research on water and energy transferring in agro-ecosystem in China since 1980s. Particularly, at the aspect of environmental and ecological monitoring of crop field and the relationship between yield formation and environmental factors, this station has done many original and leading works in China. From beginning of 1990s, we started to investigate the stomatal behaviors and its response to environmental factors through comprehensive experimental and observational works. Since 1990, the observation and experiments on energy and water transferring mechanism in SPAC system and the water process on the interfaces of Soil-Plant-Atmosphere system became one of the major foci of Luancheng station. The major achievements and advances in these fields can be summarized as followings.

(1) Characteristics of energy balance in SPAC system

From 1994, we have conducted about 10 years experiment on the energy balance over irrigated land. The daily and seasonal variation of energy balance over irrigated land were investigated, especially the difference and mechanism of energy balance before and after irrigation.

We found the energy balance processes of irrigated land are highly influenced by cultivation system, crop phonological characteristics, and soil water content. The seasonal variation of LE is highly dependent on the growing stages of wheat and maize. Moreover, evaporative ratio is linearly correlated with LAI for both wheat and maize. The slopes of the correlation lime are 0.13 for wheat and 0.17 for maize.

Our analysis indicates the diurnal courses of Bowen ratio over wheat and maize canopy are very different. The averaged diurnal course of Bowen ratio over wheat canopy has an obvious peak at around 9:00am, and then has a flat course in the rest of the day; while, for maize canopy we couldn't find any peak. Another finding is that the averaged diurnal Bowen ratio are very close to its instantaneous value after 9:00am for both wheat and maize.

(2) Hydrologic processes and stomatal conductance model

Through long years continuous observation, we specified the energy partitioning processes in agricultural ecosystems are mainly affected by crop phonological and biophysical parameters at growing stage or seasonal scales as well as soil moisture at shorter temporal scales such as daily or instantaneous. The water flux on the leaf-air interface is mainly controlled by stomata activities, which are affected by environmental factors especially soil moisture. Our field experiments at Luancheng Station proved that there are significant linear correlation between stomatal conductance and soil moisture. The higher the soil moisture the greater the stomatal conductance, but when soil moisture exceeds a threshold value stomatal conductance will not change with soil moisture; on the other hand, when soil moisture is lower than this threshold water stress will happen and stomatal will start to close to restrain the transpiration rate. We called this threshold value 'incipient stress point', which is changing according with plant.

(3) Water, energy, and CO2 fluxes experiments and modeling

From 1980s, Luancheng Station started observation of the CO2 and community photosynthesis efficiency firstly in China (Dong and Yu, 1992). From 2000, we used eddy correlation system to study carbon budget of the agro-ecosystem and water use efficiency (Zhang et al., 2002).

(4) Regional energy balance and evapotranspiration monitoring using remote sensing data

From 2000, we also involved into the study on regional evapotraspiration monitoring using remote sensing. Beside the ground experiment at Luancheng Station, we also established several simple observation systems along with the latitude 38N for the reference sites of remote sensing model. We developed a dual-source ET model for monitoring regional ET using remote sensing data. In this model we simplified the NDVI-Ts method for estimating soil wetness status. This model was applied to Luancheng area, and obtained good results.

2. Progress in farmland water use and improving water use efficiency

Because of the serious water shortage in agriculture in the North China Plain (NCP), long-term field studies have been conducted at Luancheng station to investigate the mechanisms and technologies to improve water use efficiency (WUE) of the double cropping system of winter wheat and summer maize to reduce irrigation water use. The summary of the progresses are as the following:

(1) Quantifying farmland evapotranspiration and soil evaporation

Daily evapotranspiration of irrigated winter wheat (Triticum aestivum L.) and maize (Zea mays L.) were determined using a large-scale weighing lysimeter, and soil evaporation for each crop was measured using micro-lysimeters (Fig.1). The results showed that total water consumption averaged 453 mm and 423 mm for winter wheat and maize grown without water deficit. The average crop coefficient during the whole growth period was 0.93 for winter wheat and 1.1 for maize. Evaporation from the soil surface took up 29.7% and 30.3% of the total evapotranspiration for winter wheat and maize, respectively, equaling an annual loss of more than 250 mm water. Thus reducing soil evaporation could be one of the most important water-saving measures in this serious water deficit region.

(2) Mechanisms and technologies to improve water use efficiency

Since genetic variation in transpiration efficiency exists in crops, so selecting more water efficient cultivars is an important way to reduce irrigation water use. Field studies showed that a 20% difference in grain yield and WUE was apparent among winter wheat (Triticum aestivum L.) cultivars in field experiments. The study also showed a significant correlation ($P<0.01$) between grain yield and WUE. Cultivars responded differently to irrigation applications. Using a good cultivar has the potential to improve yield and WUE and reduce irrigation water use in this region.

Root sampling results showed that winter wheat had a prolific root system with an average maximum rooting depth of 2 m. Most of the root system was concentrated in the upper 40 cm of soil. The roots in the top layer of soil played an important role in soil water uptake. When root length density was less than 0.8 cm/cm3, the root was the main factor limiting the complete utilization of soil water by crops. Effective measures to increase the utilization of stored soil water could improve crop performance under conditions of limited water supply. Results showed that deep tillage to break the soil pan improved root growth in the deeper soil layers, and sowing the crop evenly also enhanced water uptake from the top soil layer to compete with soil evaporation.

Reducing soil evaporation is one of the most important water-saving measures. Straw mulching can significantly reduce soil evaporation, especially when leaf area is smaller. By application of mulching practice to both winter wheat and maize, annually more than 80 mm soil evaporation can be reduced and the overall crop water use efficiency can be improved by 5% to 10%. Mulch is an effective water-saving measure in this region.

(3) Sustainable irrigation management practice

The influence of the extent of deficit irrigation on yield and yield components was examined. Results showed that removing the irrigations during crop revival and the late grain filling stages not only improved grain production but also water use efficiency. Reducing the normal number of 4 irrigations to either 3 or even 2 is an option for reducing irrigation water use in the region.

Long-term field experiments investigated the possibility of growing winter wheat and maize with minimum irrigation (MI) by bringing soil moisture in the top root zone profile to field capacity at sowing with no further irrigation afterwards. The average yield was decreased by 14% for winter wheat and 13% for maize compared with the full irrigated treatments (FI). The mean annual total ET of the double cropping system was 654 mm under MI and 850 mm under FI. The annual supplemental irrigation requirement of MI was only half that of the FI. Approximately 200 mm irrigation water use could be reduced annually under MI. The success of MI depended on the deeper rooting system of winter wheat using soil moisture that accumulated below the shallower rooted maize over the summer rainfall season. The results showed that an MI strategy that would be simple to implement for farmers would contribute significantly to the sustainability of the groundwater resources.

3. Nitrogen cycling and its environmental effects on agro-ecosystems

The North China Plain is one of the major regions of cereal production in China, with winter wheat and maize (in summer) as main food crops. Culture practices relaying on large inputs of mineral fertilizers and irrigations have resulted in severe environmental concerns and resources wasted. These practices increased amounts of N compounds in the general environment, and caused shifts in the rates of biological N-processes in agricultural soils.

Key aspects of the nitrogen cycle mainly including N inputs and N outputs were quantitatively examined in the long-term fertilizer experimental field with a wheat-maize cropping system at the Luancheng Agro-ecosystem experimental station, Chinese Academy of Sciences. The main objectives were (1) to quantitative estimate the nitrogen fluxes through different interfaces in wheat-maize rotation field; (2) to estimate annual loss of N through nitrate leaching, ammonia volatilization, denitrification and N2O emission; (3) to identify the factors that regulate nitrogen transformation processes; (4) to develop effective strategies of N fertilizer management and to provide important parameters for the estimation of environmental quality.

(1) Nitrate leaching loss in wheat-maize rotation field

Nitrate (NO_3-) transformation in soil profile and leaching losses below the root zone were investigated in long-term fertilizer experimental filed, using the soil water balance method and NO_3-N concentration in suction samples and soil samples. The results indicated that irrigation and fertilization were key factors that regulate NO_3-N transfermation and accumulation processes. Increased fertilization led to an increased NO_3-N accumulation in the soil profile and to a promoted risk of NO_3-N leaching. As the N applied rates increased from 0 to 600 kg N/ha/y, the NO_3-N content in soil at 4m depth increased from 2 mg/kg to 18 mg/kg. The distribution of NO_3-N in 0-20m soil profile indicated that a large amount of NO_3-N has been leached to deep soil layers under traditional agricultural management that local farmers generally followin this region. Three accumulated picks at depthes of 4m, 11m and 16m formed, correspondingly, the NO_3-N contents were 32 mg/kg, 14 mg/kg and 9 mg/kg. The amounts of accumulated NO_3-N closely related to soil texture and depthes from the soil surface. The amount of NO_3-N leaching loss was regulated by water supply and NO_3-N concentration at the low interface of root zone. Soil water deep drainage and NO_3-N leaching loss mostly occurred during the summer maize growing season (rainy season), which coincided with irrigations and significant rainfall. On average, annual NO_3-N leaching loss from soil and fertilizer N below the root zone ranged from 30 to 84 (averaging 61) kg N/ha, equivalent to 7.3%--20.3% of N fertilizer applied. Therefore, excessive fertilizer N with supplemental irrigation or N applications at the wrong time could potentially lead to high NO_3-leaching losses. To minimize the fertilizer loss and its adverse impact on the environment, precision in water and fertilizer management was necessary. Therefore, a range of management options to mitigate NO_3-N leaching could include reducing N and water application rates, synchronizing N and water supply to plant demand, precision farming, and regulatory measures.

(2) Ammonia volatilization in wheat-maize rotation field

Ammonia volatilization was measured by micrometeorological gradient diffusion method from wheat-maize rotation field under traditional fertilization measurement in the piedmont of Taihang. The result indicated that ammonia volatilization loss occurred on day time and the picks were measured in 2~5 days after fertilization. The main ammonia volatilization process caused by fertilization occurred within 7~14 days after fertilizer N applied. NH3 volatilization commenced very soon after the urea was surface broadcast to the maize field, the flux density reached a peak of N 10.5 kg/ha/d two days after urea applied, but decreased to about zero five days later. Compared with wheat season, ammonia volatilization loss was high during maize season and the amount was N 41.8 kg/ha after topdressing, accounting for 26.6% of applied fertilizer N. When diammonium orthophosphate and urea as the basal fertilizer were surface applied following plough before sowing wheat, very little ammonia volatilization occurred. The total NH3 lost following the presowing application was only N 1.2 kg/ha, accounting for 0.9% of the fertilizer N applied. The NH_3 lost at the topdressing time was N 17.1 kg/ha, accounting for 15.6% of the applied N during the wheat season. As the result of ammonia volatilization, there was about N 60 kg/ha/d lost during the maize-wheat rotation season, accounting for 15% of the total applied fertilizer. Ammonia volatilization was an important nitrogen transformation in the crop-soil system, and is thought to often be responsible for low efficiencies of nitrogen fertilizer. Deep placement of fertilizer greatly reduced ammonia volatilization.

The result of study on key factors that influence the process of ammonia volatilization indicated that irrigation and straw returned could restrain ammonia volatilization. the earlier the irrigation following the fertilization, the less ammonia volatilization, while the effect increased with the decreased water content. Both winter wheat straw and corn straw returned to the soil could lead to decreased ammonia volatilization, and the former was superior to the later especially in relative high soil water content. Increased soil organic matter, as the result of long-term rationalized fertilization, could increase the soil absorption to NH4+ and then restrain ammonia volatilization.

(3) Nitrous oxide (N_2O) emission and denitrification loss in wheat-maize rotation field

Nitrous oxide emissions and denitrification losses were monitored using a acetylene inhibition technique (intact soil cores) in different N-fertilized plots (N rates: 0，200，400，600kgN/ha/y) in a maize-wheat rotation field. Results indicated that: amounts of N-fertilized, fertilizing methods, irrigation and rainfall, soil temperature and moisture acted the key roles in N_2O emission and denitrification process. Increased fertilization led to an increased denitrification rate and N_2O emission flux. Short bursts of N_2O emission and denitrification were observed 2-3 days after irrigation/heavy rainfalls following application of N fertilizer. The N_2O fluxes and denitrification rate were much higher for the maize compared to the winter wheat. The annual denitrification losses ranged from 3.0 kg N/ha to 8.6 kg N/ha and the total N_2O emission were 1.5～6.3 kgN/ha, accouting for 0.5%~1.4% and 0.5%~0.8% of the applied N fertilizer, respectively. The relatively small difference between N_2O emissions and denitrification indicates that nitrification was an important source of the N_2O, except when soil moisture content was high. The results suggest that seasonal patterns of N_2O emission and denitrification exist and are strongly influenced by N fertilizer rate and environmental factors. The result suggested that denitrification and nitrification was not very important pathway of applied nitrogen fertiliser from this light texture soil, though the effect on environment cannot be overlooked.

(4) Nitrogen cycling and balance in eco-agricultral system

Total annual nitrogen input to farmland in Piedmont of Mt. Taihang were 523.7-540.1 kgN/ha/y through fertilizer application, straw return, irrigation and rainfall. Nitrogen output through grain offtake was 240-252 kgN/ha/y, accounting for about 65% of the total N output. Total nitrogen losses to the environment by the ways of volatilization, denitrification and nitrate leaching were 130.6-134.4 kgN/ha/y. Nitrate leaching and NH3 volatilization are the main pathways of N losses, about 48.7% and 44.8% of total N losses respectively. While denitrification loss was relatively low compared with ammonia volatilization and nitrate leaching. The nitrogen losses mainly occurred under maize season as the result of high temperature and heavy rainfall. Annual accumulation of residual nitrogen was up to 153 kgN/ha/y, which will be the potential pollution resources.

Substantial losses of N are not only financial losses for farmers but also serious environmental concerns. It is imperative to develop more effective agricultural management practices to minimize N loss, especially during the maize phase. The recommendation N application rates are about 300－350 kgN/ha/y according to our preliminary study. Scientific ways of fertilizer application such as N and P balance application, incorporated broadcast and less water irrigation should be adopted to reduce N losses.

4. Study on estimate and simulation of groundwater resources in North China Plain

(1) Agricultural water use and groundwater fluctuation

Sustainable water use in the piedmont region of the Taihang Mountains in the northern part of the North China Plain (NCP) is under serious crisis due to the rapid depletion of groundwater caused mainly by pumping for agricultural irrigation. The development of water-conserving agricultural practices is essential in order to limit agricultural water use. To find an effective way to save water in the wheat-growing season without markedly reducing wheat yield, DSSAT-wheat was calibrated, validated and used to simulate water use by winter wheat. The simulations suggest: (a) Since a moderately low growth in the leaf area index (LAI) of wheat does not result in low yield, moderate water deficits in March can save water and therefore the aim should be to avoid irrigation in March. (b) Depending on the soil water condition, irrigation in mid November is recommended to obtain a good growth of LAI and to create a moderate condition for water stress in March. (c) After the start of the growth of the ears (around 15 April), water deficits should be avoided so as to ensure there is no influence on ear growth and grain filling. Simulation of a 12-year period showed that, when irrigation practice follows the above three principles, 76 mm of evapotranspiration and 99.5 mm irrigation water can be saved without much reduction in the yield of winter wheat (only 4.5%). This is sufficient to decrease the drawdown of groundwater by 0.42 m and to improve water use efficiency from 1.27 to 1.45 kg m^{-3}.

Meanwhile it is possible to estimate groundwater resources by studying the change of agricultural water use. The effect of irrigation on groundwater flow dynamics was simulated at the North China Plain (NCP) by coupling the NIES Integrated Catchment-based Eco-hydrology (NICE) model with DSSAT-wheat and DSSAT-maize, two agricultural models. This simulation was applied to almost all of the Hai River catchment and the lower reach of the Yellow River (530 km wide by 840 km long) with a resolution of 5 km. The simulation could obtain the spatial distribution of groundwater level from 1987 to 1988 in the Hebei Plain, which showed that the degradation of groundwater level were remarkable and caused by over-pumping of groundwater for irrigation.

(2) Mechanism of groundwater recharge from precipitation

Through the use of DSSAT-3.5 wheat and maize models, we assessed water use in winter wheat and maize, two staple crops in the region, in 1987-2001. Trends between groundwater change and simulated agricultural water use were compared. The results showed that groundwater decline was sensitive to simulated crop water requirement and irrigation requirement. According to regression analysis, 100 mm of water requirement by cultivated land (mainly wheat and maize) resulted in about 0.64 m of groundwater decline. The simulation also demonstrated that aside from one-in-30-year rain storm, precipitation is difficult to recharge to groundwater ouwing to the large gap between field capacity and soil moisture.

This was also proved by samples of over 10 m soil profiles by Groprobe. Before rainy season, the gap between soil moisture to field capacity is over 170 mm in all 3 soil profiles, suggested a large requirement of precipitation before soil can become saturated.

Finding of mechanism will be important for understanding and utilization of groundwater resources in piedmont region of the Taihang Mountains.

(3) Run off from Mountainous region to piedmont region

Study by SWAT and HSPF, two distributed hydrological model, showed the dramatical decrease in mountainous runoff, which influence water supply of the piedmont region a lot, was not strongly influenced by climatic change.

5. Regional evapotranspiration estimation based on remote sensing data

Regional evapotranspiration (ET) is a major component of water cycle. A reliable estimation of regional ET is critical for the accuracy of regional water resources assessment and the effectiveness of water resources management. In our study, A regional ET model based on remote sensing data and the principle of ground surface energy balance was developed, named 'rGIS-ET'. In this model, the remote sensing data was used to calculate the daily ET value when the satellite passes, which was combined with meteorological records to be extrapolated to times periods where remote sensing data are unavailable. The development of our model is composed of three steps. First, we used MATLAB to compose and test the formula of the principles we employed. Then, we used ERDAS Model Maker to construct the complete model and process the remote sensing images from a large area. Lastly, we combined the model with ArcGIS and accomplished regional ET estimation tool named "rGIS-ET". The combined use of three programming language tools ensures the accurate expression of our algorithms, and improved the efficiency of our model development. The employment of spatial analysis tools in GIS enables user a fast processing of the large quantity of remote sensing data and other spatial data. It also provides a user-friendly interface for modeling, result analyses and display. We used daily ET measurements from a weighting lysimeter to test the performance of our model. The comparison is very satisfactory. During the crop growing season, the error of ET estimation from our model is less than 10%.

Our model can use both Landsat and MODIS data to estimate ET. In current study, using these two kinds of data, we have successfully estimated the winter wheat and maize ET in the crop fields of Luanchen County in 2002 and the regional annual ET for Hebei Plain in 2003 and 2004. In 2006, by adding there modules including adjusting surface temperature in terrain, solar radiance terrain correction, and shaded relief, we improved the rGIS-ET 2.0 version for mapping ET distribution in a semi-arid mountain area. By integrating The ET distribution pattern estimated in mountain from rGIS-ET v2.0 into SWAT simulation results, we simulated the annual flow of the component of water balance at sub-watersheds of Mt.Taihang from 1995 to 2003.

6. Precise agriculture technical research and demonstration

(1) Theories and technique study

Based on 3S techniques, two scales of precision agricultural management systems at both county and field levels were established by combining internet service, semi-auto irrigation facilities and index for guiding the irrigation scheduling.

Integrating farmland information collecting system: Multi-parameters at spatial and time dimensions were collected by remote sensing technology, automatic data collecting sensors and artificial monitoring.

Farmland information managing system: GIS as the core technology to achieve the spatial information management, analysis and decision making for precision agriculture application.

Index system and management guidelines for applying precision agriculture: An index system to guide the application of irrigation and fertilizer was set up to optimize the farmland management.

Diagnosing the crop nutrient situation: Using Vis/NIR spectroradiometers and active canopy optical sensor to measure the bio-physical and chemical parameters of winter wheat and maize to develop a nitrogen-deficiency spectrum vegetation index for guiding the fertilization.

(2) Demonstration on precision agriculture

A demonstration area at Luancheng County for application of precision agriculture was established for the purposes of probing into the precision agricultural models under the condition of individual household with small area of land at county level and field level.

Precision agricultural demonstration with semi-auto sprinkler irrigation system and real time field parameters collecting system was applied to 180 mu farmland at Luancheng station. The intellectual yield measuring equipment was improved to achieve the precision management to winter wheat at meter scale in field.

Precision agricultural demonstration with semi-auto drip irrigation system and real time field parameters collecting system was applied to greenhouse strawberry farming. Significant improvement in economic returns was achieved.

A observation net with 288 households across Luancheng county with GPS location was developed to monitor the field situation for guiding the precision field management.

A website devoted to precision agriculture was set up to provide guideline, information, consultation and services for application of precision agriculture.

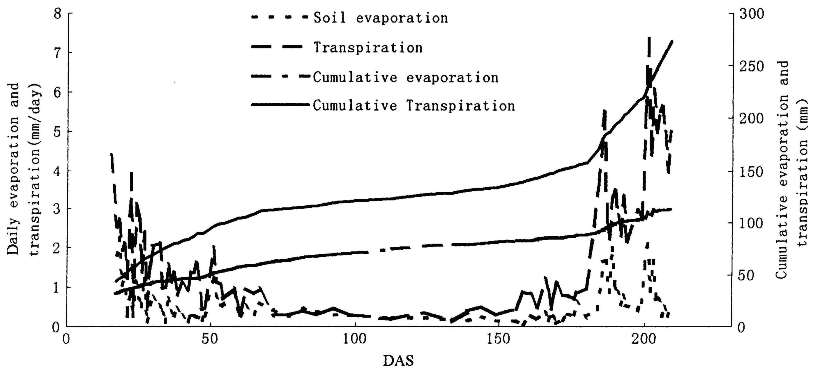

Fig. 11.1 The daily transpiration and evaporation of winter wheat at Luancheng Station

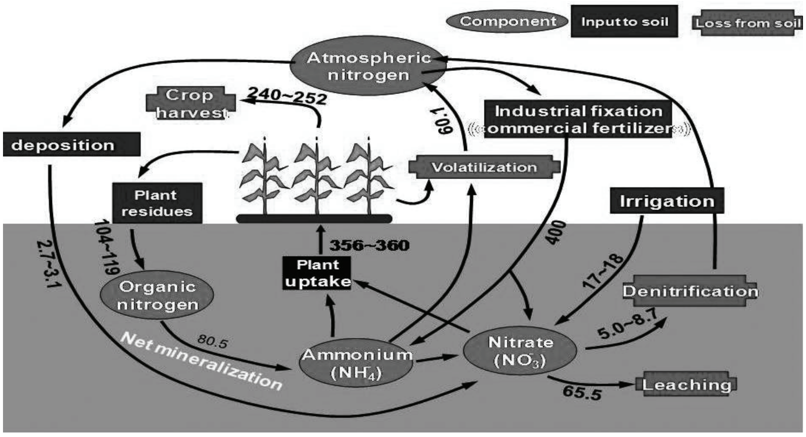

Fig.11.2 Nitrogen fluxes through different pathway in agroecosystem in the piedmont region of the Taihang Moyntains in the North China Plain（kg N/ha)

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12

Nutrient Cycling in Agroecosystem and its Environmental Effects

Scientific research progress in Changshu Agricultural Ecological Experiment Station

Introduction of Changshu Agricultural Ecological Experiment Station

The Changshu Agroecological Experiment Station, Chinese Academy of Sciences (Changshu Station for short) is located at Xinzhuang, Changshu City, Jiangsu Province in the hinterland of the Yangtze River Delta (at 31°33' N and 120°38'E). The Station is situated in the middle of the subtropical zone having a humid monsoon climate, with annual average temperature of 16.7, annual precipitation 1241mm. The soil is gleyed paddy soils derived from lacustrine deposit. Vegetation mainly consists of secondary coppice and aquatic plants. The crops cultivated include rice, wheat, barley, rapeseed and cotton.

To address new problems with agricultural development and entironment in the Yangtze River Delta, Changshu Station will constantly develop and demonstrate optimized models of high-yield, high-efficiency and good quality agriculture through systematic monitoring and research. We will do our best to make the station into a key station where long-term positioning monitoring of regional eco-environment elements and accumulation collecting of data are to be carried out, into an experiment base for field research on regional eco-environment processes and their mechanisms, into an experiment base for studying key problems with agriculture, ecology and environment in our national economic construction, and into a base for personnel training and exchange.

Research objectives: （1）Long-term positioning monitoring of elements related to ecological environment and the prediction of the evolutionary trend of the regional ecological environment under intensive human activities and global changes.（2）Structure, functioning and regulation of the agro-ecosystem for exploring harmonious development of agriculture and environment.（3） Development and demonstration of high-efficiency and non-environmental damage agricultural models on the outskirts of cities.（4）Comprehensive control of non-point pollution in farming.（5）Research and demonstration of rural environment monitoring and renovation.

The aim is to provide scientific basis for a sustainable agricultural development in the fast-growing economic area of the Yangtze River Delta, for rational utilization of water and soil resources, and for protection of the rural ecological environment.

1. Clarification of the paddy soil quality in Taihu lake region

The investigation results showed that soil pH declined evidently, soil available K rose or declined in different soil samples and on the whole, soil available P, total N and organic matter rose. Soil quality was good in most of regions and some parts of soils were polluted. Clean and goodish soils accounted for 95.7% of the total paddy soil areas, slightly-polluted soils for 3.8% and medium and high polluted soils for 0.4%. Some small parts of soils were polluted by heavy metals of Hg and Cu, which were accounted for 9.4% and 0.06% of the total areas, respectively. The first class of soil environment quality of DTT was 65.2% and the second class being 34.8%. The residues of organic chloro in soils had no dangerousness to safety quality of vegetables and foods, but having some accumulation risk in food chain.

2. Precision fertilization for high yield of rice and wheat and environment sound

With a great amount of field and incubation experiments, methods for deciding optimum fertilizer rate by the Stanford formula and the fertilizer effect function were used successfully in precision fertilization for rice and wheat. The easy method was put forward to estimate the soil nitrogen supply by measuring crop N absorbed from the plot with no nitrogen used and N mineralization from former crop. Optimum fertilizer-N rate for rice and wheat was 225~250 and 200~225 kgN.ha, respectively and the ratio of basal, tillering and panicle fertilization was 6:4 to 5:5. It was optimal time to apply panicle dressing N at the forth leaf from flag-leaf for rice and wheat. This fertilization technique changed the conventional fertilization to use great deal of fertilizer at seedling stage, and consequently raised nitrogen-use efficiency (NUE). Using this technique, NUE for both rice and wheat was over 40% and saved 20% of N-fertilizer, amounting to 110~135 kg.N.ha-1.yr-1 and crop yields hold even or over.

3. N and P migration from field to water and its effect on water bodies pollution

Explicit N and P load from paddy field in Tai-Lake region. Runoff and leaching are main pass for N migrating from farmland to water body. Monitoring of plots and fields from 2002 to 2004 showed that the rate of runoff N from rice and wheat season is 1.0~17.9 and 7.6~35.4

kgN.ha-1, accounting for 0.3~5.8% and 3.6%~15.7% of fertilizer N application, respectively. Annual runoff N amount was 8.6~53.3 kgN.ha-1, accounting for 5.9% fertilizer-N application. Nutrient leaching measured by lysimeter showed that nitrate is main formal of leaching nitrogen and occurred in wheat season (Fig.12.1). The rate of NH4+-N and NO3--N Leaching for wheat season was 0.41~0.54, 12.19~16.42 kgN.ha-1, accounting for 0.2~0.3% and 4.8~8.1% fertilizer-N application, respectively. The rate of NH4+-N and NO3--N Leaching for rice season was 0.36~1.04% and 1.55~2.25%，accounting for 0.2%~0.3% and 0.6~0.9%, respectively. Annual total leaching rate was 16.3 kgN.ha-1. Water N load from runoff and leaching was about 9.3% of fertilizer-N used.

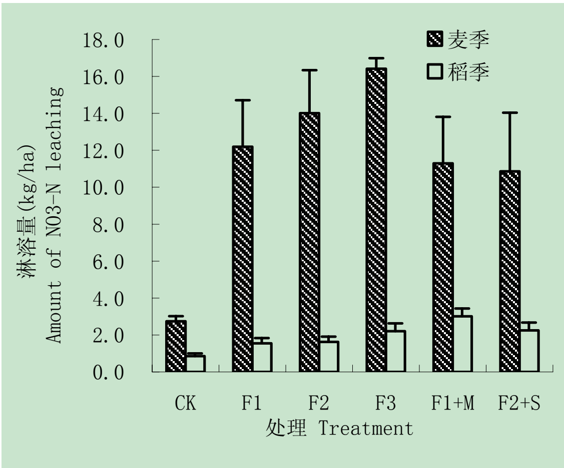

Fig. 12.1 Comparisons of the amount of NO_3^--N leaching in rice and wheat growing seasons

P migration rate from field runoff and leaching: With farmer normal P fertilization, P runoff for both rice and wheat season was 0.3％-2.7% of P fertilizer used and P leaching for two seasons was 0.36~0.41 kg.ha-1, accounting for 0.15~0.53% , average 0.25% of fertilizer-P used. The total amount of P runoff and leaching was below 3% of fertilizer-P applied. The critical value of soil available P for runoff was 25~30 mgP kg-1. With 10~15 mg kg-1 soil available P under current the normal P fertilization level, it was not dangerous to pollute surround water body.

Budget of N and P under irrigation and drainage: Lysimeter experiments showed that water requiring amount for rice growing season varied from 890~1320 mm. N and P the paddy field leaching increased with fertilizer application, but net nutrient purifying amount (Inflow load-Outflow load) was affected little by fertilization level. Paddy field could purify NH4+-N 10.7~12.3, NO3- -N 6.8~9.2 and TP -1.2~2.0 kg.ha-1 of irrigation water. NH4+-N was absorbed in the whole time and NO3--N was leached at early stage and absorbed in other rice growing period. The P appeared a negative balance, except fertilization manure treatment.

4. Sources of ammonium-N of in water bodies

Sources and concentrations of inorganic-nitrogen had an important effect on variation in the natural abundance of 15N. Measuring the 15N natural abundance could be useful in detecting the source of nitrogen. The study of the natural abundance of 15N in water, fertilizer and solid waste and so on showed that the 15N natural abundance of ammonium-N in river water and lake water was high, which was +9.97 and +23.80 respectively, the level of the 15N natural abundance of ammonium-N was closer to that of the mature of pig, human and fowl (+7.47，+13.30，+14.87 respectively), and higher than that of urea, ammonium chloride, ammonium sulfate and sodium bicarbonate (-1.12，-1.35，-1.48 and +0.91 respectively). Obviously, ammonium-N of the water bodies was mainly caused by improper handling of domestic sewage and human and animal excreta in the countryside. The results showed that the 15N natural abundance of organic-N in some water bodies was ＋3.45～142.25, which was mainly caused by petroleum contaminations and organic pollutions originated from industry wastewater. Therefore, the advice was brought forward to improvement and rectification of the nitrogen pollutions of Taihu drainage basin. Besides preventing industry pollutions, the reasonable using and handling of organic fertilizer was important.

5. Analysis of process and mechanism for nitrogen cycling in farmland

Coupled nitrification and denitrification is considered as one of the main pathways of nitrogen losses in paddy soils. The effect of NO3- on NH4+ transformation was investigated by using the 15N technique. The accumulation of NO3- would inhibit further nitrification of NH4+ at micro-aerobic sites in paddy soils, especially in paddy soils with a low denitrification rate.

Ammonia volatilization from paddy field and its affecting factors: ammonia volatilization was the main losses pathways of fertilizer N from paddy field. The peak of ammonia loss occurred within 1~3 days after the application the lasting about one week, amounting to 80.7%~ 94.3% of the total ammonia loss in each period. The ammonia loss from the tiller fertilizer was the highest and from the ear bearing fertilizer was the lowest. And some factors such as climate，pH in floodwater influenced the ammonia loss. Ammonia loss in paddy field was 75.2, 50.9 and 30.9 kgN.ha-1 from 2000 to 2002 in Changshu Agroecological Experiment Station, and it was 20.7%、17.0% and 8.5% of the total leached nitrogen. The highest ammonia volatilization flux occurred within the first 24～96 hours after the application and lasted about 10 days in the wheat growing stage, the ammonia loss from the basal fertilizer was higher than side dressing fertilizer. Ammonia loss in paddy field was 10.7、17.6 and 10.1 kgN.ha-1 from 2000 to 2003, and it was 3.9%, 6.4% and 4.5% of the total leached nitrogen. The ammonia volatilization loss in the wheat and paddy fields varied 41~85.9kgN.ha-1，with the average of 65.1 kgN.ha-1.

Wet deposition of atmospheric nitrogen: The amount of nitrogen brought into soil or surface water by the wet deposition was studied. Nitrogen wet deposition was monitored for four years (2001～2004)at Changshu Ecological Station. The results showed that NO3--N input in the air was relatively steady in a period of time, while NH4+-N input from wet deposition reached its maximum between June and August, There was a significant correlation of total ammonia volatilization loss with the average concentration of NH4+-N in wet deposition （r=0.988）, The total amount of nitrogen brought by the wet deposition in rice growing season reached 11.5～17.5 kgN.ha-1. The percent of NH4+-N in the wet deposition was about 50.3%~55.4.9%。The amount of nitrogen brought by the wet deposition in wheat growing season reached its maximum between March and April, and it was 51.9% and 45.6% of the total nitrogen in wheat growing season. The total amount of nitrogen brought by the wet deposition in wheat growing season reached 7.0～14.6 kgN.ha-1. The percent of NH4+-N in the wet deposition was about 51.2%~62.8%。The annual TN input was 18.5~32.1 kgN.ha-1, with the average of 26.2 kgN.ha-1. The percent of inorganic-N was about 80.2%~88.5%. Therefore, Ammonia volatilization and wet deposition became an important pathway of fertilizer N brought into water environment and a significant factor of optimizing nitrogen management and environmental protection.

6. Methods and techniques to reduce fertilizer N and P pollution of farmland

(1) Effects of reducing fertilization rate on surrounding water environment

To reduce 20%-25% of farmer normal N fertilizer dosage (300~330kg.ha-1), rice yield didn't show the significance difference, but can reduce loss of 30%~ 40% runoff and 32.3% leaching. The dissolved total N (TN) on the stand water and leachate of paddy field increased with N fertilizer application rate, TN concentration reached a peak value of 116 mg.L-1 after 1-2 day of fertilizer used and appeared a significant difference among the different treatments within one week, then tend to the almost same (Fig.12.2). The dissolved total phosphorus (TP) concentration of paddy surface water arrived a maximum of 15.7 mg.P.L-1 after fertilizer application and exceeded the critical standard for water eutrophication over the entire rice season and had a risk of polluting surround river water.

(2) Roles of buffer strip for intercepting nutrient loss from paddy field

Buffer strip which surround edges of paddy field with a width of 3-4 m could significantly reduce N and P concentrations of runoff and lateral seepage, with reduction of 31.7%~50.9% TN, over 50% TP of surface water as well as lateral seepage of paddy field, and thereby decreased the nutrient loading to surface and ground water. Compaired with inner paddy field, rice yield of buffer strip did not have a significant reduction, although the rice in the buffer strip did not fertilized.

7. Effects of different fertilizations on soil fertility qualities

The effect on soil enzyme activities: The relationship between soil enzyme activities and soil nutrients by long-term different fertilizer experiments in Yangtse River delta was studied. The experiment treatments included fertilizer only (NPK) , straw residues incorporation with fertilizer (NPK+S) and a control (nothing added). The results showed that the way of different fertilization influenced soil enzyme activities significantly ($P<0.05$), which of urease, invertase and acid phosphatase for NPK treatment increased by 108.7%, 170.2% and 58.0% respectively, compared to a control . Similar results were obtained that urease, invertase and acid phosphatase activity for NPK+S increased by 30.7%, 85.5% and 25.8% respectively, compared to the NPK The correlations between soil activities of urease，invertase and alkaline phosphatase were significant ($P<0.01$). The correlation coefficients between three kinds of enzyme activities and crop yield were better than that between crop yield and soil nutrients.

(1) Effects of fertilizations on soil C and N components

Long-term application of chemical fertilizer, rice straw and manure had a significant effect on soil properties with different magnitudes on the C and N content of soil organic mater, particulate organic mater（POM）, light fraction organic mater (LFOM), microbial biomass and potentially mineralizable organic mater. The manure was most effective in improving SOM and its labile organic mater and next was fertilizer NPK or rice straw plus fertilizer N, and only N fertilizer. A significant correlation between C and N content was found in soil organic mater and its labile organic mater. Significant correlation between different labile organic maters was also found. For respond to fertilizations, POM was more sensitive than other labile organic mater , and was an optimum index for indicating soil organic mater change.

(2) Effects of long-term incorporation of straw on soil fertility

The long-term field experiments showed that under coupling application of chemical fertilizer and straw, total nitrogen, total phosphorus, available nitrogen, available phosphorus and available potassium increased significantly both in Wu Shan soil and red paddy soil（$p<0.05$）, but total potassium was not significantly affected when compared with the treatment of non-fertilizer application (control). Likewise, organic matter on aforementioned soils significantly increased. At the same time, composition of humus was altered, i.e. ratios of humic acids carbon and HAC to FAC significantly increased, suggesting that the quality of organic matter was significantly improved. In conclusion, soil fertility could be improved through combining application of chemical fertilizer and straw in Wu Shan soil and red paddy soil.

8. Environmental impacts of organic manure application

(1) Effects of manure application on NP leaching in soil

The fields experiments showed that the chicken manure application increased the concentrations of ammonium and nitrate and TP in surface water at the beginning declined afterwards, but TP exceeded 0.1mg L-1 during the whole growth period. The results by lysimeter experiment showed that the concentrations of NH+4-N and NO-3-N in leachate amounted to 0.4～0.7 and 2.2~4.6 mg.L-1 and NO-3-N increased with the application of swine manure. When the application of swine manure exceeded 40 t. ha-1, TP in the leachate were 0.05~0.21 mgP/L, being significantly different from the others.

(2) Effects of manure application on heavy metals and microbes in soil:

The manure application in soils increased evidently the antimicrobial activity and numbers of pathogenic microbes in a short time. In the early days, the pathogenic microbes and antimicrobials in soils could pollute rivers and groundwater. The application of manure containing heavy metals and antibiotics could significantly influence the soil microbial activities. Cu and antibiotics could inhibit microbial activities, but Zn having no effects.

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13

Composite Agro-ecosystem in South China

Scientific research progress of CERN Taoyuan Agricultural Ecological Station

Introduction of Taoyuan Agricultural Ecological Station

Founded in June of 1978, Taoyuan Station of Agro-ecosystem Research (TYSAR) is subordinated by Institute of Subtropical Agriculture (ISA), Chinese Academy of Sciences (CAS). As a member of Chinese Ecosystem Research Network (CERN), national key stations for field scientific observation & research, science popularization union on Internet of CAS, national base of scientific activities for teenagers, and demonstration platform for science and technology, TYSAR is an important base to conduct position monitoring and researching of agro-ecosystem, and demonstrate the optimum modes of efficient resources utilization and agriculture sustainable development.

TYSAR Locates in Zhangjiang Town (111°26'E, 28°55'N) of Taoyuan County in Hunan Province, which is about 190km away from provincial capital Changsha. The regional agricultural physiognomy of TYSAR is 13.4% alluvial plain, 49.3% low hilly region, and 36.0% hilly mountain. The station represents middle sub-tropic agro-economy region cropped double-rice in China, which has plenty resources of sunshine, heat, water and biology; it also has optimized composite agro-ecosystem modes and high climatic productivity potential; besides, it is a traditional producing base of foodstuff, edible oil, pigs, cotton, hemp and subtropical fruit.

As a representation of Composite agro-ecosystem regions in hilly area of South Yangze Rive, TYSAR takes researching composite agro-ecosystem managements and its ecological foundation as its direction, developing eco-system management as its goal. The study of TYSAR is conducting around the fallowing subjects: 1) regional composite agro-ecosystem patterns and its function; 2) essential elements (carbon, nitrogen, phosphorus and water) cycling and their manipulation in agro-ecosystems; 3) the optimum allocation and sustainable utilization for agro-resources; and 4) demonstration of ecological agriculture patterns. Besides, it is charged with the task of ecology online on situ observation and research.

1. Constructive mechanisms of composite agro-ecosystems and optimized management in hilly land of South China

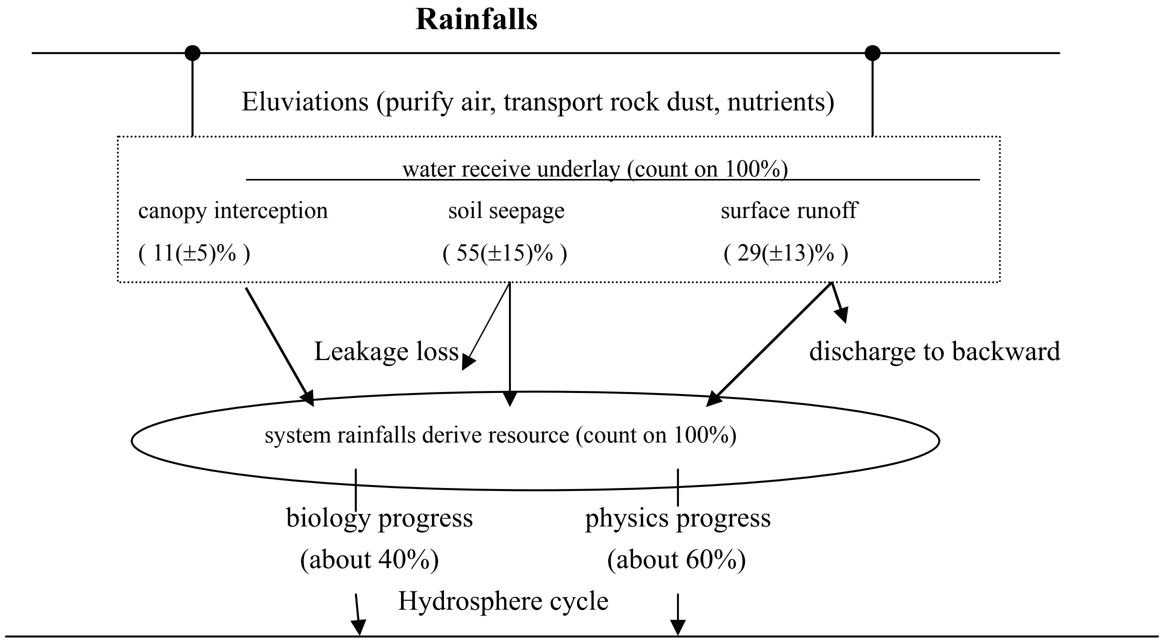

Fig. 13.1 rainfalls transportation progress of composite agro-ecosystems regions in hilly area of South China（Taoyuan，1990-2005）

Seasonal arid water shortage and nutrients imbalance are two barrier factors that result in fluctuation crop production and restrain the exertion of agro-ecosystem potential in hilly area of South Yangze River. Based on long-term monitor research and regional investigation, the characteristics of water transport proved up and optimum utilization management for local water resources were subsequently proposed. In the complex agro-unit in a small catchment, which has been rationally allocated in land structure, about 26% of the rainfalls can be gathered by small ponds through surface runoff while 50% of rainfalls can be absorbed by soil and become available agricultural water resources. The total gathered water resources could not only satisfy the irrigation for the present farmland systems, but also support the needs of upland agricultural development.

Seasonal water scarcity mainly affects upland agriculture. Surface runoff and soil erosion will increase after upland reclamation. The order of erosion intensities for different treatments is: farmland >> tea garden > orchard > natural grassland > conifer woodland > broadleaf woodland. In a catchment unit, soil erosion will be controlled in a lower level if land use structure is as the proportion of 25~30% for woodland or orchard, 20~25% for farmland, and 15~20% for grassland. Soil erosion rate will be lower than the generation rate of soil (0.05 mm/a) and this will prevent from soil degradation.

The evident issue in nutrient management is the imbalance in input between paddy and upland soil while nutrient benefit is decreasing in paddy soil. It is found that the gross amount of organic matter naturally returned to soil is 3180~6162 kg/hm2 and the maximum amount is up to 7245 kg/hm2 in the composite agro-ecosystem, i.e. double crop rice system in a red soil hilly catchment. There exists a mutually promoting relationship between organic biomass, which could be cycled in the system, and system productivity. The internal force to drive this process development is nutrient supply and utilization. In terms of the organic matter quantity in paddy soil, its stability could be maintained if the total amount of naturally returned organic material is up to 3960 kg/hm2 (the level is with nitrogenous fertilizer only), However, the yield increment of rice is lower than 5% under straw directly returning to soil. So at least half amount (3000~5000 kg/hm2) of the straw in rice cropping system can be transferred from paddy to upland eco-system, which can supply enough organic matter for 25%~30% of the upland or orchard to renew or enlarge the soil organic carbon pool. The average yield-increasing rate of returning straw to different land is more than 10% and saving water benefit from mulching is 50t/t. Under the condition of more than 3000 kg/hm2 organic matter given back to soil in the internal recycling, soil organic matter(SOM) in the present dryland, orchard, and new reclaimed slight slope land will be increased steadily if land use structure is designed by 1:4 for grassland vs. agricultural land (including arable land 20%~25% and orchard 25%~30%). Through agro-pastoral combinative management, about 35.5% N in fodder will be returned to farmland eco-system while the proportions of P and K will be 74.1% and 51.5%, respectively.

The results verified that the optimum pattern for fertilization management i.e. chemical fertilizer application is essential to obtain high yields for the sustainable development in double-crop rice areas. In the middle area of subtropics region of China, the rice yield may be maintained by the level of 5.6t/hm2 with non-fertilization and the yields could be increased up to 6.6, 7.9 and 9.0 t/hm2 with the application of N, NP and the NPK fertilizers. The circular utilization of organic nutrients can significantly promote the productivity of arable land, however, the rice yield benefit decreases with increased NPK addition. So, suitable and balancing supply of nutrient elements for rice is essential for high and stable yield while chemical fertilizer and manure have the same effects on stable rice production. Supplemental phosphorus fertilizer is the most key precondition in promoting the yield stability of early rice. Inundation and rice-planting can effectively maintain the long-term stability of SOM contents. Single application of fertilizer will not result in the decrease of the SOM content in paddy soil, but circular use of organic material in cropland ecosystem could significantly improve SOM content and nutrient bio-availability. High- efficient and sustainable development in agro-ecosystem could be realized through circular use of organic matter, decreasing fertilizer addition by greater than 20%, and reducing environmental pollution loads.

A theory and technology in soil C, N, and water optimum management, for example, reducing nitrogen addition, transferring straw from paddy to upland soil, storing water by ecological approaches, avoiding drought by cultivation, and harmonious development between lowland and hilly area were established in the complex agro-ecosystems in subtropical red soil hilly area. Furthermore, a synthetically optimum pattern and integrated technical model were established in this area.

2. Study on SOM and optimized manipulation of C，N，P and other nutrients in cultivated soil in subtropical region

According to the present issues, i.e., low contents in SOM and nutrients in arable land in the subtropical region of China, and the international advances in this field as well as the national strategic development，study were conducted in paddy and dryland soils through regional and typical landscape investigation. Three aspects of advances were obtained as the following:

(1) The regional characteristics and tendency and accumulative mechanisms of soil C, N, and P were systematically studied in subtropical area. View points were firstly raised that the spatial change of soil C, N circulation and accumulation was mainly controlled by natural conditions especially landform while P was controlled by P application levels. It was found that soil C and N largely increased in paddy soil but lower in upland soil due to the low input of organic material and chemical nutrient in the past 20 years. SOM and nutrient balance could be realized through transferring straw from paddy to upland soil. Also, soil fertility and productivity could be improved.

(2) Modeling principle and method in SOC and main nutrient cycling were proposed. SCNC model, which has an independent intellectual property, was established. This model can be used to accurately simulate the long-term change in SOC under various climatic conditions and the simulation precision is better than the popular international modes such as Roth-C and CENTURY. It was successful to predict the respondence of SOM in China to global climatic change in the future 50 years in our country. Besides, the spatial distribution under landscape unit scale was predicted.

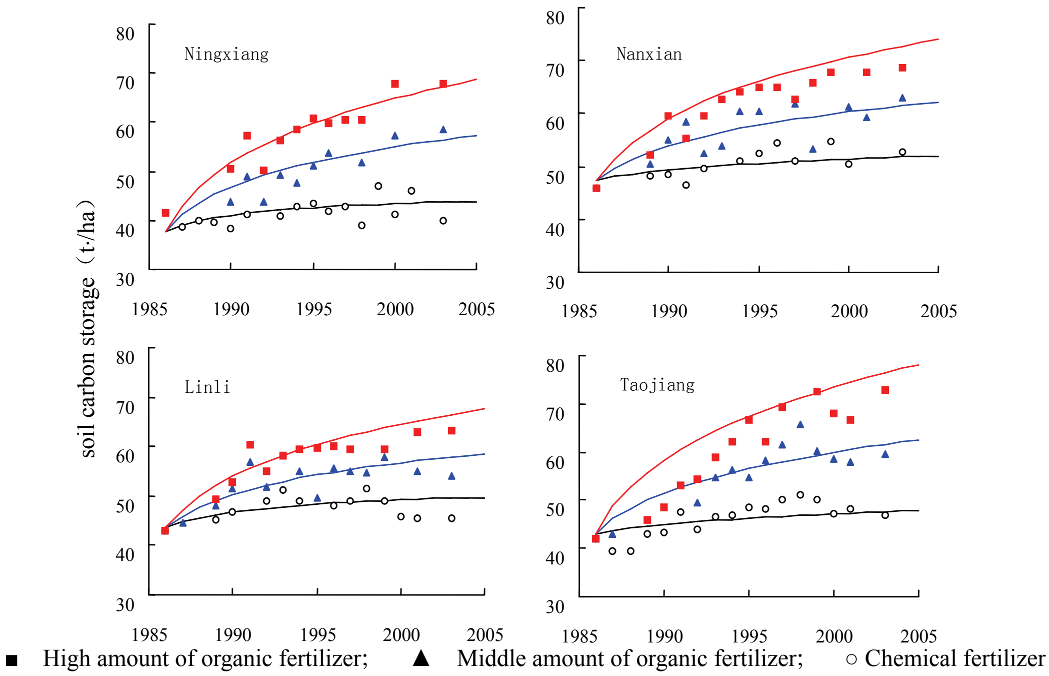

Fig. 13.2 Soil organic carbon dynamic and simulate results of paddy observation site（real line: simulate value，observation value）

(3) Study method of soil C, N, and P spatial patterns in landscape ecological unit was established. Nine analytical methods relating to soil biomass C, N, and P circulation and transformation such as turnover speed of soil biomass C, N, P, were new established or rebuilt. Furthermore, standard and criterion relating to soil monitoring was compiled which provided a comprehensive approach system for the study on CNP circulation and manipulation in agro-ecosystems.

At the same time, in terms of the sustainable use for high productive soil and amelioration for low-productive soil, the research also proposed an optimized technology i.e. transferring straw from paddy to upland soil, the economical green manure exploitation, reducing N fertilizer addition, economical P fertilization and optimum potassium nutrient manipulation for tobacco, as well as fertilization, conservation, and amelioration technology for cultivated slope-land. This technology has been popularized in 121 counties in subtropical area and the accumulative area is 2.454×106 hm-2,with which increased production value 5.174 billion Yuan.

At present，6 patents have been obtained in which four was authorized and 2 was practical patents. 209 academic papers have been published which has been cited by 639 times. Seven monographs and publications, five agricultural professional or local standards have been published which are important in promoting local agriculture progress and development. The study achievements are in an international advanced level comparing with similar research and won the first award of advance in technology in 2005 in Hunan Province.

3. Study on agriculture–forestry–livestock–fishery comprehensive development in the red soil hilly region of North Hunan Province

In view of the key restrictive factors in economic development in the countryside, such as large acreage but low development level and low industrialization, on the basis of National Large-scale Key Projects of 8th Five-year Plan, the principle and technology of protection and efficient use for soil and water resources were selected as the main target. Study on high quality and efficient comprehensive production models and management systems for industrialization was carried out for the integrative development of agriculture, forestry, livestock and fishery. The change in agricultural structure and its development mechanisms were probed. Great achievements have been obtained.

(1) The degradation mechanism of soil available P and the dynamic change in soil available N, S, Si, Cu, and B in waterlogging paddy field in red soil hilly region as well as the relationship between SOM and water holding capability in paddy field with shortage of water.

The results showed that the amount of total inorganic P in water-logging paddy soil was greatly lower than that in non-water-logging condition (decreased by over 1/3). Soil P, every 10cm water table climbed, Soil available P decreased 1.1 mg/kg when water table increased by each 10cm and the main forms of soil available P were Fe-P, O-P(account for 57.0~86.0% of the total P). These forms of available P were labile to be eluviate by seepage water under deoxidize conditions. Soil available N decreased 7.6 mg/kg for every 10cm rise of water table. Water-logging paddy soil potentially lacks of S (20.8 31.6 mgS/kg), Cu (1.62 mgCu/kg), B (0.41 mgB/kg), and low supply capacity of Si (48.3 mgSi/kg) which is contrary to non-water-logging conditions. Results also indicated that water holding capacity in 20cm layer in the gentle slope dryland could increase by 1.4mm storage when SOM increased by 1.0g/kg and, correspondingly, the duration of drought-resistance will be prolonged by about two more days. A series of practical technology was promoted such as the economic addition of P to complement soil nutrient, intensified SOM accumulation and saving and holding soil moisture. These technologies provided a new measure to ameliorate low productive soil.

(2) The characteristics of soil and water movement for different management systems on slope land and catchment in the red soil hilly region; soil erosion threshold for the hilly slope land exploitation and the harmony development mechanisms

Results indicated that the ratio of canopy interception, soil seepage, and surface runoff was 3:5:2 for the total precipitation on the well covered hilly slope land (coverage ≥85%) with 10°～15°gradient where high level and standard soil and water conservation measures have been applied. Comparing with the areas without soil and water conservation measures, the increased precipitation storage was 500~700 mm/a. The runoff coefficient of annual precipitation could be controlled around 10% and annual soil erosion rate lower than 200.0 t/km2•a. The yield or biomass of crops, wood, or fruits could increase by 23.8%-83.3%. Resource-utilizing mutual benefit model "soil-water-biology" was formed as soil storing water, water fostering soil, and biological blooming growth. This provided a scientific foundation and demonstration pattern for the integrative management of the red soil hilly region.

(3) High quality and efficient productive technology and industrialization management systems for the development of agriculture, forestry, livestock and fishery; new approaches of agricultural structure adjustment and industrialization for promoting the local economic development.

To adjust and optimize the agricultural structure and increase the benefit, study has been conducted in good quality, high output, high efficient planting and cultivation technology in farming, forestry, stockbreeding, and fishing. A series of practical technology were suggested including rice, tobacco, ramie, fruit tree, timber forest planting and new feed formula and breeding technology for livestock, birds, beasts and fish. There have established a set of base, association and support system which serves for the large-scale management and industrialization of dominant agro-products.

Through systematic analysis of agricultural comprehensive development models, it verified the present main agricultural restructuring domain (yard), approaches (creating a new leading industry and further exerting its large-scale management benefits), measures (industrializing benefits) and the driving force (technology advancement). These achievements have important significance to promote the integrated development of agriculture and sustainable high-efficient utilization of resources. According to incomplete statistics, the new technology have been popularized in the four-scale networks i.e. Pantang town (experimental plots)-Taoyuan county-north region of Hunan Province. The accumulative area has been 1,206,300 hm2 (barring the statistics of garden area) and the net income 1,845 million Yuan. The environmental condition has also been improved obviously. Meanwhile, there are 5 achievements of the project group been appraised, 110 papers and 2 special editions have been published. The 9th Five-year Plan has smoothly passed through the national check and honored by No.1 among the 13 subjects in the red & yellow soil region comprehensive and the agricultural sustainable development program in the south of China. It was nominated as one of the outstanding scientific and technical achievements of "9th Five-year National Key Science and Technology Project" by four bureaus such as the National Technical department, Ministry of Finance, the planning committee, the Economic and Trade Committee.

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14

Restoration and Integrative Utilization of Degraded Soils in the Low Hilly Region in Subtropical China

Scientific research progress of Yingtan Red Soil Ecological Station

Introduction of Yingtan Red Soil Ecological Station

The Ecological Experimental Station of Red Soil (Red Soil Station) was founded in 1985 and established in 1988. It became one of the key agricultural-science stations of Chinese Ecosystem Research Network (CERN) in 1989 and was elected as one of open stations of CERN in 1990. It was qualified as the Key Laboratory of Red Soil Research in Jiangxi Province in 2002. It was nominated as one of the National Field Observation and Research Stations of the Ministry of Science and Technology of China in 2005 and as the Demonstrative Station of Soil and Water Conservation Technology by the Ministry of Water Resources in 2007.

The directions of the station are: to monitor the components of the agroecosystems and their environment in the long term under the fast growing global climate change and anthropogenic impacts; to study the evolution of the structures and functions of the agroecosystems and its effects on ecology and environment for sustainable development of agriculture; to explore the mechanisms of agroecosystem degradation and strategic technology for restoration; and to develop models of sustainable agriculture and corresponding supporting technology. The aims of these studies will provide scientific, technological and decision-making supports to increase use efficiency of soil and water resources, productivity of agroecosystems, sustainability of ecology and environment, and establishment of sustainable rural economy in the low hilly region of Southern China. The station itself will develop as a research orientated field station with well teamed talents, with well equipped field facilities and self-contained accommodation, with graceful living environment and become an open and never edged-out base for long-term position monitoring, researching and demonstration and talent exchange and training.

The Red Soil Station locates in Liujia Station, Yujing County, Yingtan City of Jiangxi Province (116O55’30”E, 28 O15’20”N), being 12 km from Yingtan City or 135 km from Nanchang, the capital city of Jiangxi Province. It lies in the typical low hilly region of Jiangxi and Hunan provinces with evergreen broadleaved forest-agriculture and humid subtropical climate and represents a large area of comprehensive agroecosystems in the low hilly region of Southern China. The station has altitudes ranging from 30 to 600 m, annual temperature of 18.8℃and mean annual precipitation of 1700 mm. The typical soils are so called red soils and paddy soils developed from sandstone, Quaternary red clay and granite and other parent materials. The regional vegetations are evergreen broadleaved forest, forest plantation and the main crops are orchards, peanut crop and double rice crops. With the predominance of the natural resources, landforms and location between the west and eastern China, the represented region plays an important role in securing food production and ecology of the nation. In respects to these functions the region faces two main problems, the seasonal drought that corresponds to low and unstable productivity and the accelerating degradation of soils and ecosystems in relation to intensifying anthropogenic disturbances. Therefore, the Red Soil Station is an ideal place to conduct integrative research on comprehensive ecosystems in subtropical China. The station has typical representativeness for studying degradation, restoration and integrative utilization of red soils, sustainable development of agriculture and ecological and environmental construction and for demonstration of the achievements to a larger region.

Since early 1980s, the Red Soil Station has started to the comprehensive study on soil degradation such as soil and water erosion, acidification and nutrient depletion, aiming at effective countermeasures and controls of soil degradation in the region. Through field survey and long-term monitoring, this study has revealed the temporal-spatial variations, processes and mechanisms of soil degradation in the region. The most innovative achievements are the development of an indicator system for soil degradation assessment and its application in the region with utilization of GIS, GPS and RS, the mechanisms of P fixation and release in the red soils, the soil erodibility factor K and prediction of soil acidity. Through the breakthroughs, demonstration and extension of key technologies, a series of models and technologies with regional characteristics such as rational P application, rapid vegetative restoration of severely eroded and degraded soils, and integrative planning and utilization of natural resources have been established and efficiently contributed to the soil and water conservation, restoration of degraded soil fertility, the increase in forest coverage and sustainable development of agriculture. In addition to the well established research teams, the publications of more than 200 peer reviewed papers and 6 volumes of books, this study has been received the second award of National Scientific and Technical Progress of China in 2004.

1. Temporal and spatial variations of the main soil degradation types

(1) Soil erosion

Based on the remote sensing images in 1970s, 1980s and 1990s and on the field survey data, the tempo-spatial variations of different soil erosion types were analyzed for the whole red soil region and typical counties with the help of GS. The results showed that the total area of soil erosion increased from 1950s to 1986 and thereafter decreased up to date in the 8 provinces in the red soil region. The erosion area was 106 thousand km2 in 1950s, 249 thousand km2 in 1986, 200 thousand km2 in 1996, and 196 thousand km2 in 2002. The total erosion area in 2005 was 131 thousand km2, accounting for 15.1% of total land area, in which the severe erosion area accounted for less than 17%. The severe soil erosion area locates mainly in the hilly and low hilly regions of Jiangxi, Fujian, Hunan and Guangdong provinces.

(2) Soil fertility

Based on the second national soil survey, the content of soil organic carbon (SOC) varied largely among the soils from <1.5 g kg-1 in the severely eroded soils to >20 g kg-1 in the paddy soils, following in the order of paddy soil > secondary forest > orchard > upland and eroded soil, clayed soils > sandy soil, and footslopes > upslopes > middle slopes. SOC increased linearly with time within 30 years after the land use was changed from upland to paddy field and after 30 years the increase was retarded and stabilized（Fig. 14.1）. The nutrient status of the most of the red soils reached the lowest due to soil erosion, with the land area of moderate and severely nutrient depletion accounting for more than 88% of the total. Phosphorus in the soil was the most limiting element, the area with severe and extremely severe depletion accounting for 93%. Potassium in the soil was the least limiting element and the area with severe and extremely severe K depletion accounted for 14%. The area with severe and extremely severe N depletion in soil accounted for 18%. The balance between inputs and outputs of N and P showed that N and P were largely in plus status and within the past ten years in the provinces of Zhejiang, Jiangxi, Hunang, Guangdong, Fujian and Guangxi, resulting increases in N and P in the soils. The K balance showed plus in Guangdong, Fujian and Guangxi provinces and negative in Zhejiang, Jiangxi and Hunan provinces, but the magnitude of the negative balance decreased within last 10 years.

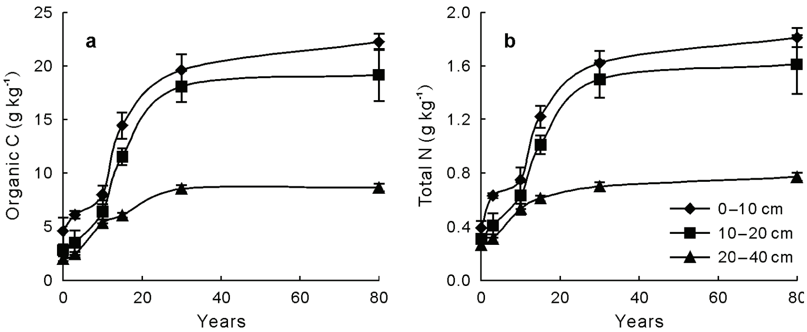

Fig.14.1 Changes in SOC (a) and total N (b) of the paddy fields with different years of cultivation in subtropical China. The data points are mean values of three replicates and vertical bars are standard errors.

(3) Soil acidification

Based on the second national soil survey, the forest soils with pH from 5.6 to 6.5 accounted for

15.4%, with pH from 4.6-5.5 for 72.2% and with very low pH ≤4.5 for 8.8% of the total area. The arable soils had relatively higher pH and the proportion was 39.6%, 50.4% and 1.0% respectively. This study used the newly proposed concept, buffering capacity and acidity sensitivity index defined from the acid buffering curves to assess the regional soils.

2. Processes and mechanisms of the main soil degradation types

1). Soil erosion. The study on the driving forces of soil erosion in the red soil region showed that the natural and anthropogenic factors co-work on soil erosion: a) the undulating mountainous and hilly landforms provides huge erosivity of overland flow; b) the large amount of rainfall concentrating in the rainy season provides 2.5 to 5 time larger rainfall erosivity than in the loesss plateau region; c) the moderate to high erodibility (K=0.2-0.25) of the soils covers 5.16% of total land area in the region. For example, the soils developed from the well weathered granite have weak structure over the deep soil profiles, providing erodible materials for gravity falling erosion, which is unique in the region; d) the long cultivation history under the guidelines of irrational policies destroyed the natural vegetation; e)the increasing pressure of growing population and economy on land demand leads to fast land use change and landform erosion during the large-scale reclamation into industrial and agricultural development.

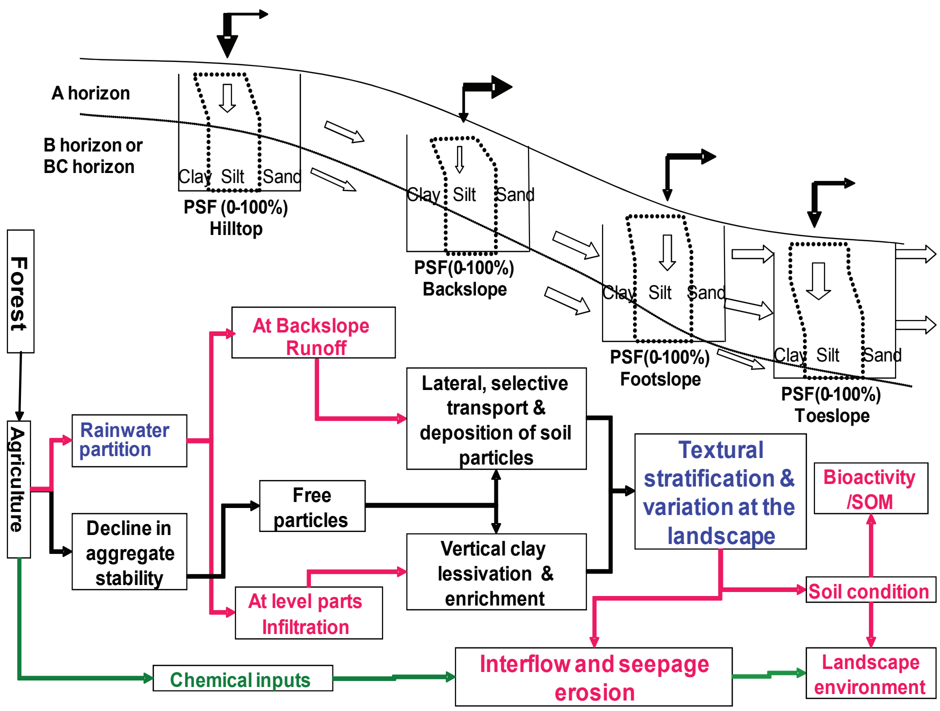

Fig. 14.2 Soil hydro-ecological processes after land use change from forest to agriculture and the impacts on the environment and ecology in the low hilly region of subtropical China.

The impacts of soil erosion in the region were tremendous. Soil erosion damages the arable land in quantity and quality and reduces soil productivity. The long-term monitoring showed that soil erosion washed off soluble N of 84.08 kg ha^{-1}, available P of 0.83 kg ha^{-1} (P_2O_5), available K of 422 kg hm^{-2} (K_2O) with soil and overland flow. The arable soils on the gentle slopes lost 300 kg ha^{-1} of SOM, 25 kg ha^{-1} of N, 15 kg ha^{-1} of P and 200 kg ha^{-1} of K due to soil and water erosion. Soil erosion not only caused the on-site impacts, but also the off-site impacts. Soil and water erosion caused the increasing damages to the rivers and lakes through sedimentation, leading to the loss of the transport function of most of the rivers and the function of flooding control. The decrease of holding capacity of the lakes was responsible for increasing damage of disasters such as seasonal drought, flooding, landslides and etc. Soil erosion was noticed to increasingly contribute to non-point source pollution from agriculture not only through the overland flow, but also through the interflow or throughflow in the soil (Fig. 14.2). In addition, soil erosion deteriorated the living conditions in the rural area, retarding the poverty alleviation and tensing the relationship between the regions in different reaches of watersheds.

2). Soil fertility. In addition to soil erosion, leaching is another important process responsible for the degradation of soil fertility of the upland soils. The leaching of nutrients depended on soil parent materials, rainfall, land use, fertilization and soil management. The losses of nutrients through leaching accounted for 3.6-52.3% in N, for 1.0-34.6% in K and little in P. With the increasing acidity the leaching process was intensified for the soluble nutrients such as K, Ca, and Mg. Due to existence of Al- and Fe- oxides, the red soils had a large capacity of P fixation and the P fixation capacity increased linearly with the decreasing of pH when pH was lower than 6. The analysis of soil samples from Jiangxi. Zhejiang and Hunan provinces showed that the P fixation capacity ranged from 58 to1297 mg P kg^{-1} and the availability of the fixed P to plant decreased exponentially with time due to the fixed P transforming from Al-P to Fe-P and then to O-P.

3). Soil acidity. Soil acidity in the region is a natural process during the soil formation and development, but the process was accelerated by the agricultural practices such as application of physiological acid fertilizers. Using the newly developed methodology to extract, isolate and determine the concentration of low weight molecular acids, it was demonstrated that these acids also played a very important role on soil acidification. These acids not only caused the acidification in the surface soil, but also in the subsurface soils, which was more deteriorative than in the surface soil. The protons in the red soils can be exchanged into the positive surface charge, with mineral Al and releasing soluble Al, and into exchangeable acid. The results showed that the exchangeable acid and Al were well correlated. The accelerated acidification caused not only the increase in the total concentration of the elements of Al and Mn in the soils, but also in the proportion of the toxic form in the soil solution, which influences the microbial activity, organic matter decomposition and biochemical cycling of C, N, S and P and then impacted on soil fertility and the environment and ecology. The increase in soil organic carbon, the anion types of acid substrates, soil mineralogy, initial soil pH and agricultural management practices had significant influences on the buffering capacity of the red soils to acidification.

3. Degraded red soils restoration techniques and integrative utilization types

1). The overall strategies for regional restoration. According to the geomorphologic and soil erosion characteristics and the ecological regionalization, it was proposed that the hilly region with a land area of 1.1 million km^2 in southeastern subtropical China was focused for restoration and integrative utilization and the breakthrough region was the low hilly region south to the Yangtze River with an area of 0.45 million km^2. The general strategy was to combine the biological and engineering countermeasures at the small watershed scale, combine the restoration and economic development and consider the long-term and short-term benefits in ecology and economy. The direction of the development was proposed to aim at harmonizing and balancing the demands for sustainable development of agriculture, rural economy development, integrative utilization of natural resources and the ecological and environmental protection. The restoration and development countermeasure should set the priority to increase local farm incomes and regional economic development for quick relief of poverty and environmental degradation.

2). Restoration of degraded soils. The Red Soil Station promoted two models for the restoration of the degraded soils developed from granite and Quaternary red clay according to the ecological principals of plant succession and long-term experiment. For the soils developed from granites, natural rehabilitation of forest by sealing mountain passes and development of site-specific economic forest and timber forest were proposed for the slight erosion region. Combination of the natural rehabilitation by sealing with engineering measures at critical location and afforestation for fuel wood and timber were proposed for the moderate erosion region. The engineering dominant measures such as terracing and deep ditches with knots along the contour were constructed to harvest water before planting in the severely eroded soils. For the gravity collapse erosion, more intense engineering measures to modify the land form to induce the overland flow passing by the collapse face in the up position and make dykes at the outlets of the sediment depositional position and afforest in-between. For the gully developed soils, the dykes should be made along the contours to collect sediments and before planting vegetation heading the dykes. These countermeasures were demonstrated in the Xingguo County, which was known for its severe soil erosion, presenting the benefits in both ecology and economy since the species such as Japanese varnish trees and willows were planted.

Restoration of degraded soils from Quaternary red clay in the eroded bare land needed the combination of engineering measures and biological measures. Holes or furrows were made along the contour or gully heads and beds. The holes were mad when the slope was less than 30^{O} while the furrows were made when the slope was larger than 30^{O}. Triggering P fertilizers were applied for planting. The local tree seedlings, such as *Cinnamomum camphora, Castanopsis sclerophylla, Cinnamomum porrectum and Camptotheaca acuminata* were transplanted into the holes on the gully beds where household waste matter from farmland (mostly ash from straw) were applied. The seeds of leguminous tree, *Lespedeza bicolor,* were sowed to the furrow or holes along the contours on the gully walls. After the planting measures, no further disturbance and management were allowed in the experimental site so that the vegetation could recover naturally. Three to five years later, multi-story plant communities consisting of trees, shrubs and grasses developed and soil erosion was then stopped.

3). Recovery of soil fertility and optimization of fertilization. The experiments showed that the combination of organic and inorganic fertilizers and an increase in organic matter application were the most effective measure to improve soil organic carbon and N pool. The reconstruction of P pool in the soil must depend mainly on the application of P fertilizers or animal manure and on the reduction of P fixation. To reconstruct K pool in the soils, application of chemical K was the most effective way although return of rice straw can enhance slowly K pool in the soils. Application of animal manure has little effect on soil K pool size. The long-term experiment showed that application of N, P and K in a rational combination together with application of organic manure was the main way to quickly increase soil organic carbon. When application organic matter at a rate of 4500～9000 kg ha^{-1}, the surface soil organic carbon content in the degraded soils developed from various parent materials increased by 2.1-7.5 g kg^{-1}, within an average of 4.7 g kg^{-1} within 5 years. At the high application rate (9000 kg ha^{-1}), the content of SOC increased from 1.3～3.0 g kg^{-1} to 7.0～9.7 g kg^{-1} within 5 years, which was similar to the average level in the arable uplands. With 9 to 10 year continuous application of organic manure, the soil organic carbon content reached the 80～85% of that with 30 years continuous application and the soil fertility reach the moderated curing level.

4) Control of soil acidification. The experiments showed that application of locally adapted alkaline amendment and conditioners to improve soil acidity and selection of Al or acid tolerant crop varieties to reduce acid toxicity were the main self-complementary measures to control soil acidification. Liming at a rate from 750 to1125 kg ha^{-1} increased soil pH by one unit and was considered as the most effective method to control soil acidity in the region. Liming neutralized the acidity, alleviated Al toxicity, increased soil temperature and stimulated the proliferation of soil microbes and indirectly adjusted soil nutrient supplies. Liming together with application of organic manure increased peanut yield by 10%, soybean yield and rice yield by 10 to 20%. But continuous application could result in hardening of surface soil. In addition, phosphogypsum, a byproduct of phosphoric acid and calcium magnesium

phosphate were other effective agents used to control soil acidity.

5) Water saving technology and its extension. The Red Soil Station analyzed the characteristics of spatial and temporal variations of water resources, the characteristics of water movement through the SPAC and the characteristics of seasonal drought and its main causes and impacts. Based on the water supply and demand dynamics of the main crops such as rice crop and peanut under the controlled irrigation, the water management and fertilization schedules were developed for the cropping systems with the late rice cropped in the upland with rice straw mulching. The effects of the water saving soil management techniques such as rational fertilization, root-promoting bio-agent, tillage and mulching were studied and the schedules of application of the techniques were established. Some new alternative cropping systems with high water use efficiency were evaluated and corresponding technique regulation was proposed for the cropping systems such as early rice-peanut, early rice in flooding followed by late rice in upland and mono rice cropping in a year as well as peanut-turnip system in the upland. Dynamics of subsurface ground water were observed and its potential for irrigation was also assessed. A small agricultural watershed with various land use types were equipped to optimize irrigation schedule, to monitor pathways of nutrient losses, and to evaluate the impacts of agriculture on the environment. Questionnaires were carried out to study the effects of policy, farmer decision making behavior and technology development on the extension of water saving technology and water resource use efficiency. An extension system consisting of governmental officials, enterprises involving in water management and end-users (farmer and state farm) and extensionists was operated and studied in terms of policy and effects on increasing water resource management.

6). Integrative control and utilization. The Red Soil Station also carried out a large amount of extension work to integrate the controlling techniques of soil degradation and the optimal utilization techniques. This work was orientated to optimize the agricultural structure, to develop the stereo layout of agriculture at the landscape and to improve the environmental condition for better utilization of water and soil resources. To guarantee these orientations, the Station developed the soil conservation farming systems with the integrated technologies to control soil erosion and to improve soil fertility through rational application of organic and inorganic fertilizers, proper tillage and combination grass cultivation and animal husbandry as well as to control acidity with various methods. According to the agroecosystem theory and food chain principles, the Red Soil Station practiced the model of “forest on the hill top, orchard on the middle slope and cropping in the valley and fishery in ponds”. This model increased the material use efficiency by 20 to 30%, and energy use efficiency by more than 15%. More importantly, the local agriculture structure was optimized after the extension of the model to the county level, resulting in an increase in the proportion of animal productivity to 65% of the total agriculture productivity.

4. Soil quality recovery mechanisms after re-vegetation on degraded soils

The fast restoration of forests on the degraded soils developed from Quaternary red clay showed that the aboveground ecosystem was well established within 8 years (Fig. 14.3). The long-term monitoring showed that on the severely eroded bare land, annual runoff varied from 303 to 1056 mm and annual total soil loss from 53 to 256 t ha^{-1}. After establishment of restorative vegetation using the integrative measures, soil erosion dramatically reduced to 2-43 t ha^{-1} a^{-1} from 1988 to 1990, and became negligible since then. Soil chemical and physical properties were also improved after the vegetation restoration. For example, the water holding capacity increase one fold and the soil organic carbon and hydralyzed N increased 5-10 g kg^{-1} and 2-3 mg kg^{-1}.

Fig. 14.3 Vegetation recovery on the eroded bare soil

The established experiment was used to study how soil quality was improved. The results showed that soil aggregate stability increased and mechanical resilience recovered due to the recovery of soil organic carbon content. Deep exploration revealed that particulate organic matter in soil aggregates improved soil aggregation and increased the compression index and friction angle. Using the analog root extrude (PGA), it was found that PGA addition increased the surface energy, elastic and plastics of soil particles, resulting in higher tensile strength of soil aggregates. The mineral associated organic carbon had more profound contribution to soil aggregation than particulate organic matter. Different vegetation types had different soil structure and soil stability, partly due to the difference in soil water repellency. The water repellency was falling in the order of Champhor tree soil > Masson Pine soil > Lespedeza soil > vegetable soil and the bare soil had no repellency. The water repellency was affected by soil organic carbon content and the porosity of soil aggregates. The repellent dissolved organic matter could be enriched on the surface of soil aggregates and enhance soil water repellency and the stability against fast wetting.

Improvement of soil structure determined the recovery of soil microbial biomass, soil biological resilience and biodiversity. The molecular T-RFLP results showed that the bacterial community components differed from the eroded bared soil, but not recovered to the soil which was not degraded. Slaking of soil aggregates influenced soil biological resilience to Cu and heat perturbation (Fig. 14.4) .Figure 4 also showed the biological resilience varied between the two perturbation and vegetation types had a large effect on the development of bacterial community component.

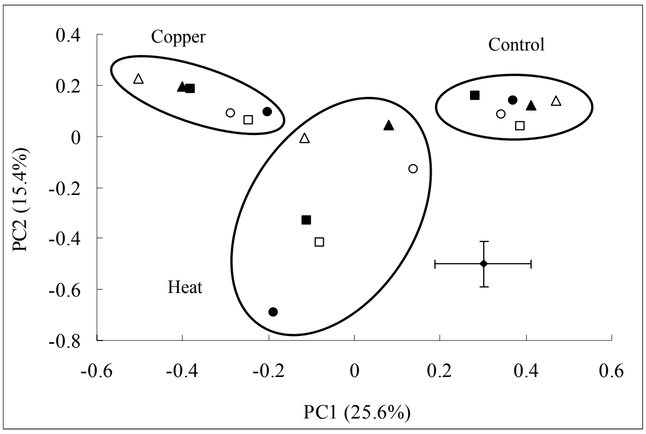

Fig. 14.4 PCA analysis of bacterial T-RFLP data from control, heat perturbation and copper perturbation at day 28.

Symbols: void, slaking; solid: un-slaking; triangles: P. massoniana; circles: C.camphor; squares: L. bicolor. Graphs generated from T-RFs of PCR amplicons digested with Alu I restriction endo-nuclease.

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15

Integrated Regulation and Ecosystem Processes of Hilly Areas in Red Soil in Southern China over the Past Two Decades

Scientific research progress of Qianyanzhou Agricultural Experimental Station of Red Soil and Hilly Land

Introduction of Qianyanzhou Agricultural Experimental Station of Red Soil and Hilly Land

Qianyanzhou Experiment Station for Comprehensive Development of Natural Resources in Red Earth Hilly Area (Qianyanzhou Station for short), which belongs to Chinese Academy of Sciences (CAS) and lies in Taihe county, Jiangxi province (26°44'N，115°04'E), was founded by CAS in 1983 as a pilot experimental site of Integrated Scientific Survey in Mountainous-hilly Region of Southern China. In 1989, the station was officially established by the cooperation of the CAS and Jiangxi Province based on the experimental site. In 1998, it was selected as one of the basic stations of the Chinese Ecosystem Research Network (CERN). In 2002, Jiangxi Key Laboratory for Ecological Process and Information System was established and affiliated to the station. The station owns an experimental area of 107.40ha (1,611 acres) and a demonstration areaof 104.73ha (1451.5 acres) for long-term management, the total land area covers as large as 212.13 ha (3,182 acres) (Figure 1). There are complex ecosystem landscapes in Qianyanzhou Station, which include forest, shrub, wetland, and farmland. Of which, forest covers two thirds of the total land area. Coniferous tree species, such as slash pine and Chinese fir, dominated the forest plantation.

1. Carbon cycle characteristics of planted subtropical coniferous forests

The carbon cycle characteristics of planted coniferous forests in Qianyanzhou Station were studied by various means in different scales, including micro-meteorological technique, forest measurement method and space information technology. In 2002，Qianyanzhou Station became one of the earliest stations in China where eddy covariance technique was used to measure forest ecosystem carbon fluxes. Researchers first systematically measured and studied the carbon cycle process of planted coniferous forest plantation in red soils hilly area. After several years of continuous observation from 2002, 300 GB of original data were collected. Scientists initially revealed the regulation of planted forest ecosystem carbon budget process and the impact factor, including seasonal and diurnal variation of carbon accumulation after the ecological restoration. The forest ecosystem carbon storage was precisely measured and estimated; moreover, some achievements were obtained on fluxes observation of non-uniform terrain surface. In order to conjugate with eddy covariance flux research, the annual dynamics of carbon sequestration rate and its relationship with climate factors were measured through forest survey method. Furthermore, the annual accumulation of aboveground biomass was initially revealed and these results can provide a strong validation data for eddy covariance flux observations.

The contribution of shrub population to the accumulation of carbon was studied in detail for the first time and filled the gaps of previous research. Meanwhile, based on the data of land use and soil carbon since 1983, soil organic carbon changes of 8 major land-use types in station from 1984 to 2002 were analyzed using geographic information system technology in landscape scale and in conjunction with soil profile survey in field. There was quantitative description of the soil organic carbon increasing trend after the ecological resumption. Furthermore, the influence of plantation on function of ecosystem carbon sink was also studied.

2. Comprehensive management and agricultural techniques for sustainable development in red-yellow earth region in southern China

This research was awarded the Second-class Prize of National Science and Technology Progress in 2003. The main achievement was the establishment of a stereo development mode on agriculture (Qianyanzhou mode) in southern China. The concept of Qianyanzhou comprehensive development and governance in red soils region was to take the region as a whole system and to develop integrately by establishing a multi-horizon agriculture and eco-agriculture systems in hilly region through rational land use strategy, to fully use the potentiality of resources to gain the maximum benefit. The relationships between governance and utilization, present and future, hilly land and gulley land, investor and developer had also be considered. It emphasized not on the benefit of ecology, economy or society separately but on the all aspects. In detail, the “Qianyanzhou mode” (the principal mode) was 1) to plant the economic and/or fruit tree species in hilly with weak slope and deep soil; 2) to plant timber forest, protective forest, water and soil conservation forest, and firewood forest in hilly with steep slope and poor soil; 3) to prohibit forest harvest and restore vegetation through planting tree and grass in hilly with poor soil and sparse vegetation.

At present, it has been successfully developed to an eco-agricultural chain with a pattern as "to plant forest and pasture upon the hillside, to establish farmland and orchard in flat valley, to develop fishery in scattered ponds, to promote animal husbandry and fishery together with agriculture, to flourish both farm products procession and circulation". The "Qianyanzhou mode", as a successful pilot program, has been providing an example for developing, restoring and rebuilding ecosystem in red soils hilly area. It combined the benefits of short, medium and long term into ecological system, moreover, it not only boosted the economy, but also realized the benign cycle of ecosystem. Meanwhile, it also improved the quality of eco-environment of the compound ecosystem of water reservoirs/pools and surrounding land, controlled the soil and water loss significantly, increased the production of biomass, built the conformed foundation of agriculture sustainability development.

Participant institutions: Chinese Academy of Agricultural Science; Jiangxi Academy of Agricultural Science; Institute of Subtropical Agriculture, CAS; Sichuan Academy of Agricultural; Institute of Geographic Science and Natural Resources Research, CAS et al 14 institutes.

Study period: 1997-2001

Principal contributors: 189 scientists participated in total, Jiayong Li, working in our station, as the seventh contributor.

Publications: Chinese academy of agricultural science et al edit. Comprehensive Improvement and Techniques of Agricultural Sustainable Development for Red-Yellow Soil Area in South China. China Agricultural Press. 2001, Beijing.

3. Evaluation of effects of ecological restoration on degraded ecosystems in red soil hilly regions in southern China

In red soil hilly regions in southern China, the ecological restoration greatly changed the environment of a small watershed. Many studies on ecological effects having been carried out at Qianyanzhou Station soon after ecological restoration. The investigation items include biodiversity, biomass, meteorological variables, physical and chemical properties of soil, hydrological effect and the change of soil erosion. Using the quantitative methods of community ecology, the change of species composition and productivity of ecosystem was analyzed to reveal the important role of ecological restoration for improving productivity and increasing species diversity. The microclimate changes, which including seasonal fluctuations and diurnal variation of temperature and humidity in the forest, followed ecological restoration and reforestation were thoroughly discussed. The comparison on the microclimate between the inside and outside of the forest verified the importance of forest on regulating microclimate.. The results showed that the humidity in the forest was obviously higher than that out the forest, especially in the drought season; the variation range of the temperature in the forest was smaller than that out the forest. By observing the regularity of precipitation distribution and sediment yields, the soil and water conservation function of plantation, which proved the effect of forest on reducing surface runoff, especially on reducing the coarse sand outflow, was expounded. Based on the analysis of soil sample, the organic carbon and other chemical properties were showed, which tried to reveal the effect of tree species composition on soil nutrients and PH value, and provide scientific basis for plantation management.

Through continuous observation of the structure of nutrient and the precipitation chemistry in some major forest communities, we tried to reveal the effect of plantation ecosystem on elements accumulation, water regulation and nutrient balance, expound the rainfall interception and water conservation by the plantation, analyze the connection of precipitation, stem sap flow and surface runoff between in the plantation and out the plantation, evaluate the function of the plantation on water regulation, especially on the water balance of small watershed. Based on the nutrient content of precipitation in and out the plantation, we analyzed the effect of precipitation and canopy on twenty nutrient elements import, and the output of nutrient from runoff, in order to reveal the function of throughfall and stemflow on supplement and adjustment of the source and composition of nutrient, especially on improvement of soil nutrient for forest land. To provide scientific basis for plantation management, we also learned the nutrient interaction in different organs and components of community, and the basic law of nutrient absorption, retention and returning of tree, by analyzing the content of nutrient of live plant and litter. In addition, we discussed the effect of afforestation on soil nutrient condition.

4. Ecosystem structure and material cycling process in subtropical evergreen broadleaved forest

Jiulian mountain, lies on the boundary between Jiangxi and Guangdong province, is one of observation sites of Qianyanzhou experimental station. The virgin forest in Jiulian mountain could represent zonal vegetation of subtropical forest. Under the international cooperation, a comprehensive research on forest ecosystem was carried out, including flora and fauna, species composition in community, primary productivity, nutrient cycling, climate and water balance. By investigating the vegetation in this district, the characteristics of flora and fauna was learned, and then a list of plants and animals was established. Through community surveys, the spatial structure of some major types of forest was analyzed. And the structure of biomass and productivity of the community in this virgin forest was uncovered firstly by measuring the growth of tree. Based on the research on the return process of litter fall and the law of water output, the ecosystem function of nutrient cycling in evergreen broadleaved forest was expounded. Furthermore, to reveal the important influence of natural virgin forest on adjusting the water balance, the process of precipitation and water flow of small watershed was observed by using weir. All these researches provided abundant and systemic data resource for conservation of biodiversity and function of ecosystem in subtropical evergreen broadleaved forest.

Cooperation Organizations: Kyoto University of Japan, Shimane University of Japan, Institute of Geographic Sciences and Natural Resources Research, CAS, Jiulian Mountain Reserve Administration Bureau of Jiangxi Province.

Main researchers: Li ChangHua, Toshio Tsutsumi, Shigeo Katagiri, Liu XinZhong, Xiao ZhongYou, Hideyuki Kawaguchi, Yasuhide Nagayama, Yasunori Nakagama, Ma JianHua.

5. Ecological function zoning of Jiangxi Province

According to the requirements of State Environment Protection Administration (SEPA) and provincial conditions of Jiangxi, with the advisement of relative department and professor of the province, based on the assessments of eco-environmental present situation, eco-environmental sensitivity and ecological function significance, the report takes ecological landscape, ecosystem and sub-ecosystem as ecological foundations of ecological zones, ecological sub-zones and ecological function areas, respectively, landform as major factor for spacial differentiation of ecological functions , large-scale landform regions, important basins and locations in the basins as zone units and the province was divided into 5 ecological zones, 16 ecological sub-zones and 43 ecological function areas. This regionalization considered the need of major ecological categories and ecosystem service functions of the province, carry joint out successfully with the center and east china, and the most important characteristic is uncovering the macro-spatial distribution and variation of ecosystem service functions in province scale, and it reflects the position of the ecosystem service functions and ecosystem functional zones in national ecosystem function. The report has gained the high light of the government of Jiangxi province and would be an important basis for ecosystem management of the province.

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16

Theories and Practices on Sustainable Development of Agro-ecosystem in Purple Soil Area

Scientific research progresses of Yanting Agricultural Ecological Station on Purple Soil

Introduction of Yanting Agricultural Ecological Station on Purple Soil

The scientific research focused on the fields of soil fertility, soil water conservation, agro-ecosystem evolution related on structures and functions changing and the optimized management practices. During the recent years, researches on restoration of degraded ecology and environment, non-point-source pollution and water quality improvement, and sustainable agricultural techniques have been extensively conducted and promoted in Yanting station (CERN). Research progresses and achievements were summarized as following aspects, including researches of purple soils in China, restoration of soil fertility in the degraded slope cropland of purple soils, soil and water conservation and non-point-source pollution control at the small watershed in the hilly area of central Sichuan Basin.

1. Researches on purple soil in China

(1) Land resources distribution of purple soil in China

Purple soils, young and fertile, are derived from sedimentary rocks formed during Mesozoic Era (Periods of Triassic, Jurassic, Cretaceous) and Tertiary Period. Purple soils were distributed widely in the southern China with cropland area of 21.99 million hectares in which of 18.89 million hectares as dry land and 3.10 million hectares as paddy fields based on the second soil survey data. Purple soils are fertile and productive for agricultural crops in the southern China where it is in subtropical monsoon climate zone. Purple soils distribute in the province of Hunan, Hubei, Guangxi, Guangdong, Anhui, Jiangxi, Fujian, Zhejiang, Henan, Shanxi, Jiangsu, Hainan etc (Fig. 16.1), and especially concentratedly distribute in Sichuan, Chongqing and Yunnan province.

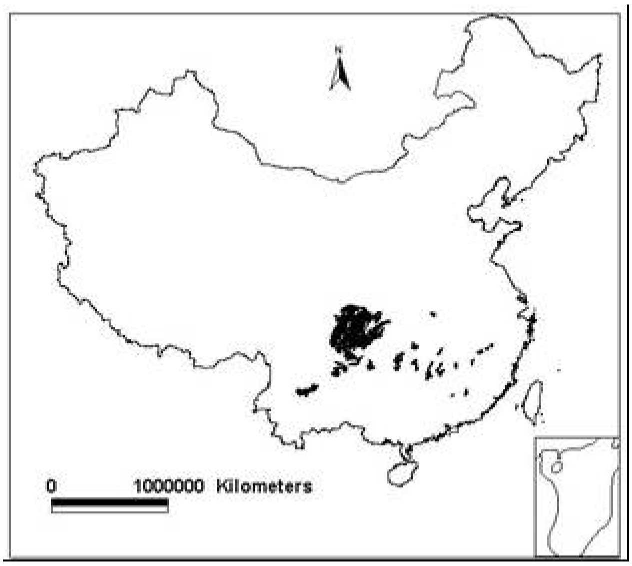

Fig.16.1 The distribution of purple soils in China

According to the principals based on the China Soil Genetic Taxonomy, purple soils were classified as purple soil group in Inceptisol order and classified as acid, neutral and calcareous sub-groups. There were 4, 2.7and 2 million hectares of calcareous, neutral and acid purple soil, respectively, in Sichuan province.

(2) Systematic research on soil formation, development and fertility evolvement of purple soil

The purple soils are developed from marine and limnic sedimentary rocks which formed during Mesozoic Era (Periods of Triassic, Jurassic, Cretaceous) and Tertiary Period under alteration of dry-hot or humid-hot environment. These parent rocks were also called “Red stratum” with red-purple color.

Soil formation of purple soils is controlled by physical weathering, which involves at stage of rock disintegration- clast- soil skeleton- clay etc. It is in quick soil formation rate with 11.2~19.6mm layer of soil will be developed within a year. Nevertheless, purple soil is in weak chemical weathering when it is compared to the zonal soil- yellow soil in China.

Purple soils inherit the physical and chemical properties of their parent materials with rich of mineral nutrients, and total phosphorus and potassium are as high as 23.5 and 7.8g/kg, respectively. Clay contents in purple soils are not more than 300 g/kg. However, serious soil erosion after cultivation results in exposure of parent materials, and accelerates rock weathering and soil formation leading to high release of nutrients. Thus, soil fertility inherits features of parent materials in the cycling process of “erosion- weathering- nutrient releasing- erosion”. There are plenty of nutrient release from weathering of parent materials at release rate of 31.13-52.78, 71.81-121.31, and 2016.9-3948.4 $g/m^3 \cdot a$ for N, P and K, respectively.

2. Soil fertility restoration and maintenance of degraded purple soil

(1) Mechanism of degradation of purple soil

Slope cropland covered 70% percent of total land area of purple soils with high population density of 510 persons per square kilometer in the central Sichuan Basin. Over land reclamation and irrational cultivation in slope cropland of purple soils caused the serious soil and water losses, and the soil erosion rate reaches to 4800 $t/km^2 \cdot a$. Based on long term observation and experiment, it was concluded that the soil erosion was the main driving force for soil degradation with phenomena of thin soil layer, soil drying, and poor in nutrients which resulted in low productivity.

(2) Degraded purple soil fertility restoration techniques

After analyses on mechanism of soil degradation and long-term parallel experiments in the field, the conservation tillage system with ridge-furrow and seasonal no-tillage (SNTRCS) was constructed. SNTRCS consisted of ridges, furrows and small earth blocks. This net-like structure was built-up with ridges (30-cm high, 100-cm wide) and furrows (100-cm wide) at a 2-m interval perpendicular to land slope direction, and small earth blocks (10 cm high and wide) were piled at a 5-7 m interval in the furrow. 15 Mg/ha composted manure was applied to soil before building net-like framework. In summer, mulches and crop residues were left on the ridge after harvest with no tillage before planting. However, the furrows were mechanically tilled to a depth of 30 cm. If soil depth was less than 30 cm, purplish shale were excavated and exposed in order to accelerate soil forming. Ridges were interchanged with furrows at an interval of 3-4 years.

(3) Effects of degraded purple soil fertility restoration

Based long term field experiment from 1985~2000, SNTRCS with ridge-furrow cropping and seasonal no-tillage increased topsoil depth by 118 mm over the conventional cropping. The interaction between the soil and water management played an important part in the gains. Soil structure and soil physical, chemical and biological characteristics were also improved when SNTRCS adopted. Therefore, the average yield of SNTRCS was 15% higher than the conventional tillage. After the exchange of the ridge and furrow, crop yield of SNTRCS reached 13.3 t/hm^2 and was 30% higher than the conventional tillage. In conclusion, SNTRCS is a suitable management model for conserving soil and water resources, therefore for restoring productivity of slope land in degraded hilly area of Sichuan Basin, China.

3. Integrated controlling systems on soil loss and non-point-source pollution in small watershed of purple soils

Long term orientation observations were conducted in a typical small watershed in the hilly area of central Sichuan Basin through 2001 to 2006. Soil erosion and non-point-source pollution were analysed, and integrated controlling measures were performed to soil water conservation and prevention of nutrient loss so as to protect in situ and offsite water environment.

(1) Characterizing soil erosion and non-point-source pollution

A Soil erosion and N, P losses in slope lands under different land uses

Average soil erosion rate from the bared land, slope cropland, grassland and woodland were 12000, 1500, 300, 150 t/ km^2·a, respectively, thus the grassland and woodland could used as measures for soil conservation. Meanwhile, N, P losses from the bared land, slope cropland, grassland, woodland and residence area reached 14.2, 20.0, 7.4, 8.6, 38.9 and 24.7, 26.1, 8.8, 9.7, 42.5 kg/hm^2·a for N and P, respectively. Slope cropland and residence area had high risk of nutrient losses. The runoff and sediment were the main transport pathways. And N lost mainly through runoff as dissolve forms of nitrogen, whereas, P lost through sediment as particulate P.

B Environmental effects of soil erosion and N, P loss

Soil erosion and nutrient losses resulted in thinning of soil layer, soil fertility degradation and water quality deterioration. The N, P concentrations in the surface waters were high and only met the water quality Standard Ⅲ established by the national environment protection agency of China, while the pond water met Standard Ⅳ. And there were more than 57% of monitored ground water could not be used as local drinking water according to threshold of WHO with nitrate concentration.

(2) Integrated controlling system of soil erosion and non-point-source pollution in small watershed of purple soil

A Structure adjustment of forests at hill tops

Evolution of mixed plantation of alder-cypress to simple forest with cypress at hill top resulted in low efficiency of soil and water conservation. Defoliated arbor, shrub and liane were introduced and planted randomly to form complicated forest structure and litter layer for water preservation. And prohibition for graze would be performed for increasing plant covering.

B Structure adjustment of agriculture in slope croplands

Based on the long-term in-situ observation, the processes of sediment formation, N, P nutrient transport and their environmental effects had been primarily clarified. Before construction of ridges and furrows in SNTRCS, tall economic plant was planted in the furrow, and low food crops was planted on ridge to form intercropping system and agro-forestry. According to market request, intercropping system would be modified for increasing economic income of local farmer. And agricultural cropping system would be changed for high-profit farming system with soil water conservation and low chemical fertilizer applied.

C Optimized management of soil nutrient in slope croplands

Based on long term field experiment of fertilization, balanced fertilization, inorganic-organic and straw mulching with compound chemical fertilization reduced both soil and nutrient loss in slope cropland. In which, straw mulching with compound chemical fertilization could reduced maximum of chemical fertilizer and increase using efficiency of chemical N fertilizer. Meanwhile, crop yield and productivity of agro-ecosystem kept at the same level of usual fertilization. So, optimized fertilization of soil nutrient could not only improve soil productivity but also supply for environment-friendly fertilization system.

D Sediment and non-point-source pollution control by natural ditches with artificial wetlands

Paddy fields and ponds were artificial wetlands for conserving sediment and nutrient by deposition, adsorption. Natural ditches were located at lower parts of watershed and consisted of natural falling off, small ponds and different plant. They could act as natural purification setting for non-point-source pollution by nutrient sink and plant absorption. With combined setting of artificial wetlands and natural ditches, non-point-source pollution and sediment would be reduced to low output.

E Integrated system for watershed sediment and non-point-source pollution control

Concretely, agro-forestry with foliated-arbor-shrub-liane-local grass and slope cropland intercropping at top and middle of the hill were built up as basic conservation for sediment and nutrient. Optimizing management of soil nutrient could enhance using efficiency of chemical fertilizer and reduce application rate. Artificial wetlands and natural ditches at lower parts of watershed combined with falloff, ponds, aquicolous plants could play sink effects. So that, agro-forestry at top, slope cropland at middle, artificial wetlands and natural ditches at valley would act as function of source reduction and sink enlargement for integrated system for sediment and non-point-source pollution control.

4 Nitrate leaching and its environmental effects in sloping croplands of purple soil

Nitrogen (N) is one of the most important life-limit elements for plant growth, and meanwhile becomes the constituent of the increasing environmental pollution. Nitrogen pollution was regarded as the third major threaten to earth after biodiversity loss and climate change. Specially, excessive nitrate of groundwater could affect human health by causing methemoglobinemia. Nitrate leaching from cropland is an important source of nitrate pollution of groundwater. There were increasing researches on nitrogen leaching from flat cropland, however, nitrate leaching from slope cropland is difficult to explore because of complex hydrological pathway. So, nitrogen leaching process from slope cropland are rarely independently measured or quantified.

Field experiments and in-situ observation at runoff plot with function of subsurface flow monitoring have been conducted to study nitrate leaching process from slope cropland of purple soil through 2003 to 2006. Results and conclusion were summarized as follow.

(1) Nitrate accumulation at profiles of purple soil

Soil analysis on NO_3^--N distribution at soil profile during the winter wheat plantation period showed that NO_3^--N at surface layers (0-30 cm) decreased in the growing period and was the lowest value as 2.35 mg/kg at the harvest stage, while soil NO_3^--N at deeper layers (30-60 cm) increased and was the highest as 56.48 mg/kg, suggesting that nitrate accumulated at deeper soil layers. However, in the consecutive plantation of corn, nitrate was observed in low concentration at soil profile, which implied nitrate moving away in the raining season.

(2) Characteristics of subsurface flow in slope croplands of purple soil

Subsurface flow is overgrown owing to shallow soil layer (60 cm), low water-infiltrate parent rock beneath soil and heavy rainfall at summer. Average discharge of subsurface flow from 2003 to 2006 was 108.1mm, and amounted to 58.3% of total runoff at raining season. The subsurface flow lagged the yield of overland flow and lasted for a long time.

(3) Nitrate leaching via subsurface flow

The analysis of the NO_3^--N in the subsurface flow through 2003 to 2006 demonstrated subsurface flow is the main pathway of nitrate leaching loss at raining season. The content of NO_3^--N was persistently high with range from 8.31 to 43.63mg.$L^{-1}$and average content of 14.92 mg.L^{-1}. Annual average loss flux of NO_3^--N through subsurface flow was 29.87 kg.hm^{-2}, and accounted for 10.02% of total fertilizer nitrogen applied within a year. NO_3^--N loss flux via subsurface flow accounted for 84.62% of total loss. NO_3^--N loss fluxes through subsurface flow changed with seasonal patterns and yearly differences, and it reached at peak through jointing to stamen-growing stage, which accounted for 69.6% of annual loss flux. Nitrate leaching flux was dominative influenced by discharge of subsurface flow.

(4) Environmental risk of nitrate leaching in purple soil region

Nitrate leaching loss via subsurface flow results in large amount of nitrate loss from slope cropland. The high concentration NO3--N of subsurface flow was in response of that in ground water of well bellow the monitoring cropland. This could indicate that nitrate leaching loss from slope cropland results in not only in-situ nitrate pollution of ground water, but also off site pollution by long-distant travel of soluble nitrate, and would throw threat to water environment in the region of Three Gorges Reservoir.

Refereneces

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17

Ecosystem Restoration of the Hilly Areas in the Loess Plateau

Scientific research progress of Ansai Integrated Experiment Station on Water and Soil Conservation

Introduction of Ansai Integrated Experiment Station on Water and Soil Conservation

Ansai station, first as a field station of Institute of Soil and Water Conservation, Chinese Academy of Science (CAS) and the Ministry of Water Resources （MWR） has been in operation since 1973. In 1990, it became one of the leading stations of Chinese Ecosystem Research Network (CERN), and was selected as Agricultural Science Experiment Base of Shaanxi Province in 1998. In 2000, it became one candidate of the field observation and testing stations of the Ministry of Science and Technology in China, and in 2005, it turned into a formal one.

Research aspects： Based on watershed unit, Ansai station carries out long term positioned monitoring in agricultural resource and ecological environment of loess hilly areas. It includes the following aspects: to explore the law of soil and water losses and its impact on ecological environment; to research eco - environment characteristics and evolution features of loess hilly areas; to evaluate the present situation, change and development trend of agri - ecological environment and to analyze the key restrictive factors; to study structure, function and regulation of eco-agriculture system with soil and water conservation; to develop method and management for watershed health diagnosis. The station focuses its work on the ways and measures of rational exploitation and utilization of agricultural resources, eco-environment improvement, reconstruction for degraded ecosystem and improvement of integral system function, which can provide evidence for decision-making for resource optimal allocation, comprehensive regional development and environment treatment. It will be the base for eco-environment long term positioned monitoring, researching, experimental demonstrating and talent training.

Ansai Station, 30 kilometers away from Yan’an City, situated in the suburb of Ansai County, Yan'an Prefecture of Shaanxi Province, lies in the typical loess hill and gully region of the

Loess Plateau, latitude 36°1'30" N, longitude 109°9'23" E, with altitudes ranging from 1068 m to 1309 m,mean annual temperature of 8.8℃, mean annual precipitation 500mm. For the soil type, it is at the cross area of loamy loess soil and sandy loam loess. Climatically it is situated at the transition area of warm temperate zone, semi-humid area and semi-arid area. The vegetation is forest-steppe zone, which is the transitional type between deciduous broadleaved forest of warm temperate zone and dry steppe. It is a typical region with impact of severe soil and water loss and human activities. With the multiplicity of landform and resource the station has typical representativeness for experiment of soil water conservation and research of eco-entironment.

1. Demonstration and experimental research on degraded ecosystem rehabilitation on the Loess Plateau

Based on the long-term located experimental results in standarded monitoring plots and model watershed in Ansai station, the scientific basis, approach and key techniques of soil erosion controlling and ecological rehabilitation on the hilly Loess Plateau were explored. Different demonstration models on ecological rehabilitation in different scales were established. Long-term research data on eco-environmental evolution and rehabilitation was accumulated.

（1）The approach and key measurement on soil and water conservational eco-agriculture construction on the hilly Loess Plateau were brought forward and improved gradually. The guiding ideas on soil and water conservational eco-agriculture construction, such as taking enhancing precipitation infiltration to control soil erosion as the central idea, taking rational using of land and water resources as the precondition, taking restoring vegetation, building basic cropland and developing cash tree and breeding as leading measurements, were proposed. A physical model was built up in Zhifanggou watershed. Soil and water conservational eco-agriculture construction was proposed to conduct according to the 3 periods of initial restoration, stable improvement and fine development. After 20 years continuous construction of a serous degraded ecosystem in Zhifanggou watershed, the system has been rehabilitated and coming to fine development. Practice in eco-restoration demonstrates that severe degraded eco-system in loess hilly region could be restored gradually and go into fine cycle status after more than 20 years continuous vegetation construction.

（2）The research on watershed ecosystem rehabilitation was extended from small watershed to meso-scale and demonstration zone covering 707 square kilometer was developed. The approach and model for eco-agriculture construction under intensity capital input and continuous construction were explored. The demonstration models and their technical systems for eco-agriculture construction, such as cultivation and fruit tree compounding, agriculture with high-performance facilities, and forest combing stock breeding, were explored. The principle, approach and suitability for these models were also established. All of these have provided technical support and demonstration on eco-environmental construction and county economics development on multi-scale in the Loess Plateau.

（3）The process of small watershed ecosystem degradation and restoration on the Loess Plateau was researched systematically. The temporal and spatial dynamics of Land use pattern in watershed and the process of watershed ecosystem degradation and restoration were demonstrated. Database of 60years' eco-economic system evolvement in Zhifanggou watershed and its monitoring system were established. The database was deemed to be the most systematic data for small watershed ecosystem.

（4）Eco-economic system health assessment indicators and corresponding criteria for the indicators, assessing model were built up. The connotation of Eco-economic system health on the hilly Loess Plateau was put forward, i.e., ecological security under erosion and drought stress, stable productivity and necessary ecosystem service, and state of sustainable development. A case study on ecosystem health of 5 different eco-economic developing models in Yan'an demonstration zone, such as cultivation and fruit tree compounding, agriculture with high-performance facilities, and forest combing stock breeding and so on, showed that the health condition on the demonstration zone was improved gradually with rational landuse and the "grain for green" policy.

The demonstration research on ecosystem restoration of different scale could clarify the possibility, approaches and models for degraded ecosystem restoration on the serious eroded region of the Loess Plateau and will provide scientific reference for national ecological construction.After signing the agreement of "demonstration zone of soil and water conservation and ecological construction in North Shaanxi Province" by the Ministry of Water Resources, Shaanxi Province government and the Academy of Sciences corporately in 2002, the ecological construction demonstration zone has extended to 80 thousand km2 on the Loess Plateau, and a multi-scale demonstration research system on ecological construction has also developed.

Picture of eco-agriculture construction with soil and water conservation model in Zhifanggou watershed

2. Vegetation restoration mechanisms and key technologies in loess gully region

（1）Mechanisms of vegetation restoration in loess hilly region

By constrast vegetation change of restored eco-system in Zhifanggou small watershed with degraded eco-system in Xiannangou watershed, in the froest-steppe zone of loess hilly region, vegetation succession and communities development of degraded ecosystem have reflected a perfect effect after 30 years continuous preventing domestic animal from grazing the vegetation. The results have showed that the environmental basis and species for vegetation succession were not destroyed fundamentally by the past eco-environmental destruction in the forest-steppe zone of the Loess Plateau, vegetation communities could be restored by natural power (succession), that means vegetation communities could be restored in the region by itself succession.

Based on the long-term position monitor, the composition, structure and interspecies relationship and distribution patterns of typical communities have been studied in loess gully region, the species diversity change of vegetation succession process for 40 years in slope cropland conversion into grassland have clarified in detail. Based on field survey and lab statistical analysis, such as PCA, DCCA, the effect of microtopography, soil and microclimate on the plant communities has been analyzed. We found that the key factors influencing community restoration are soil moisture, slope gradient and nutrient in loess gully region.

（2）Study on key technologies of artificial vegetation restoration

Establishment of the basic principles of artificial vegetation building in loess gully region: artificial vegetations should be coordinated with the distribution of regional natural community; the native species should be chosen as predominant species of artificial community; the structure of artificial community should simulate the structure of natural community in loess gully region.The criterion of vegetation building: we found that the plant communities will have good functions of soil and water conservation and the functions of ecological service when the vegetation coverage is not less than 60% in loess gully region. Key technologies of vegetation building: based on the study on mechanism of photosynthesis, respiration, water balance and endogenesis incretion control of native tree species, the configuration of typical stand conditions in loess plateau has been suggested for local government and farmers.

Table 17.1 status of plant species diversities in artificial vegetation communities after 9 years natural succession

Name	Abundance index		Simpson index		Shannon index		Pielou index	
	Shrub	Herb	Shrub	Herb	Shrub	Herb	Shrub	Herb
Platycladus orientalis	1	22	0.000	0.9434	0.000	2.9660	0.000	0.9595
Pinus tabulaeformis Carr.	4	16	0.6300	0.9306	1.1263	2.7082	0.8124	0.9768
Populus simonii Carr.	4	23	0.7116	0.9457	1.3138	3.0023	0.9477	0.9575
Caragana microphylia	2	16	0.1032	0.9335	0.2113	2.7287	0.3049	0.9842
Hippophae rhamnoides Linn.	4	19	0.4841	0.9384	0.9398	2.8241	0.6779	0.9771
Hippophae rhamnoides Linn.(cutting)	5	18	0.5450	0.9255	0.9921	2.7358	0.7156	0.9456

By means of investigation on engineering of farmland transforming to forest or grassland and long-term accumulation of scientific research, a report "analysis and suggestion of the grain-for-green project in loess plateau" has been formed and be submitted to China Central government and be written instructions by Premier Wen Jiabao.Participating the national soil and water conservation and eco-restoration layout of MWR. It provides a scientific basis for the layout that vegetation on the loess plateau could realize self-restoretaion by means of closing hill and cultivation. In 2004, there is a workshop of national soil and water conservation and eco-system self-restoration, organized by MWR and CAS. Dr Guobin Liu give a thematic report of some scientific issues of soil and water conservation and eco-system in the workshop.To guide the regional eco-construction, by means of Experiment and demonstration, we put forward two measures of "soil preparation by disturbing lightly" and "mixed model by using local species", extended widely in Yan'an area. The principle of ecology self-restoration is applied in Yan'an region and Yan'an city government implement 300 thounsands mu of farmland transforming forest or grassland in 2004.

3. Response of hydrological environment and soil quality to ecosystem restoration on the hilly Loess Plateau

（1）Research progress on hydrological environment

The dynamics of water resources in point, line and plane and their transfer rule were manifested. Rational water resource using strategy was also proposed. Suitable rainfall amount, suitable time, and rainfall efficiency were identified as indicators for rainfall-crop water requirement. Runoff during April and May was used as indicator for assessment of agriculture irrigation potential. Soil water deficiency was taken as an indicator for vegetation restoration potential and collocate models. The reason in bio-climatology for soil desiccation and dry layer was clarified. The desiccation intensity in different region and different vegetation types was brought forward. The soil desiccation from southeast to northwest was consistent with the climate desiccation. There was significant difference of soil desiccation among vegetation types. Response of watershed hydrology to watershed management was illuminated. The effect of watershed management on runoff was obvious for small and long time rainfall, but not so effective for high intensity of rainfall. Soil infiltration capacity and runoff amount in dry reason were enhanced with watershed management. The transfer of precipitation to groundwater may be achieved by surface and cranny infiltration. Infiltration in loess soil has formed a hydraulic relationship with groundwater, precipitation to supply groundwater has a combined characteristic of surface and cranny infiltration.

（2）Progress on soil quality

Soil quality assessment indicators and corresponding assessment model for the erosion environment in the hilly gully region of Loess Plateau were established, the criterion for soil quality assessment in the region were also set up. 8 soil quality indicators including organic matter, K10、anti-scrubility、CEC、invertase、MWD、available phosphorous and MICMWD, were identified. Integrated soil quality evaluation model was established by applying weighted integrating method in fuzzy mathematics. The evolvement rule of soil chemical, physical, biological indicators and soil quality index was clarified with landuse years in different landuse types. The regression models for soil quality evolvement were also established. Linear function or power function was suitable for fitting the correlations mentioned above and was used to establish the regression models for soil chemical, physical and biological quality evolvement with landuse years. In the hilly-gully region of Loess Plateau, land use change was the driving force for soil quality change. Landuse change was the main resources of soil quality variance and could explain 97% of soil quality variance. Soil available phosphorous and soil anti-scrubility were the limiting factors for soil quality in the erosion environment on hilly-gully region of the Loess Plateau. The process of soil quality restoration in the region had characteristics of long time and hysteresis. The criteria for vegetation coverage of planted woodland, planted shrub land and natural grassland was at least 65% in order to restore soil quality to middle level.

Under the new situation of ecological constriction in west region, it will be the key for environment sustainable development in west region that how to assess the effects of vegetation restoration on water security, water capacity and soil quality. The results of years for ecological restoration, soil quality evolution, soil dry layer indicators and restoring techniques will provide scientific support and assessment basis to the “grain for green” project. The integrated water resources development technique system was extended in the Yan’an demonstration zone. The research results of hydrological environment and soil quality were cited more than 180 times.

4. Mechanisms and techniques research of facility vegetable sustainable production on the Loess Plateau

Solar greenhouse vegetable production is a successful example for its high-yield, high-quality, and high-efficiency, and it's also a main type of facility agriculture. Facility agriculture is an important measure to decrease the rural surplus labors, increase farmer's economic benefit and make sure the economic and environment sustainable development of rural areas on the Loess Plateau.

The research based on the experimental vegetables of cucumber and tomato, which take 60%-70% area of solar greenhouse vegetable in the region, the objective is to reduce the use of pesticide and fertilizer, produce safety green vegetable. The research based on the main scientific technology problems which restrict the Loess plateau facility vegetable production, to ensure facility vegetable high-yield, high-quality, high-efficiency, ecology safety and sustainable development.

（1）Find out the biological mechanism of the solar greenhouse cucumber continuous cropping obstacle on the Loess Plateau. The main cause of cucumber continuous cropping obstacle is the amount of soil bacteria and fungus increase, and the crop auto-toxicity caused by accumulation of cucumber, pumpkin and grafted cucumber root metabolism and producing of secretion.

（2）The law of main plant disease and insect pests in facility vegetable is researched systematically. Some new technologies about nutrition control are suggested. Do away germs and insects with 03, fruit bagging and pick flowers.

（3）Found a mathematic model about the effect of fertilizer amount to the cucumber yield. Suggested a high-yield, high-efficiency and no pollution fertilizer use plan about cucumber and tomato, etc, provide theory basis for scientific fertilizer use technology.

（4）Find out the law of cucumber and tomato water sensitive period in solar greenhouse, suggested water control quota in facility cucumber and tomato production.

The research find out the mechanism of facility vegetable sustainable development on Loess plateau, increase the facility vegetable production technology content and the use efficiency of fertilizer and other chemical resource, decrease the pollution to the environment and vegetable production, to lay the foundation of provide security and nutrition vegetable production and guarantees the facility vegetable sustainable development. Coordinate the relation of "the small oasis" and "big ecology", provide the scientific basis of construct "blue sky and green water" and both soil and food safety environment. The research has scientific significance to deep recognize the internal relation of vegetable—environment—disease and insect pests of facility vegetable, protect soil ecology, encourage subject progress and realize green food production.

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18

Structure, Function and Management of Agricultural Eco-System in the Loess Tableland-Gully Region

Scientific research progress of Ansai Integrated Experiment Station on Water and Soil Conservation

Introduction of Changwu Agro-Ecological Experiment Station in Loess Plateau

The Changwu Agro-ecological Station was established by Institute of Soil and Water Conservation, Chinese Academy of Sciences and Ministry of Water Resources in 1984, and was incorporated into the Chinese Ecosystem Research Network (CERN), Chinese Academy of Sciences in 1991. Later on, it successively became one of Agricultural Experimental Bases of Shaanxi Province, one of Field Research and Education Bases of the Northwest Sci-Tech University of Agriculture and Forestry, and a member of GTOS-TEMS, FAO. In 2005, the station was honorably selected to be one of the national stations of field scientific observation and research.

The Changwu Agro-ecological Station is located in Changwu County, Shaanxi Province (N35°12′，E107°40′) of the tableland-gully area on the south Loess Plateau. The mean annual precipitation is of 580 mm, and the mean temperature 9.1°C. Vegetation type in Changwu Station is the deciduous-broadleaf forest, and the typical ecological system is of rainfed cropland. The tableland-gully area of 69,500 km2 crosses over the three provinces of Shanxi, Shaanxi and Gansu, being one of two major types of geomorphologic and ecological area on the Loess Plateau and dominated by grain production in the above provinces mentioned. The area has developed into the largest base for high-quality apple production in our country since the 1980s.

The Changwu Agro-ecological Station addresses the agricultural issues on the south Loess Plateau, especially the farmland ecosystem in the tableland-gully area. Researches conducted in the station include studying the structure, functions and environmental effects of agricultural ecosystem, establishing theory and techniques of water-saving ecological agriculture, providing a sci-tech support for sustainable agricultural development and eco-environment improvement in the area. We intend to develop the station into a national base opening to the world, for factor monitoring, experiment, research and technical demonstration in ecological agricultural system, and make it to be an educational and training platform.

Scientists working in the Changwu Agro-ecological Station have published over 500 papers and 5 monographs since the founding of the station, of which more than 50 papers are collected in SCI. By the end of 2006, the station was awarded 1 “the First Prize of State Scientific and Technological Progress”, and 1 “the Second Prize of State Scientific and Technological Progress”, as well as 3 the first prize and 4 the second prize at the provincial or ministry’s level. Changwu station ranks first in the 11 awarded institutions of “the First Prize of State Scientific and Technological Progress”, the good position that the station has in China for studying water cycling in agricultural ecosystem is important to obtaining the achievement as a whole.

1. Evolution and potential of rainfed grain yield

Three laws of rainfed grain yield have been revealed by systematic research on grain yield developing process conducted in the Wangdonggou Experimental Area , Changwu County, Shaanxi Province. They are the yield wavering followed by a new jump, rainfed grain yield fluctuation, and dominant effects transferring from nutrient to moisture in dryland. Rainfed grain yield wavers in a certain period, and yield increase to a higher level needs some new factors. The advanced technology can alleviate but not eliminate the annual fluctuation of rainfed grain yield. Yield fluctuation in high yield farmland is not less than that in low yield farmland, and sometimes, even higher. Applying nutrient was the main measure to increase grain yield in the loess plateau before 1990s. Due to high fertilization and nutrients accumulated in the soil, water became a main factor to some high yield farmlands. The finding of the above three laws clarifies the erroneous understandings in the past, and provides a guidance in policy and technology for dryland farming.

Determination of the potential maximum rainfed grain yield, namely rainfed grain yield potential, is an important basis for the position of a region in grain production . However, the models used to calculate the rainfed grain yield potential are immature, and the results predicted by the models are unbelievable because the prediction value is much higher than the reality. Therefore, it can not serve for establishing the grain plan of national economy. Lack of an experimental basis and subjective selection of the parameters are the two main reasons for the poor prediction. In order to solve these problems, a field experiment conducted in the Changwu Agro-ecological Station for 10 years. Use efficiency of solar energy, correction coefficient of water factor and crop coefficient in this region are worked out, and a series of calculation methods including cultural system are also established based on FAO model by field experiments. Predicted values have good credibility by comparing with those of the field experiment. In order to study the position of the loess plateau in grain production and measure the level of grain yield at present, the 'realizable rainfed grain yield potential' is defined and calculated in 11 national experimental regions in Shaanxi, Ningxia, Shanxi, Inner Mongolia, and so on. Results showed that the yield was less than 50% of grain yield potential before "the seventh five-year plan", and it increased to 59, 65 and 77% during "the seventh five-year plan", "the eighth five-year plan" and "the ninth five-year plan", respectively. The researches on grain yield potential can provide a quantity basis for analyzing the level of present crop production and programming the future goal.

2. Transformation and regulation of carbon (C), nitrogen (N) and phosphorus (P) in cropland ecosystems

The transformation characteristic and mechanism of C, N and P are preliminarily revealed through the rotation fertilization experiment in agro-ecosystem for 22 years.

Soil productivity has been significantly increased in the loess plateau by applying chemical fertilizer since 1980s. However，increase of the soil carbon storage is not so significant, being only 1.3～2.4 $t \cdot hm^{-2}$. Soil carbon storage has a significant linear correlation with organic carbon applied into soil, but it is not related to the manners of chemical fertilizer application and rotation. Input of organic matter is the main factor for increasing soil organic carbon in the loess plateau. The limitation of RothC-26.3 model applying in the loess plateau is analyzed by using the data from long-term experiment. The carbon cycle model which can suit to this region should be established in later research.

The change of annual precipitation amount in growing season is the main factor that results in extremely fluctuated rate of yield increase by N fertilizer application. The Nitrogen use rate extremely fluctuates in common conditions, which is 37% on average. Applying 135 kg N fertilizer and 39kg P fertilizer per hectare can obtain higher wheat yield and rate of yield increase by N fertilizer application. However, if applying more N fertilizer, the change of wheat yield is insignificant, but the annual fluctuation of wheat yield is significant. The excessive applied N fertilizer is accumulated as nitrate N in the 100-200cm soil layer. Plant use ability and precipitation are important factors for nitrate N to move down to deep soil layer in farmland. If N is applied with P and deepl rooted crop is rotated with shallow rooted crop, the amount of nitrate N accumulated in deep soil layer can be reduced.

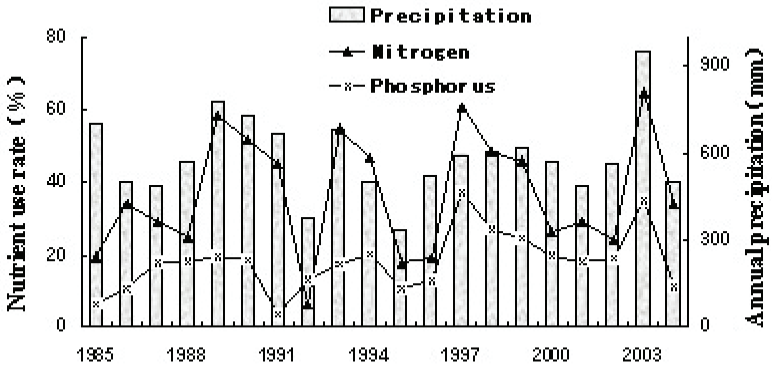

Fig. 18.1 Use rates of nitrogen and phosphorus, respectively, in the monocultural winter wheat on the long-term rotation experiment site in different years

Singly applied phosphate fertilizer has an insignificant effect on wheat yield. P fertilizer use rate is 10% on average in monocultural winter wheat under N applied with P. P fertilizer is accumulated in the upper layer of soil, so its use rateis low. Inorganic P is the main part of P fertilizer which is accumulated in the dark loessial soil. Ca-P, O-P, Al-P and Fe-P account for 70, 9.19, 5.96 and 5.23% of inorganic P, respectively. The P fertilizer applied to soil is mainly transformed to Ca8-P and O-P. Using N to increase P use efficiency and applying P fertilizer in every two years can increase P fertilizer use efficiency significantly.

3. Interrelation of crop yield, evapotranspiration and water use efficiency

The elasticity of water production (EWP), which is a ratio of marginal water use efficiency to water use efficiency and based on the functional relationship between Y and total seasonal ET, was used to reveal the dynamic interrelations of yield (Y), evapotranspiration (ET), and water use efficiency (WUE). If the ET production function is linear, the trend of WUE with ET is directly affected by the intercept of the function, and the EWP will correspond to the yield response factor (Ky) when ET reaches the ET at maximum yield (ETm). If the ET production function is quadratic, the maximum WUE comes earlier than the maximum yield, and the ET for maximum WUE equals the arithmetic square root of a ratio of the intercept term to the coefficient of the quadratic term.

The WUE at a particular level of yield is only one aspect of WUE to be considered. Use of the EWP to explore water use efficiency can also be extended to other areas of crop water use relations, including dry matter production per unit of ET or T during a particular growth stage and net photosynthesis production per unit of T for a leaf, etc. If the ET production function relation is expressed in a form other than linear or quadratic functions, the interrelations of Y, ET, and WUE can also be evaluated by analyzing the EWP of the function.

An ET production function is developed under specific conditions of water and nutrient supplies. It may be derived by applying different levels of water supply at a given level of soil fertility. For a given ET production function and water supply, strategies can be developed to optimize the water applied during different growth stages. Analyzing the interrelations of Y, ET, and WUE with the ET production function developed for the specific crop system condition would provide more complete information for obtaining the joint goals of water conservation and economic yields in farming operations.

4. Water cycle evolution of compound agro-ecosystem under high efficient management in a small watershed

Soil desiccation occurred under high-yield fields where wheat yield was greater than 3750kg/hm^2 or maize yield was greater than 7500kg/hm^2. The average annual soil water consumption was increased by 48mm, and desiccation was observed in the 1-3m soil layer. Average soil water content was decreased from 17.3 to 10.9%, and the depth of annual precipitation infiltration was reduced from 224 to 110cm. Soil reservoir is unable to make ends meet for a long time, so its adjustment ability for annual and seasonal drought is weakened.

The planting density and bio-mass of the orchard, soil & water conservation forestland and grassland are greater than those of natural vegetation. Serious desiccation occurred under the layer of precipitation infiltration because evapotranspiration increased. Soil water content decreased to around 10-12%. In order to have a sustainable production of forest and fruit, reasonable planting density and yield are necessary.

The depth of annual precipitation infiltration is related to precipitation amount. For the year of 2003, a record wet year,, the precipitation infiltration in high-yield field reached to 5m, and the layer of desiccation disappeared. Furthermore, the depth of infiltration in low-yield field and bare fallow land in tableland was deeper than 6m. For alfalfa land in tableland , terrace orchard, and forest-lands of *Robinia pseudoacacia, Hippophae rhamnoides* and *Biota orientalis* on slope, precipitation infiltrated to 2.5-3.5m deep. Soil desiccation layer lessened, but did not disappear (Fig. 18.2).

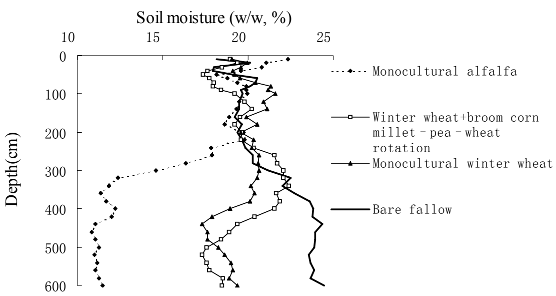

Fig. 18.2. Profile distribution of soil water content in the monocultural winter wheat, winter wheat+broom corn millet–pea–wheat rotation, and monocultural alfalfa with balanced supplies of nitrogen, phosphorus and organic fertilizer, and in the bare fallow on the long-term rotation experiment site in December of 2003

High-yield agro-ecosystem formed by comprehensive management in small watershed resulted in the changes of water cycle, accelerated soil desiccation, decreased the surface runoff, heightened the small cycle of water, and weakened the large cycle of water. Along with the process of soil and water conservation, the areas of man-made forest, orchard and grassland are increased; their effects on river's runoff can not be ignored.

The average runoff depth in floodtime in Wangdonggou watershed during "the ninth five-year plan" was 5.9mm, whereas the depths during "the eighth five-year plan" and "the seventh five-year plan" were 4.9 and 9.4mm, respectively. After the influence of precipitation was deducted, the surface runoff was decreased by 27.6% due to the comprehensive soil water conservation management during "the ninth five-year plan". The annually averaged soil erosion module was 504 t/km^2 during "the ninth five-year plan", whereas the modules during the period of "the sixth, seventh and eighth five-year plan" were 1869, 1050 and 383 t/km^2, respectively. After the influence of precipitation was deducted, soil erosion was decreased by 22.4% during "the ninth five-year plan".

5. Potential response of hydro-ecological process to climate change in Changwu tableland-gully region

The potential impacts of projected climate changes in 2070–2099 under three emission scenarios (A2a, and B2a, and GGa1) on hydrology, soil loss, and crop production were studied in Changwu tableland-gully region on the Loess Plateau. Climate change scenarios used in this study were taken from the recent climate change experiments conducted using a third generation general circulation model (HadCM3) at the Hadley Centre, UK. The HadCM3 issues monthly projections for the next 100 years for the entire globe. Future climate projections of different GCMs are similar at the global level, but may differ in particular regions. A stochastic weather generator (CLIGEN) and the Water Erosion Prediction Project (WEPP) were used to analyze the hydro-ecological process.

Monthly precipitation and temperature distributions including mean and variance were changed into daily weather series using CLIGEN model. The future daily precipitation and temperature were related to the monthly mean and variance. So the occurrence of large storms which mainly result in soil erosion can be reflected by this method.

Monthly precipitation and temperature for the periods of 1950–1999 and 2070–2099 were used from the Hadley Center's general circulation model (HadCM3). The CLIGEN model was used to downscale monthly HadCM3 projections to daily values at three spatial scales. The WEPP model was run for a wheat–wheat–maize rotation under conventional and conservation tillage at the 5° and 10° slopes. The result showed that HadCM3 predicted a 23–37% increase in annual precipitation, 2.3–4.3℃ rise in maximum temperature, and 3.6–5.3℃ rise in minimum temperature for the region over the century. Compared with the present climate, predicted percent increases under climate changes, as averaged over the three spatial scales for each emission scenario and slope, ranged from 29 to 79% for runoff, 2 to 81% for soil loss, 15 to 44% for wheat grain yield, 40 to 58% for maize yield, 25 to 28% for crop transpiration, 21 to 34% for soil evaporation, and 4 to 12% for long-term soil water reserve under the conventional tillage. However, adoption of the conservation (delayed) tillage could reduce runoff by 18–38%, and decrease soil loss by 56–68% as compared to the conventional tillage under the present climate. These results suggest that the use of the conservation tillage would be sufficient to maintain low runoff and erosion levels, and thus protect agro-ecosystems under projected climate changes.

6. Establishment and benefitsof agro-ecosystem with the three-part-structure of grain, fruit and industry

Soil water conservation by straw coverage and optimal fertilization according to soil water content are used to achieve a high realizing rate of rainfed grain yield potential. Average grain yield per unit area has reached 4100 kghm-2 since the experiment station set up. A technical system of high yield and drought resistance in different precipitation year is set up, so the water and fertilizer use efficiency are increased. Eco-environment is significantly improved after five projects implemented in the low-yield sloping area which accounts for two thirds of the tableland-gully region of the Loess Plateau. The five projects include the construction of gully-slope road erosion controlling system, intensive management of low-yield farmland, limited water resources utilization, construction of ecological orchard on gully slope, and improvement of low-yield forest with double benefits. Farmland shelter-forest on tableland, economic forest on gully slope, and timber wood and protective forest in gully have been constructed. Forest and grass coverage has increased from 18.2% in 1986 to 48% at present. Farmland shelter-forest, economic forest, soil and water conservation forest and grass account for 5, 17, 20 and 5% of total coverage, respectively. With such a reasonable proportion of land use, the production value of gully-slope land increases more than one hundred times. Soil erosion module is constantly below 800 $t \cdot km^{-2} \cdot a^{-1}$ for more than 10 years because of the superior measures of soil and water conservation. Rural industrial structure has been adjusted from one-crop farming to multiple structures (grain, fruit and industry). The incomes of crop planting industry, fruit industry and the rural industry and sideline account for about 18, 30 and 50%, respectively. The livestock and forestry industry only account for 2%. The income of industry and sideline increases persistently because the rural surplus labor force is transferred reasonably. 20% of local farmers are engaged in fruit production and marketing, and 25% are engaged in the third industry. Both stability of agricultural eco-economic system and the level of productivity have been enhanced due to the reformation of the rural industrial structure.

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19

Ecosystem Studies on Inland River Basins in Dryland Areas of Northwest China

Scientific research progress of Linze Inland River Basin Comprehensive Research Station

Introduction of Linze Inland River Basin Comprehensive Research Station

Linze Inland River Basin Research Station, Chinese Ecosystem Research Network (Linze Station) is located in the middle of the Heihe river basin, Hexi corridor region of northwest China. It carries out the long-term monitoring of desert and oasis ecosystems. The research of Linze Station is focused on the integrated management of water-ecology-economy system in the Heihe river basin. It aims at providing scientific base and technological support for sustainable development in the inland river basin of arid regions. Some research advances obtained in recent years are summarized as follows:

1. Water-saving protective forest system construction in desert-oasis ecotones

In 2001-2004, Linze Station performed the establishment and demonstration on water-saving protective forest in ecotone between desert and oasis under the support of knowledge innovation projects of CAS named “Experiment and demonstration on integrated management of water-ecology-economy systems in Heihe river basin”. The corresponding researches were carried out.

The research contents include the distribution patterns, physiological/ecological characteristics and water use efficiency (WUE) of desert plants, and their responses to groundwater depth, the transpiration rates and water use strategies of the main plant species in protective forest, the vegetation ecological water requirements, as well as the wind-defending effects of shelter belt in ectone between desert and oasis. Base on these researches and practices, the theories concerning the construction of high water-use-efficiency protective forest system for maintaining oasis stability was further improved. Guided by these theories, a mult-stratum protective forest system integrating trees, shrubs and grasses was established at the transitional zone between desert and Pinchuan oasis. This protective forest system has significant ecological and water-saving effects.

The completed protection system included: 1) grass reservation belts with an area of 2000 ha were built by enclusion in the periphery of oasis to recovery and conserve Nitraria sphaerocarpa and Reaumuria soongorica populations and stable nebkhas to control the encroachment of drift sands into oasis; 2) A 100 ha of artificial sand barriers were setup at the edge of the desert by establishing straw checkerboard barriers and planting drought-resistance desert plants such as haloxylon ammodendron, Hedysarum scoparium and Tamarix spp. The artificial vegetation was established by stimulating the patterns of natural desert plants and the water consuming characteristics; 3) Mixed forest belts of Populus spp and E.angustifolia L or Populus spp and Tamarix spp were built along the channels at the margin of newly cultivated oasis and a forest-grass intercropping zone was established in the interior of protective forest belts; 4) Converting marginal farmlands to alfalfa grasslands were performed to control soil erosion by wind; 5) The forest grids in the interior of the oasis were changed moderately without reducing its sheltering effects, the Populus spp in protective systems were partly replaced by Ziziphus jujuba Mill to reduce the water consuming happened in farmlands. These changes in the structures of protective forests have significantly reduced the water consuming while at the same time guaranteed the protective effects. The newly developed construction model of protective systems is generally suitable for use in oasis areas endangered with sandy desertification in arid areas such as oases in Xijiang and Hexi corridor of Gansu.

Beside the obvious ecological effects, some distinctive advances also have been made in the aspects as below: 1) the amount of water consuming of the main tree species and protective forest were determined by continuous measurement of the sap flow; 2) the distribution patterns of desert plant in the oasis-desert ecotone, the responses of the desert plants to the groundwater depth, and the stability mechanisms of the nature vegetation were thorough studied, which contributed to the construction of the artificial rainfed vegetation; 3) the adaptation mechanisms of desert plants to desert environment were identified by studying the physical and ecological charactersteics and the WUE of the typical desert plants, and the strategies of tree species selection and the maintain of vegetation stability were proposed; 4) the vegetation ecological water requirements(EWR) was estimated by employing the ecohydrological theories and analyzing of the multiyear data set of climate, soil moisture, land use etc., and the programming schemes of EWR in the areas of Zhangye, Linze, and Gaotai were proposed.

2. Water-saving techniques integration and demonstration in oasis agriculture systems

A comprehensive water-saving agriculture demonstration area was established in Pinchuan irrigation area, Linze county in responding to the sharply lessened agriculture water resources after the implement of the Water Allocation Project of the Heihe River. A series of research works were carried out. The construction of water-saving agriculture demonstration area and water-saving technical application in large area have successfully promoted the harmonious development of the regional water-ecology-economy, and have made great contributions to the successful implement of the Water Allocation Project of the Heihe River. The main achievements can be summarized as below: 1) the quantity of water consuming and requirements for the main crops under different cultivation types on sandy soils in the marginal oasis were identified, which contribute to providing reliable decision-making bases for the water distribution management and agricultural planting structure adjustment; 2) The effects of wind erosion and soil water conservation under different land use patterns were studied and water-saving planting and cultivation management which was suitable for use was determined. The measurements to mitigating soil erosion by wind on sandy farmlands including winter irrigation and no tillage, plastic film cover before transplanting were used in the marginal oasis; 3) the optimal irrigation unit of 0.5 Mu was determined by studying the amounts of irrigation and irrigation water loss for different size of farmlands. Significant water-saving effect has been made by the cementing of irrigation channel, the layout of irrigation units, and the level of farmlands; 4) a program of agriculture construction adjustment with high water resource use efficiency was proposed by comparing the production value per cubic water under different agricultural land use and cultivation management patterns, i.e., withdrawing croplands to alfalfa forage grasslands, crop-grass rotation and intercropping in the marginal oasis region; reducing planting area of high water consumption crops such as wheat/corn stripping fields and applying the model of jujube-grain intercropping in the area of old oasis；5) the demonstration of water-saving cultivation techniques and management of artificial grassland boosted the development of grass industry promoted the structure adjustment of agricultural structure.

An effective water-saving agricultural technique system and integrate management model with practicality and easy to spread was proposed through extensive researches for various single agricultural water-saving measures. This system included: establishing water-ticket system to prevent unreasonable water utilization in the whole irrigation area; planting alfalfa to develop grass industry and to adjust cultivation structure, introducing concrete lining channel and 0.5 mu irrigation unit, and spreading grass-crop rotation and intercropping, winter irrigation, no tillage and rational fertilization and plastic film cover before transplanting, and so on. The application of integrate techniques contribute to significant water-saving effects. After the implement of project, the total amount of water use in the demonstration area has decreased from 6.3×10^8 to 4.9×10^8, the amount of water consuming decreased by 20% and product value per cubic of water increased by 40%.

3. Concept, standard and determining method of vegetation ecological water requirements (EWR) in arid regions, and Heihe river basin EWR estimation

Taking the characteristics of desert oasis into consideration, a concept system of EWR has been proposed, which includes critical EWR, optimal EWR and saturation EWR. Critical EWR refers to the water regimes needed to maintain vegetation growth at a low level of risk; optimal EWR refers to the water regimes needed to maintain ecological function of vegetation at a continuable level; and saturation EWR refers to the water regimes needed to maintain maximum throughput of vegetation community. According to the definition of concepts, the determination of EWR should comprehensively consider the soil moisture status, plant growth modeling, plants transpiration, and issue of transformation between scales of individual, population and ecosystems. Besides, the contribution of groundwater, surface water and precipitation to the water consumed by plants, its variance in temporal scale, and the evaporation-transpiration partition also should be considered in the EWR estimating processes. In considering that the concepts of EWR is served to ecological management and environmental protection, the category of EWR should be the water resources that can be managed and controlled by human beings, so the precipitation can not be counted as a portion of EWR.

Obvious differences exist in vegetation between the middle and lower reaches of Heihe river basin: It is artificial oasis in the middle reaches and there is various vegetation types, while in the lower reaches, it is a natural oasis and the vegetation is relative simple, so different estimating methods were applied to determine EWR.

To estimate the EWR and ecological water shortage of middle reaches, the theory of water balance, meteorological data of the counties from 1956 to 2000, monitoring data of soil moisture in the different vegetation areas from 2002 to 2003, and 3S techniques were employed. The results show that: the optimal ecological water requirement is 2.37×10^8~2.89×10^8 m^3; subtracted the amount of effective precipitation, 1.93×10^8~2.45×10^8 m3 water should be supplied in the form of runoff; ecological water shortages of April, May and June are the most serious in the middle reaches of Heihe River. It is obviously that the temporal variances of EWR should gain more attentions as well as the spatial ones in the establishment of water resources allocation scheme.

The EWR of the Ejina desert oasis is estimated through the relational equation between normalized difference vegetation index (NDVI), productivity and transpiration coefficient, which was established by a combination of the RS, GIS, GPS techniques with the field measurements of productivity. The results show that about 1.53×10^8 m^3 water would be needed to maintain the present state of the Ejina Oasis, and the ecological water requirement would amount to 3.49×10^8 m^3 if the existing vegetation was restored to the highest productivity level at present. Considering the domestic water requirement, river delivery loss, oasis vegetation water consumption, farmland water demand, precipitation recharge, etc., the draw-off discharge of the Heihe River (at Longxin Mount) should be 1.93×10^8~2.23×10^8 m^3 to maintain the present state of the Ejina Oasis, and 4.28×10^8~5.17×10^8 m^3 to make the existing vegetation be restored to the highest productivity level at present.

4. Physiological and ecological characteristics and water use efficiency of typical desert plants

Desert plants, such as Haloxylon ammodendron and Calligonum mongolicum, which widely occur in the desert regions of northwest China, have well adaptation to the harsh environment with high temperature, water deficit, intensive light and frequent wind. They are the main plant species selection for the protection system in the transition zone between desert and oasis in arid region. From 2000 to 2004, physiological and ecological characteristics and water use efficiency of several typical desert plants were systematically studied, and the results are showed as follows:

The response mechanism of photosynthesis of xerophytes Haloxylon ammodendron, Calligonum mongolicum which grow naturally on sand dune and mesophytes Elaegnusn angastifolia, Populus hosiensis of shelterbelt arborous species were comparatively studied. The result showed that the changes of stomatal conductance were mainly controlled by air relative humidity and vapor pressure deficiency. The closure of stomata was the response of rapid decrease of air relative humidity and increase of vapor pressure deficiency. Four plants all showed this feature to different degree. H. ammodendron, C. mongolicum and E. angastifolia have higher photosynthesis rate, however, Populus hosiensis has lower one. The diurnal changes of photosynthesis of H. ammodendron, C. mongolicum and E. angastifolia showed the type of two-peaks and P. hosiensis showed one-peak. The midday depression of photosynthesis of H. ammodendron, C. mongolicum resulted mainly from non-stomatal factors. The decrease of photochemical efficiency was a possible non-stomatal factor for C. mongolicum. The midday depression of E. angastifolia resulted from the closure of stomata. The diurnal change of photosynthetic rate and stomatal conductance has the same tendency. High irradiances caused the photo-inhibition to the four plants. C. mongolicum and E. angastifolia recovered very quickly, but that of H. ammodendron and P. hosiensis fluctuated greatly and recovered slowly. However they all recovered in the evening. They all express different adjustable protection mechanism to high irradiances in desert under drought stress.

The cross sectional anatomical structures, the stable carbon isotope ratio ($\delta^{13}C$) and photosynthetic characteristics of the assimilating shoots of the two species H. ammodendron and C. mongolicum showed that: (1) Assimilating shoots of H. ammodendron and C.

mongolicum have a layer of hypodermal cells and two layers of chlorenchyma on the stem periphery, i.e. an outer layer of palisade cells and an inner layer of bundle sheath cells. The central portion of the shoot is occupied by water storage tissue with the main vascular bundles located in the center. Central bundles are thus separated from Kranz-type cells by layers of water storage cells. There are some small peripheral bundles that have contact with bundle sheath cells. For H. ammodendron some crystal-containing cells existed in mesophyll and water storage tissue, for C. mongolicum many mucilage cells in mesophyll and water storage tissue. It was proved by those that the two species have Kranz anatomy. (2) The δ13C values of both H. ammodendron and C. mongolicum were –14.3‰and –14.8‰ respectively. Under different growth seasons, as well as high and low water conditions, the δ13C values of these two species varied between –14‰ to –16‰. (3) The CO2 compensation point (CCP) of H. ammodemdron and C. mongolicum was 2 and 4 μmol·mol-1 respectively. (4) The light saturation point (LSP) of H. ammodemdron and C. mongolicum was 1660 and 1756 μmol·m-2·s-1 respectively. (5) The apparent quantum yield of H. ammodemdron and C. mongolicum was 0.044 and 0.057 mol CO2·mol-1 photons. It was concluded that H. ammodendron and C. mongolicum, which widely occur in the desert regions of China, belong to C4 plants. Their photosynthetic pathway did not change during the growing season and water condition changing.

The δ13C values and carbon isotope discrimination (Δ) of leaves and assimilating shoots of several desert plants in the desert of central Hexi Corridor region were analyzed. The characteristics of seasonal δ13C of leaves or assimilating shoots and WUE of plants indicated by δ13C values in this region were also studied. At the same time, comparative studies of shelterbelt arborous species and some oasis crops were also carried out. The results indicate that theδ13C values of assimilating shoots of H. ammodendron and C. mongolicum are - 14. 31 ‰ and - 14. 8 ‰ respectively, and stable carbon isotope discrimination (Δ) is between 5 ‰～6 ‰. The δ13C values of leaves for Caragana korshinskii , Nitraria sphaerocarpa , Hedysarum scoparium and Reaumuria soongorica are – 25. 75 ‰,- 25. 79 ‰, - 26. 38 ‰and - 28. 05 ‰respectively, while Δ is between 16 ‰～20 ‰. The long-term water use efficiency of several desert plant species can be ranked in the general order: H. ammodendron≈ C. mongolicum > C. korshinskii ≈ N. sphaerocarpa≈ H. scoparium > R .soongorica.

Populus euphratica Oliv. is an important tree species of desert riparian forest. Leaf shape of *P. euphratica* is variable but can be roughly classified into two types, namely poplar leaf and willow leaf. Representative leaves of these types were ovate and lanceolate respectively. Some standard adult plants with both ovate leaves and lanceolate leaves were selected from the Nature Reserve of *Populus euphratica* in Ejin Qi，Inner Mongolia and were studied. In this measurement, their photosynthesis, transpiration and water use efficiency were compared using the LI-Portable Photosynthesis System of LI-cor; the response to CO_2 enrichment was also compared. The results showed that under present atmospheric CO_2 concentration

($350 \mu mol \cdot mol^{-1}$) and 1 $000 \mu mol \cdot m^{-2} \cdot s^{-1}$ of light intensity, the net photosynthetic rates (*Pn*) of ovate leaves (leaf blades of adult tree) (A) and lanceolate leaves (1ower coppica shoot leaves of adult tree) (B) are 16.40 $\mu molCO_2 \cdot m^{-2} \cdot s^{-1}$ and $9.38 \mu mol\ CO_2 \cdot m^{-2} \cdot s^{-1}$ respectively; water use efficiency (*WUE*) is 1.52 mmol $CO_2 \cdot mol^{-1} H_2O$ and 1.18 mmol $CO_2 \cdot mol^{-1} H_2O$ respectively. Under these conditions, the light saturation and compensation points of A are 1 $600 \mu mol \cdot m^{-2} \cdot s^{-1}$ and $79 \mu mol \cdot m^{-2} \cdot s^{-1}$ respectively，while the corresponding values of B are 1 $500 \mu mol \cdot m^{-2} \cdot s^{-1}$ and $168 \mu mol \cdot m^{-2} \cdot s^{-1}$. When CO_2 concentration reaches $450 \mu mol \cdot mol^{-1}$ and 1 $000 \mu mol \cdot m^{-2} \cdot s^{-1}$ of light intensity, the photosynthetic characteristics of A and B exhibited quite different responses．The light saturation of A rises by $150 \mu mol \cdot m^{-2} \cdot s^{-1}$ but light compensation point falls by $36 \mu mol \cdot m^{-2} \cdot s^{-1}$ while the light saturation point of B falls by $272 \mu mol \cdot m^{-2} \cdot s^{-1}$ and light compensation point rises by $32 \mu mol \cdot m^{-2} \cdot s^{-1}$. The two types of leaf blade exhibit completely contrary responses to CO_2 concentration elevation; the poplar leaves are more adapted to atmospheric CO_2 concentration elevation. This study shows that the willow leaves have a lower photosynthetic efficiency and so are likely mainly used to maintain normal growth． With the growth of the tree the willow leaves can no longer support normal growth and hence poplar leaves occur. Poplar leaves have higher resistance to atmospheric drought and higher photosynthetic efficiency. They can accumulate photosynthetic products to maintain the growth of P. euphratica in extremely adverse environments and reach a higher increment. This seems to be the real cause responsible for leaf shape changes of P. euphratica from seedlings to adult trees. With the increase in CO2 concentration the photosynthetic time of willow leaves shortens and light use efficiency decreases, but poplar leaves show the opposite tendency in these two respects. When the ground water level decreases and near-surface air becomes dry, or with climate warming due to increasing atmospheric CO_2 concentration，the number of willow leaves are predicted to decrease, even disappear .

5. Ecological effects of desertification control around oasis in arid regions of northwest China

Linze Station is located in the edge of desert oasis in Pinchuan town, Linze county in the middle of the Hexi corridor region. The northward of Linze oasis is connected with dense moving and denudation residual dunes as well as Gobi. This region has a typical temperate desert climate: dry and hot in summer, cold in winter, plenty of sunshine, very little precipitation, strong winds, and frequent drifting sands. The average annual rainfall is 117 mm. Soil erosion by wind is very serious owing to loose sandy soils together with frequent strong wind in the spring seasons. Desertification control and rehabilitation of desertified lands is one of the major issues being long-term attention and research since the establishment of Linze Station in 1975. In the initial stage of the station establishment, some effective techniques pertaining to establishment of sand-protecting system and desertified land reclamation were performed which included: to establish forest grids to protect farmland in the interior of the oasis; to built forest-shrub integrated sand breaks at the fringe of the oasis; to set up sand barriers in dune areas of periphery of the oasis and to plant dune stabilization shrub species within break; to built grass reservation belts outside the protection system by forbidding grazing and firewood gathering to facilitate natural vegetation recovery. A protect system combining breaks, stabilization with reservation from fringe to periphery of the oasis was formed and became the successful model suitable for combating desertification around oasis in arid regions. After applying these effective measurements, the rate of shifting sand area around the Linze Station have declined from 54.6% in pre-treatment to 9.4% and the oasis extended toward the northward of desert by 1000-1500m. Owing to the success of desertification control, the local government encouraged some farmers in the poverty area in the middle of Gansu province to immigrate the restoration area of desertified lands in the 19th of last century, making the oasis further expand towards the desert. However, loose soil structure and poor soil fertility together with improper land use such as single grain production resulted in a low use efficiency water resource and severe soil erosion by wind in the newly cultivated region of the oasis. Also, the fragile environment characterized by severe wind erosion jeopardizes the stability of oasis ecosystem. In 2000~2004, a project named “ecological rehabilitation and demonstration in the desert oasis in Pianchuan, Linze county, Gansu province” was carried out by the Linze Station cooperated with Linze bureau of water affair. Through the performance for four years, a protect system in the fringe of oasis with a area of 1.32 hm2 was established and improved, and the shifting sand area of 175hm^2 was stabilized by building straw barriers and clay soil barriers. The infertile croplands with an area of 10hm2 were converted to alfalfa grasslands in the marginal oasis. Grain-grass intercropping system was performed to enhance soil fertility and improve soil structure for sandy soils. Following the establishment of the project, a newly protect system, i.e., sand barriers composed of Haloxylon ammodendron at the periphery of the oasis, forest-shrub integrated protect forest grids at the fringe of the oasis, and alfalfa belts in the interior of the forest grids, was formed in the edge of oasis. The conversion of marginal croplands to alfalfa forage grasslands not only controlled effectively soil erosion by wind, but also promoted the development of grass and stock raising industry and the adjustment of agricultural structure, as well as mitigated the shortage of water resource for agriculture, ending in the improvement of ecological environment in the restoration area. The measurement for soil erosion by wind in the restoration area indicated that sand transportation rate in alfalfa fields is only 0.4% of that of the bare crop fields during sandstorm events in 2003. Soil organic carbon concentration in alfalfa soils following the converting crop to alfalfa for 5 years increased significantly compared to the adjacent crop soils, and the carbon sequestration rate in the 0-20cm surface layer was, on average, 0.47 Mg hm^{-2}yr^{-1}.

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20

Carbon Cycling and Processes in Tibet Plateau Ecosystems

Scientific research progress of Lhasa Qing-Zang(Tibet)Plateau Ecosystem Research Station

Introduction of Lhasa Qing-Zang(Tibet)Plateau Ecosystem Research Station

Physical conditions Location:Dagze county, Lhasa, Tibet (21 km east to Lhasa city), Latitude:29°0'40'N, Longitude: 91°0'37'E, Altitude:3688 m.

Vegetation: The vegetation in Lhasa station is categorized as alpine shrub-grassland dominated by Sophora moorcroftiana and Aristida triseta. Other species, such as Ceratostigma minus, Orinus thoroldi, Pennisetum flaccidum, Poe spp., Oxytropis sericopetala, Stellera chamaejasme and Korbresia spp., are also commonly found in the community. Aspen and willow dominate the forest plantation. Crops in farmland are cool-like ones such as wheat, Tibet barley, oilseed rape, pea, horsebean, potato and various vegetables. The vegetable varieties cultivated in greenhouse are fairly abundant.
Soil: The soil in the station is brown soil developed from inundated materials in the valley. The physic-chemical prosperities are: pH 7-8.5, 1.5~2.5 % of organic matters, 0.015% of total nitrogen, 8.5, 48.0 and 107.5 mg respectively of fast effective N, P, K in per 100g soil.

Objectives: (1) structure and function of main ecosystems and its response to environmental change (2) Optimal modes of sustainable agro-pastoral development Under the guidance of ecological principles, a series of key techniques for plantation, animal husbandry in agricultural area and agriculture-livestock combination will be research and demonstrate in the Lhasa River Valley.

Main Tasks: l long-term monitoring of climate, water, vegetation and atmosphere; l researching net primary production of vegetation, characteristics of biogeochemical cycling of carbon and nitrogen, sink/source relation, and their response to global change. l R and D of agriculture and livestock sustainable development; providing support base for Plateau ecology research and corporation;l training personnel for Plateau ecology research

1. Solar radiation and crop production on the Qinghai-Tibetan Plateau

Qinghai-Tibetan Plateau has high altitude and so the solar radiation is intense. Solar global radiation in growing season from April to October on the plateau is 20 % higher than that of eastern lowland plain. However, the ratio of photosynthetically active radiation (henceforth, PAR) is 10 % lower than the latter. 1 joule of energy is equivalent to 4.43μmol of photon. From heading to mature period, the average net radiation accounted for 75 % of the global radiation. The daily mean albedo ratio of PAR on the crop canopy ranged from 2% to 12%. From flowering to grouting period, the radiation permeation ratios were in minima, whereas the PAR radiation interception reached maxima, accounting for 80% to 95%. In later grouting period, radiation permeation gradually increase. There are 40 days of PAR interception over 90% during the growing season.

Tibetan Plateau is characterized by lower atmospheric pressure due to high elevation, with atmospheric CO_2 partial pressure 60% of sea level. In Lhasa Plateau Ecological Station with 654 mbar of atmospheric pressure at an elevation of 3688 m, at the air temperature of 25 °C, the average value of α was 0.0487 ± 0.0030. It is not quite different from the values in contrast with lowland areas. The values of α were 0.0435～0.0570 and 0.050～0.075 from temperature 20°C~30°C respectively on the plateau and eastern China lowland plain. α was control by temperature and the ratio of CO_2 and O_2 partial pressure ([CO2]/[O2]). α is expected to increase 16.8 %~26.2 % in the CO_2 double enrichment scenario on the plateau.

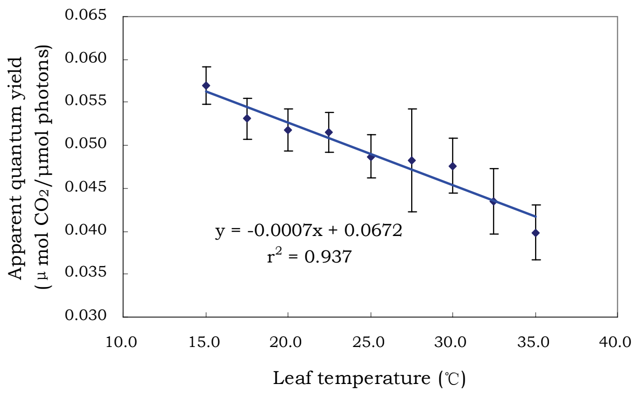

Fig. 20.1 Relationship between apparent quantum yield of photosynthesis of winter wheat and leaf temperature on the Tibetan Plateau

The winter wheat on the Tibetan plateau is characterized by unique features of vertical leaf distribution and low extinction coefficient, strong straw and long duration of growing season, which are more adaptable to environment of high elevation. The diurnal variation of net photosynthetic rate of winter wheat flag leaf is single-peak type, without obvious "midday depression" of photosynthesis, but with lower net photosynthetic rate than lowland area. The photosynthesis of winter wheat on Tibetan plateau has a high light saturation point and a low light compensation point. The initial light use efficiency is not significantly different from that of lowland winter wheat.

Winter wheat has maximal leaf area index in late May, in the period of late spiking and early flowering. Then leaf area index decreases sharply after flowering. The leaf area index is the function of active accumulative temperature. In comparison with lowland area, winter wheat in Tibet has lower filling rate, but twice longer filling period. The higher yield on the Tibetan plateau is a result from longer accumulation of mass. The seed has higher quality, with 55 g per 1000 seed. Light use efficiencies vary little from elongation to milking period, ranging from 1.6～1.8 %. The biomass accumulation is in logistic-curve shape in the growing season from regreening to mature. The winter wheat bears higher production due to long growing season although mass accumulation rate is not too high.

The climate on the plateau is cool and favorable to higher production of C3 crop. It is showed that: ①The cool climate extends growing season to two months longer than the winter wheat in North-China plain. Especially, one time longer period from flowering to mature, lasting 60～70 days in contrast 30～40 days in lowland plain, is significant for mass accumulation. This is one reason of high yield of winter wheat on the plateau. ②The daily air temperature is relatively low, especially in nighttime, but higher in daytime. The daytime with average temperature of 15～18℃ is in the optimal temperature of photosynthesis extent (15～25℃) and is very beneficial for mass production. ③The mass loss from respiration decreases due to lower air temperature on the plateau. In harvest period, the total mass loss due to respiration account for 40% of annual productivity, lower than the ratio of 42～45 % in lowland. According to modelling, the optimal yield of winter wheat in Lhasa is 25 t.hm-2, the optimal economic yield is 14.4 t.hm-2, approximately the yield of 960 kg.mu-1. This is much higher than that on the plain areas.

2. Soil respiration and carbon balance

The diurnal variations of soil respiration of cropland, alpine meadow and alpine steppe were in single-peak curve. The maximum and minimum effluxes occurred at 13:00~14:00 and 5:00~6:00 in local time. Daily variation is more apparent in summer. Seasonal variations of above-mentioned ecosystems also show single-peak curves, with minimum and maximum efflux during December to January and June to July. The minimum CO_2 effluxes of cropland, alpine meadow and alpine steppe were 704.64 mg CO_2 m-2 d-1 in January, 1369.56 mg CO_2 m-2 d-1 in October and 96 mg CO_2 m-2 d-1in January. The maximum effluxes were 13624.80 mg CO2 m-2 d-1 in June, 8781.70 mg CO_2 m-2 d-1 in July and 1440 mg CO_2 m-2 d-1 in June respectively. Soil CO_2 efflux was strongly dependent on soil temperature with highest correlation found with 5 cm depth temperature, maximum values of CO_2 efflux coincided with maximum values of leaf area index and live root biomass in mid June but not with maximum soil temperature in July. Soil respiration in grassland is also closely correlated with grass growth phenological rhythm. Precipitation modified the response of soil respiration to temperature. Soil respiration in cropland, alpine meadow and alpine steppe amounted to 20.8 t. hm-2 (whole year), 10.26 t.hm-2 (from May to October) and 1.87 t.hm-2 (whole year) respectively.

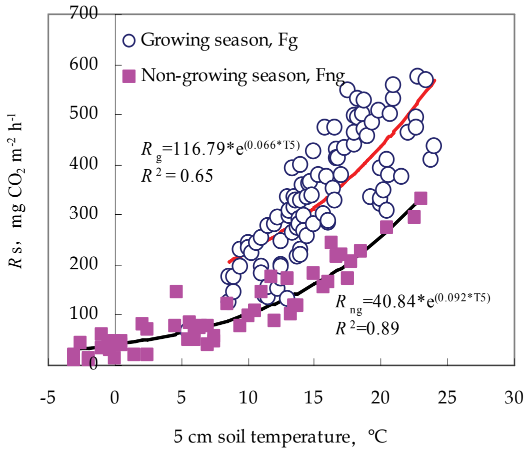

Fig. 20.2 Correlations of growing season and non-growing season soil respiration to soil temperature at 5 cm depth

Soil respiration was synchronized with seasonal change of temperature. Soil CO_2 efflux was influenced by soil and air temperature as an Arrhenius function. Soil temperature in 5 cm depth is the key controller of soil respiration, although the dependence of soil temperature varied in different ecosystems. Q10 is the indicator of temperature sensitivity of soil respiration. It ranged from 2~2.5 in cropland, meadow and steppe ecosystems.

Partitioning of soil respiration into root respiration and soil heterotrophic respiration is significant because they response differently to environmental change and it is also important to evaluate ecosystem carbon balance. In cropland ecosystem, crop root experiences growth in growing season and death in non-growing season. Root respiration ratio can be theoretically evaluated the discrepancy between soil respiration with root activity in growing season and without root activity in non-growing season. On the basis of this method, root respiration ratio in cropland possessed average 42% of total soil respiration in soil temperature ranging from 10℃ to 25℃. Root respiration ratio in alpine ecosystem was estimated by subtraction from no root soil heterotrophic respiration from soil total respiration. The ratios of root respiration in regreening, growing season and senescence were 48%, 69% and 48% respectively.

Carbon budget of ecosystem can be simulated by calculating NPP and soil heterotrophic respiration. Soil CO_2 loss from soil respiration overshadows carbon assimilation by vegetation in the period between crop harvest and elongation. After elongation, carbon gain exceeds soil CO_2 loss. Cropland ecosystem was a carbon sink with an amount of carbon of 7.2 t.hm-2. Buy using the same method, the carbon sink of alpine meadow and alpine steppe was 4.9 t C. hm-2 and 0.71 t C.hm-2 respectively.

3. Carbon flux observation by eddy covariance

Knowledge of seasonal variation of net ecosystem CO_2 exchange (NEE) and its biotic and abiotic controllers will further our understanding of carbon cycling process, mechanism and large-scale modelling. Eddy covariance technique was used to measure NEE, biotic and abiotic factors for nearly 3 years in the hinterland alpine steppe-Kobresia meadow grassland, the present highest fluxnet station in the world, on the Tibetan Plateau.

The above-ground biomass of the vegetation in Damxung started to accumulate on regreening stage, and reached maximum on early September. With the plant perishing, the increasing rate of biomass became slower and even began to drop. While for the below- ground biomass, there was a drop on regreening stage, and then began to increase with the maximum reached in the perishing period. Over 80% of the grass root distributed at the soil depth from 0 to 20 cm. The below-ground net primary production (NPP) was 415.6 $g.m^{-2}$, and the above-ground NPP was 150.9 $g.m^{-2}$. Hence, the annual NPP was 566.5$g.m^{-2}$.

During the growing season, PAR、temperature、precipitation and phonology were the key influencing factors of NEE. The daytime NEE fitted fairly well with the PAR in a rectangular hyperbolic function, with α declining in the order of exuberance period > early exuberance period > seed maturing period>withering period. The Pmax didn't change much during the first three periods. TER was exponentially correlated with surface soil temperature. Temperature was the key limiting factor for the NEE during the non-growing season.

The main objectives are to investigate dynamics of NEE and its components and to determine the major controlling factors. Maximum carbon assimilation took place in August and maximum carbon loss occurred in November. In June, rainfall amount due to monsoon climate played a great role in grass greening and consequently influenced interannual variation of ecosystem carbon gain. From July through September, monthly NEE presented net carbon assimilation. In other months, ecosystem exhibited carbon loss. In growing season, daytime NEE was mainly controlled by photosynthetically active radiation (PAR). In addition, leaf area index (LAI) interacted with PAR and together modulated NEE rates.

Ecosystem respiration was controlled mainly by soil temperature and simultaneously by soil moisture. Q10 was negatively correlated with soil temperature but positively correlated with soil moisture. Large daily range of air temperature is not necessary to enhance carbon gain. Standard respiration rate at referenced 10°C (R10) was positively correlated with soil moisture, soil temperature, LAI and aboveground biomass. Rainfall patterns in growing season markedly influenced soil moisture and therefore soil moisture controlled seasonal change of ecosystem respiration. Pulse rainfall in the beginning of and at the end of growing season induced great ecosystem respiration and consequently a great amount of carbon was lost.

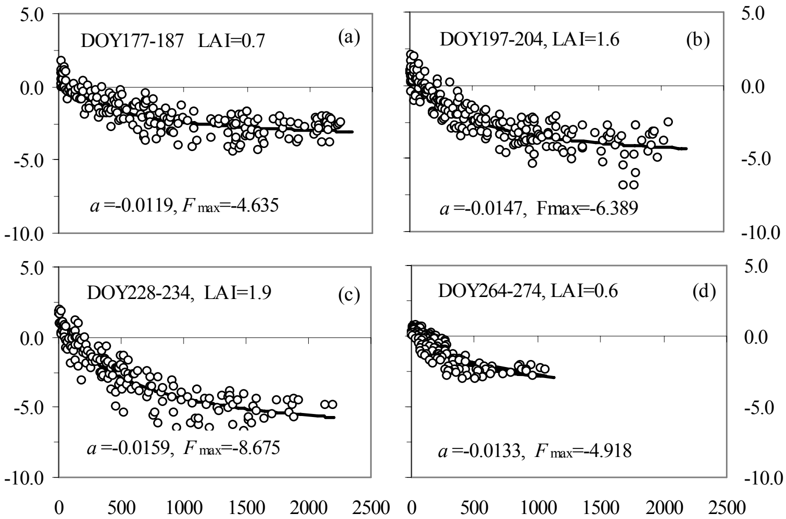

Fig. 20.3 Characteristics of ecosystem photosynthesis in different phonological stages and their relation to leaf area index

Short growing season and relative low temperature restrained alpine grass vegetation development. The results suggested that LAI be usually in a low level and carbon uptake be relatively low. Rainfall patterns in the growing season and pulse rainfall in the beginning and at end of growing season control ecosystem respiration and consequently influence carbon balance of ecosystem. The alpine grassland of Damxung is a small carbon source. This ecosystem can be changed into a small carbon sink in the future scenarios of global warming, CO2 enrichment and increase of precipitation. Precipitation distribution in the season will greatly change the sink-source relation.

4. Treeline formation mechanism research advances in eastern Himalayas

The highest alpine treeline among the world bears the unique answer to test and explain its ecophysiological cause. The altitudinal reduction of temperature may either impede photosynthetic activity to an extent, at which tree growth declines due to a lack of photo-assimilate replenishment; or alternatively, inhibit tree growth through a direct limitation of cell growth processes at otherwise sufficient C-supply i.e. growth limitation. Deciduous taxa at treelines is prune to negative carbon balance due to short growing season with leaves and low CO_2 partial pressure in addition to low temperature due to high elevation. Lhasa Ecological Research Station implemted a long-term monitoring of tree growth and carbon economy on the east Tibetan plateau in order to disclose the mechanism of treeline formation.

The size of the mobile carbon pool of trees along altitudinal gradients across treeline ecotones may thus answer the question of whether carbon is a limiting factor for tree growth at alpine treelines. In case of an altitudinal increase of carbon limitation, the trees' mobile carbon pool can be expected to become depleted as the treeline is approached. In contrast, a direct temperature induced growth limitation of trees may induce an increase of the mobile carbon pool with increasing altitude, because of a reduced carbon demand for tree growth at otherwise sufficient supply by photoassimilates.

According to treeline temperature and NSC measurement in 2 functional groups and 9 treeline species, the growing season mean soil temperature under treeline conditions on the Tibetan Plateau ranges from 6.6 to 7.8 °C, which is consistent with the threshold temperature 6.7 ± 0.8 °C found at treelines world-wide. Trees showed no depletion in NSC (carbon limitation) at treeline at all four investigated sites, but NSC rather increased in most cases, suggesting a direct growth limitation. The results for the eastern Himalaya treelines are thus in accordance with previous studies from other mountain ranges.

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21

Ecological Processes and Sustainable Management of Forest Ecosystems in Changbai Mountain

Scientific research progress of Changbai Mountain Forest Ecosystems Research Station

Introduction of Changbai Mountain Forest Ecosystem Research Station

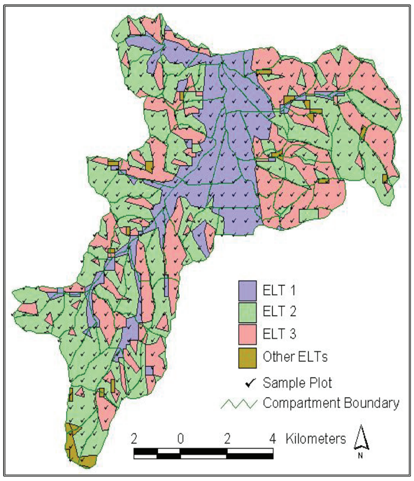
National Research Station of Changbai Mountain Forest Ecosystems is situated in the northern slope of Changbai Mountain, within the National Reserve and Erdaobaihe Town, Antu County, Jilin Province, with 42°24' N latitude, 128°28'E longitude, and 736m altitude. The annual mean air temperature is 3.6 ℃ and annual precipitation is 695 mm. The researches of the station cover the original and disturbed ecosystems along the northern slope of Changbai Mountain. There are 4 vegetation zones arranged from lower to higher elevations. The broadleaf-Korean pine mixed forest is below 1,100m. The coniferous forest distributed between 1,100m and 1,700m parallels to the boreal forests on a horizontal means; the Erman's birch forest extended from 1,700m to 2,000m is an unique dwarf forest in the higher mountain; the alpine tundra is above 2,000m. The original forest ecosystems in Changbai Mountain are typical natural representatives of N. E. Eurasia.

Research directions: Regarding the global hot issues in population, environment, and resources, the major research objectives in the station are to reveal the law of structure, function, and dynamics of the forest ecosystems, to express the response of forest ecosystems to human activities and environment changes, and to find the effective ways of sound management and sustained development of the forest resources.

Current research projects: The aim of the research is the global change and sustained development of forest ecosystems. There are 3 major fields of researches: (1) Carbon cycle process, including carbon cycle of forest ecosystems, influences of enrichment of CO_2 on water transferring of root-soil interface of typical tree species, eddy covariance measurements of CO_2 flux between the forest ecosystem and atmosphere, chamber measurements of soil CO_2 flux and so on; (2) Water cycle process, including modeling of evapotranspiration, mechanism of forest hydrology process and regulation of water resource in watershed. (3) Management and sustained development of forest ecosystems, including forest resource management in northeast of China, healthiness and benefit assessments of forest ecosystem, dynamics and sustained management of typical forest ecosystem.

1. Operation and management system of the Korean pine-mixed broadleaf forest ecosystem

As early as 1980， Prof. Wang zhan put forward the thought on sustainable management of forests that “selective planting and cutting” and “planting conifers and preserving the broadleaf”，to solve the problem of cutting mode and the secondary forest restoration of broad-leaved Korean pine forest cutover land in Northeast of China. In 1983, through investigating, Prof. Xu Zhenbang et al found the about 60 years development interval of forest gap agrees with the renewal for generations, and thought that the disturb is the impulsion of regeneration of broad-leaved Korean pine forest, especially the gap renewal of Korean pines. In 1980, Cui Qiwu et al, from the homeostasis viewpoint of the ideal cutting interval and mode of forests’ growth quantity in successive years, brought forward the math model of continuous exploitation of forests, and in 1985, from the nutrition dynamics theory, educed a new basic equation of the population growth (The Cui law). Dr. Shao Guofan (2002), by the matrix model, forecasted each diameter dynamics of the different aged broad-leaved Korean pine forest under different cutting strategy, and developed the software of “the aptitude 3S system of the forest management”（FORESTAR），which is proved by the application of the software to the Baihe Forest Bureau (Fig. 21.1). Dr. Liu Guoliang (2003), by FSOS, marked elementarily programming of the sustainability of forest of the Baihe Forest Bureau. These theories noted above are the scientific basis of the ecological management of the forest ecosystem.



Left: ecological land types (ELT) in Baihe forestry Bureau;

Right: topic map of forest management decision

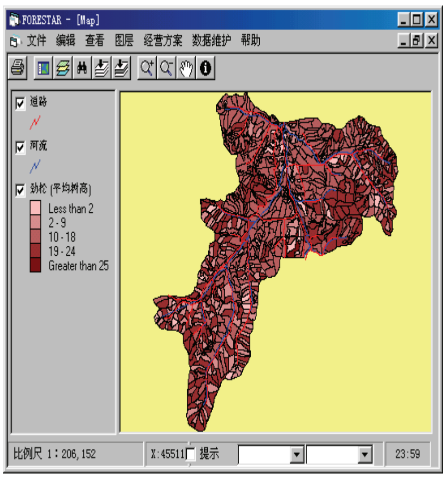


Fig. 21.1 The decision support system for multi-objective forest management

2. Mechanism of forest eco-hydrological processes and model construction

Long-term field observation and laboratory simulation were conducted to analyze the interaction between eco-hydrological processes and the broad-leaved Korean pine forest. The primary progress is as follows.

（1）The mechanism of eco-hydrological process: A semi-theoretical model of canopy rainfall interception model was established, which calculated the distribution of rainfall process in forest canopy for any period of time, and discussed the mechanism of the rainfall redistribution process in forest vegetation canopy (Fig. 21.2). The logarithmic sub-models that saturated conductivity and effective porosity vary with depth was put forward, depended on which the modified storage—discharge mode1,compared with the famous Sloan's and Robinson's, was 15% more accurate when simulating in subsurface flow and 20-32% in total runoff (Fig. 21.3). Through rainfall-runoff simulation experiments conducted on a manmade hillside, the relationship between the average water depth on the hillslope and that at the outlet, which is nearly a quadratic curve, is obtained. The relationship is different from the assumption, in which the average water depth on the hillslope is equal to that at the outlet; thereby the classical hillside rainfall-runoff Horton model which had been used for many years was modified, so that both the theoretical and experimental basis was provided for hillside rainfall-runoff process. Understanding of the mechanisms of these processes, such as rainfall distribution, subsurface flow, evaporation and hillside rainfall-runoff, and model construction put forward new theoretical basis and sub-models for watershed eco-hydrological model construction and amelioration.

(2) Construction of forested watershed rainfall-runoff models: The conceptual forested watershed storm-runoff model was established, which calculated the relationships in different forest quantities and qualities between watershed rainfall-runoff ,analyzed and appraised the effect of ecological damage in jamming on forested watershed flood disaster, put forward the control countermeasures to forested watershed flood disaster and ecological engineering flood control and disaster mitigation system. Distributed rainfall-runoff model was constructed in the middle watershed, and the model structure was applied separately on the large and small watershed to simulate rainfall-runoff response processes, which showed good fittings with observed series, with the coefficient of efficiency above 0.65 and the peak discharges and peak times close to measured ones. By elucidated the effect on hydrological process of forest vegetation changes and constructed distributed hydrological model, exact simulation of watershed hydrological process was implemented.

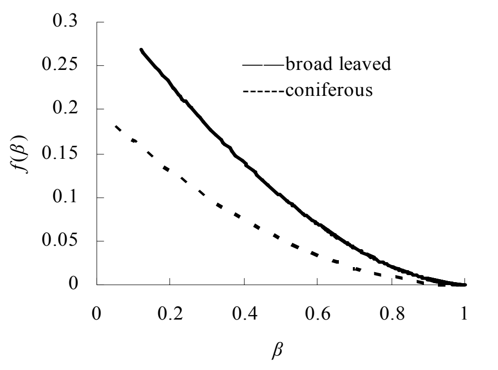


Fig. 21.2 Interception index *f(β)* for broad-leaved and coniferous trees

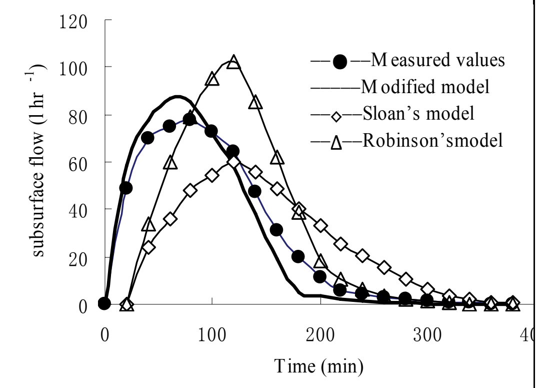


Fig. 21.3 Comparison of the results of the modified model with those of two other models

3 Korean pine-mixed broadleaf forest in Changbai Mountain as a carbon sink of atmosphere

The average age of natural Korean pine-mixed broadleaf forest in Changbai Mountain is about 200 years，however, there was no scientific study on principles of its carbon process and its role played in global carbon cycle before 2002. The results of eddy-covariance measurements for carbon flux showed that net ecosystem exchange (NEE) in this forest ecosystem ranged from 317 to 171 g m-2year-1, which was higher than that in boreal forest (68 C g m-2year-1; Gower et al. 1997) ，but lower than that in North American temperate forest (585 C g m-2year-1; Turner et al. 1995; Malhi et al. 1999). NEE calculated through biometry method was 366.8±110.6 C g m-2year-1, 16% higher than the maximum value calculated using eddy-covariance techniques (Fig. 21.4).

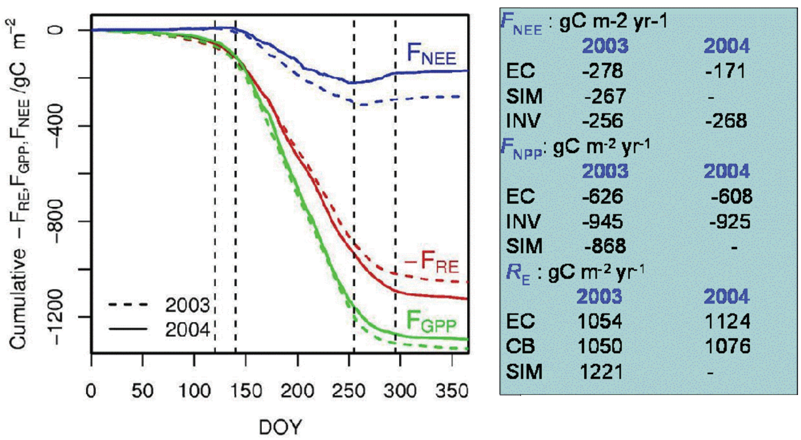


Fig. 21.4 Cumulative carbon exchange of the broad-leaved Korean pine forest (EC: eddy covariance; INV: inventory; SIM: SimCycle model)

Those studies above proved the carbon sink capacity of the natural Korean pine-mixed broadleaf forest in Changbai Mountain, and also provided scientific foundation for evaluating scientifically the carbon exchange of the forest succession from secondary temperate forest to the zonal climax forest of our country.

4. Spatial pattern of broad-leaved Korean pine mixed forest

CBS plot, a 25 ha (500 × 500 m^2) Broad-leaved Korean pine (Pinus koraiensis) mixed forest plot that abided by performance criteria of 50 ha permanent plot in tropical forest in Barro Colorado island of Panama, was established in the summer of 2004 in Changbai Mountain Natural Reserve, Northern China. CBS plot was chose in the core zone of the Reserve, and the composition and proportion of main tree species were considered when the plot was established. Our survey was based on these 5× 5 m2 quadrates. All free-standing trees at least one centimeter in diameter at breast height (DBH) were mapped and identified to species, and their geographic coordinates were recorded following a standard field protocol (Fig. 21.5).

The total number of living individuals in the first census of 2004 was 38,902, consisting of 52 species, 32 genus, 18 families. Mean stand density was 1556 living trees ha^{-1}. Mean basal area was 43.2 m^2 ha^{-1}. Three species comprise 60% of all individuals, fourteen species comprise 95% of all individuals, while other 38 species only comprise fewer than 5% of all individuals. The clumping index analyses of different growth stages showed that intra-species competition increased with plant growing. Spatial pattern analyses of 46 species with at least 4 individuals suggested that 43 species were aggregated distribution, 3 species were random distribution, and no species showed regular distribution. The analyses combined with elevation and slope suggested that no significant topography dependence was found in the plot (Fig. 21.6).

Meanwhile, spatial patterns of four dominant tree species (*P. koraiensis, Tilia amurensis, Quercus mongolica, Fraxinus mandshurica*) were analyzed at different vertical layers and spatial associations of these species among different layers in order to get insights on the processes driving regeneration and succession of the forest. We found that: (1) *P. koraiensis* is a discontinuous regeneration population, *T. amurensis* and *Q. mongolica* are continuously regenerating populations, and *F. mandshurica* may be a declining population. (2) Generally, higher layers tended to random or regular distribution at almost all scales, lower layers tended to aggregated distribution at smaller scales, and the aggregation degree decreases with canopy height. (3) Spatial associations of intra- and interspecies varied with species, layers and scales: positive association or spatial dependence of *P. koraiensis* and *T. amurensis* to most species at upper layer at almost all scales indicated that they have broad niche and grow well under the canopy of other species, *Q. mongolica* showed spatial independence at smaller scales and negative association at larger scales to non-conspecific adults, suggesting that spatial heterogeneity may be important, and *F. mandshurica* was negatively associated with non-conspecific adults, suggesting that its shade-intolerant character. (4) scale is an important factor for pattern generation, and spatial patterns of different species changed differently with scaling up.

CBS plot provides a better template to link patterns with processes at different scales. Clearly, future studies should examine these environmental factors which generated the patterns with sound experiment designs and long-term monitoring data, and compare our results with other large scale stem-mapping plots of different geographical zones.

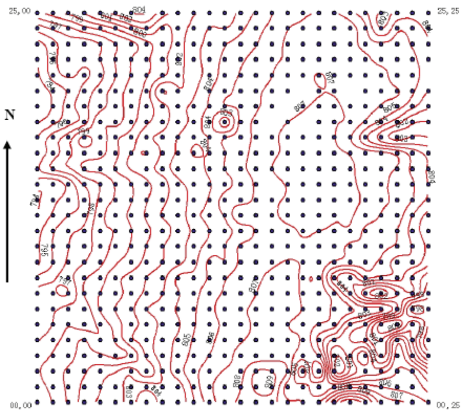


Fig. 21.5 The topography map of the study plot in Changbai Mountain, China

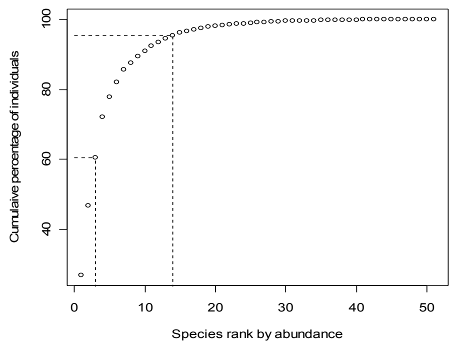


Fig. 21.6 Cumulative distribution curve of species abundance

5. Demonstration on pinus koraiensis breeding intensification

Pinus koraiensis seed orchard in Dew River Forestry Administration which established in 1984 has the sources of gene breeds of *Pinus koraiensis* in Northeast Asia, North Asia and Central Asia. Currently, there is a 182.3 hectares' seed orchard, including production region, collection region, descendant determination region, experimentation forest region and shelter-forest region. 1012 superior trees are selected in the seed orchard and the clone orchard is being at the phase of producing fruit. Through years of construction, the seed orchard has been developed into an integrated base of seed multiplication encompassing gene collection, scientific research, demonstration and generalization, with special emphasis on well-born seed production. In recent years, this orchard has cooperated with our station to do biological study at the molecule scale, including identification of 150 well-born clones and selection of 56 excellent series. These works provides scientific basis for the establishment of highly generational seed orchard, the maintenance of superior sources and the construction of well-born base.

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22

Dynamic Mechanism, its Structure and Functions of Major Forest Ecosystem in Warm Temperate Zone, China

Scientific research progress of Beijing Forest Ecological Station

Introduction of Beijing Forest Ecological Station

Beijing, as China's political and cultural center, is more urgent than other regions to need integrate structure and sound function of natural ecosystems. Therefore, it is important to restore and preserve the natural ecosystems around Beijing areas. The mountainous areas in northern and western of Beijing are *crucial* parts to keep stable regional ecosystems around Beijing, due to relatively original natural conditions, low population density, and water conservation, climate regulation and species conservation functions of these ecosystems.

Beijing Forest Ecosystem Research Station (BFERS) is the unique forest ecology research station established in Beijing area *by* Chinese Academy of Sciences (CAS), its establishment indicated that research on ecosystems around Beijing has been paid great attention from the people, government and scientists, and push forward ecology development in warm temperate zone, China by extensive-intensive combined study.

The Station was founded in 1990, located in Xiao Long Men National Forest Garden (39°58'N，115°26'E), Men Tougou District, is 114 kilometers away from downtown Beijing. Dong Ling Mountain (altitude 2303 m a.s.l.), the highest peak in Beijing area, and Baihua (hundred flowers) Mountain (altitude 2050 m a.s.l.), a mountain of the greatest richness of plant diversity, both within the research area of this station, where the major soil type is mountain brown soil, climate type is warm temperate sub-humid monsoon climate, annual mean temperature is 4～6℃, annual precipitation is around 650 mm, 70% precipitation occurs from June to August.

The zonal vegetation is deciduous broad-leaved forests in warm temperate zone, representative vegetation of deciduous broad-*leaved* forests in east-China. The station locates in the central area of warm temperate zone of China. The research area of the station is 16600 hm^2, where altitude range is 400~2303 m, including plenty of landscape, ecosystem types, and plant and animal species (886 plant, 43 mammal, 50 birds, over 1000 insect species).

The dominant ecosystems are deciduous broad-leaved forest in warm temperate zone, artificial needle-leaved forest, secondary bush and sub-alpine meadow. These ecosystems have been seen as research objects of this station since its establishment for nearly 20 years. And the following four aspects have been studied *intensively*. 1. The structure and function features of dominant forest ecosystems in warm temperate zone; 2. Approaches and methods of ecosystem diversity conservation and sustainable utilization; 3. Natural succession principle, restoring technology of degraded ecosystem, and artificial optimization ecosystem reconstruction; 4. The influence of global change on the structure, function, and dynamic processes of different ecosystems in warm temperate zone. The aims of the station are to become a national basis with international influence and significant contribution to long-term forest ecosystem research in warm temperate zone of China through long-term ecology research, monitoring, demonstration and person training and teaching.

Achievements & Development

In terms of scientific research, BFERS, based on warm temperate zone, has been conducting long-term comprehensive research in various hierarchies and subjects. Meanwhile, it has obtained many significant results in *different* aspects of forest ecosystem research, including the structure and function research of dominant forest ecosystems in warm temperate zone; the ways of ecosystem diversity conservation and sustainable utilization; the natural succession mechanisms and restoring approaches of degraded ecosystem and artificial optimization ecosystem reconstruction; and the effects of global change on the structure and function and dynamic processes of different ecosystems in warm temperate zone of China.

1. Systematically clarifying the structure and function rules of dominate forest ecosystems in warm temperate zone

Based on multi-year field survey and long-term permanent plot monitoring, long-term research on basically ecological processes of dominate forest types in warm temperate zone has been conducted (Fig. 22.1), and then the function and characteristics of ecosystems has been analyzed and summarized according to the results of observation and research.(Chen, 1997).

The structure of deciduous broad-leaved forests in warm temperate zone, Liaodong oak (*Quercus liaotungensis*) forest, birch forest, pine plantation, and larch (*Larix principis* rupprechtii) forest, have been elaborated; and also the influence of different management methods on forest *regeneration* and species composition of different forest types has been studied.

The features of energy flow, efficiency of solar radiate utilization and internal mechanism of representative deciduous *broad*-leaved forests and Chinese pine (*pinus tabulaeformis*) forest have been explained through measuring absorption of solar radiation, allocation of the different levels utilization of solar energy in photosynthesis process in different levels of the forest ecosystems.

The biogeochemical circling characteristics of dominate forest types have been analyzed and studied, which included *traits* of nutrient element, amounts of element accumulation, amounts of element remainder, amounts of element return and amounts of element storage in soil; nutrient circle rules of representative deciduous broad-leaved forest, Liaodong oak forest, birch forest, and the nutrient factors which have limited forest growth in warm temperate zone have also been found and described.

The water use efficiency and the water and soil conserving and holding function of ecosystems, and the differences between ecosystems have also been learned through the forest hydrology research (including canopy flow, throughfall, stem flow, surface runoff, water holding capacity of litter, soil moisture) of different ecosystem types.

The research results summarized the structure and function of forest ecosystems as a whole in warm temperate zone, and it is also further applicable in Beijing area and east-China, especially it is significant for *degraded* forest restoration and reconstruction in warm temperate zone.

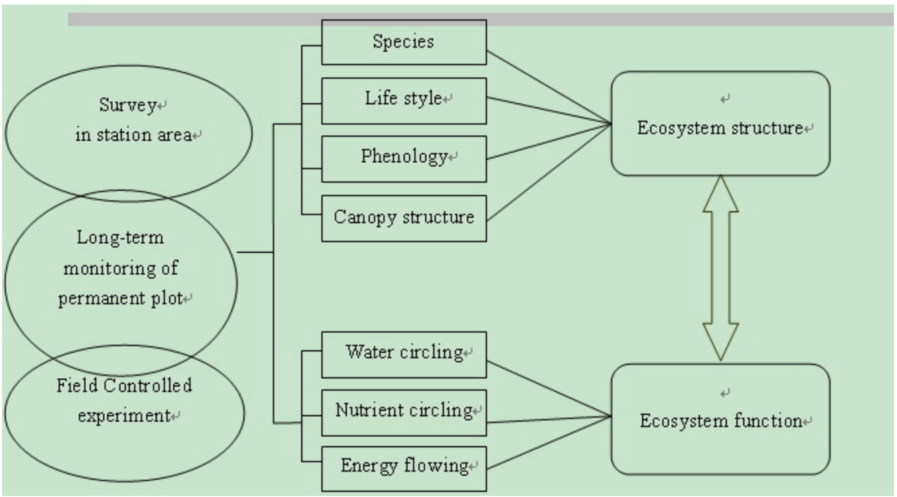

Fig. 22.1 the technical pathway of long-term dynamic research of forest ecosystems in warm temperate zone

2. Modeling effects of global climate change on deciduous broad-leaved forest ecosystems in warm temperate zone

Based on insights of the structure and function, energy flowing and material circling features of deciduous broad-leaved *forests* in warm temperate zone, modeling and controlled experiments have been developed under the global change background. Following results have been obtained:

The amount of carbon storage of the deciduous broad-leaved forests in warm temperate zone has been estimated. *Numerical* value pattern of the amount of carbon storage of the representative deciduous broad-leaved forest ecosystems in warm temperate zone (Fig. 22.2) has been built, based on analyzing and studying the data and published relative results of biomass, productivity and biogeochemistry accumulated by Beijing Forest Ecosystem Research Station during its more-than- 10-year research on the structure and function of forest ecosystems in warm temperate zone. The amount of carbon storage in soil, accounting for 58% of the total amount of carbon *storage*, is the main carbon sink of the forest ecosystems in this area. Furthermore, changes of the amount of carbon storage in soil of the forest ecosystems will certainly result in changes of the amount of carbon storage in the whole area.

For the first time, process-based BIOME-BGC model was applied to model the potential response of net primary production (NPP) of the Liaodong oak ecosystem in the area of Dong Ling Mountain in Beijing to global climate change. After modeling the response of NPP of Liaodong oak ecosystem to 7 different climate changes by BIOME-BGC, the results showed that: 1. NPP was not sensitive to the change of temperature but more sensitive to the change of precipitation and CO_2 concentration; 2. the influence of temperature, precipitation and CO_2 on NPP did not reveal the interaction among them (Su and Sang, 2004).

Through studying the long-term dynamic rules of deciduous broad-leaved forests in warm temperate zone, it was discovered that the dynamic process of Liaodong oak population showed fluctuated pattern; the *period* of fluctuated cycle was 110 years; the dynamic process of leaf area index was relative to the competition condition of woods; the productivity changed in no distinct order, and appeared a climax in 30 years, which was comparable in result to other studies. All these discoveries laid the groundwork for choosing important factors, which affected the function of forest ecosystems, among accumulated temperature, water, soil, and the physical and ecological traits of organisms themselves, for building a model of mechanism which can simulate the dynamic process of current vegetations under global climate change by combining process-based biogeochemistry model and forest gap model (Sang, 2004).

At last, the policies and measures of restoring secondary forest ecosystem in warm temperate zone were put *forward*, based on the results of above mentioned monitoring, simulation and controlled experiment, so as to provide guidelines for ecological and environmental conservation in regional scale, and to supply long-term and systematically scientific data for resources sustainable utilization and decision-making foundation.

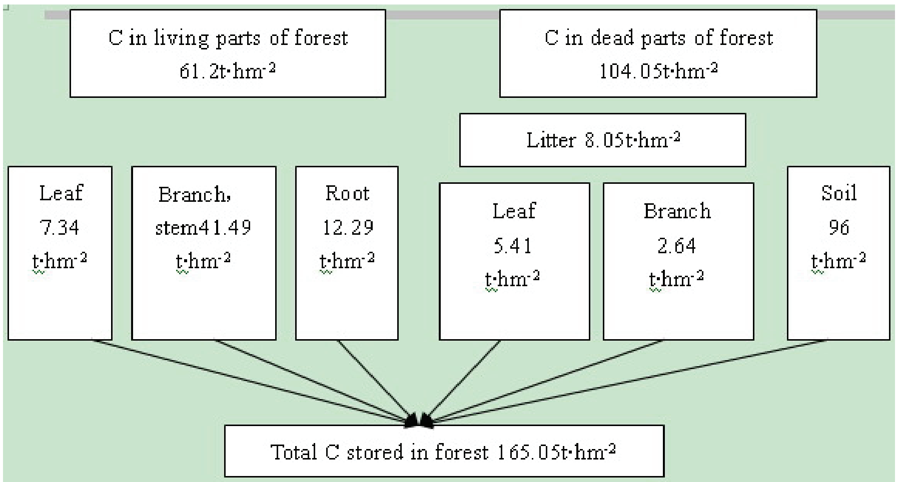

Fig. 22.2 Numerical value pattern of the amount of carbon storage of the representative deciduous broad-leaved forest ecosystems in warm temperate zone

3. Revealing the natural regeneration mechanism of Liaodong oak (Quercus liaotungensis) seedlings

Lack of seedlings is a widely *existing* problem for Liaodong oak regeneration. Therefore, Liaodong oak regeneration is one of the hotspots among the international ecological academes. But the research subjects are always be limited within the relationship between oak seeds and the vegetarians. BFERS has systemically studied the whole regeneration process of Liaodong oak seeds that includes the seminal rain, trait of shooting roots, living through the winter and germinations. We set about our study with the influence on early survive and growth of Liaodong oak seedlings by missing cotyledons, the influence on the growth and resistant traits of seedlings by the forming and development of the root system before germination, the relationships between the movement of the small carnivores in the forest and the regeneration of Liaodong oak forests on the spot, the investment countermeasure of Liaodong oaks growing, the structure of Liaodong oak population and so on. We also discover the germination trait and ecological significance of Liaodong oak seeds by the experiment that planting them in different conditions. Especially, it is a strategy against missing cotyledon that Liaodong oaks shoot roots quickly. While, the growth trait during the early periods of Liaodong oak seedlings' growing is a waiting strategy. The movement of small carnivore in the forest can mostly promote Liaodong oaks to regenarat on the spot. These conclusions have not been reported among the international ecological research on oaks, and they also have widened the content of research of this field. To some extent, the results have clarified the regenerating mechanism of Liaodong oaks further, and the conclusions can provide some theoretical according and practical guides to the management of the Liaodong oaks and/or other hardwood oaks (Gao and Sun, 2005).

4. Revealing C-N cycling mechanism of deciduous broad-leaved forests in the warm temperate zone

(1) Systematical understanding on the main process of C cycling of the deciduous broad-leaved forests in the warm temperate zone

All these have been studied: the status, process and character of the biomass and productivity of the deciduous broad-leaved forests in the warm temperate zone, the dominating section of the C cycling process: photosynthesis assimilate and absorb C, distribution and translation of C in the live fronds, content of C and its translation rules in the forest wither and the soil, C respiration in organism and soil, and so on. Using dates in the aspect of biomass, productivity and bio-geochemistry which we have *researched* on for 10 years and results which have been published, we collect and analyze the data, and integrate systematically them, and then, compute and establish the numerical value model of C biomass cycling.
(2) Researches on the main process of N flowing in the forest ecosystem

We have mainly analyzed characters of N content in leaves, branches and roots from different plants, and researched characters and differences of net mineralization and nitration N in soil of different forest community type. And we also use δ15N nature abundance method to research the nitrogen fixation ability of the main nitrogen fixation plants in Dongling mountain area. Using data of nutrition elementary content in water and N content of penetrate rain and eluviations, and combining with precipitation observation in meteorology for past years, we have got annual N balance *process* mode for forest research. Using data of biomass, productivity and annual wither quantity of the forest, and combining data of physical and chemical character of soil, we can get the storage of N in the forest ecosystem and establish the N-cycle scalar mode.

5. Revealing community diversity characteristics in warm temperate zone and their demonstration on protection

On the basis of the research data, we have analyzed and compared the biodiversity of the deciduous broad-leaved forests from central section to southwest in warm temperate zone. And its results show that: 1) in the normal condition, the species abundance (Sp) and the diversity index (D and H') of arbor, *shrub* and grass mainly showed arbor > shrub >grass; but the eveness index (Ea) of the shrub is usually high; 2) the diversity index (D and H') of each layers in the forest community which are in the sub-peak phases; 3) the Ea of each layers in the community all are above 0.5 when the community be in the peak to sub-peak phases; 4) when the overall importance value of the community can be used as the measure index to measure the community's overall species diversity index and Ea, the overall Simpson diversity index (D) in the community can be used to judge the stability of the community. To explain further, when D is under 0.5 or approach 0.5, the stability of the community is slightly low, or the community belongs to the type that survived in the special habitat; when D is higher than 0.5, there are two complexions: *the* community whose Ea is bigger than D belongs to terrain community type and it has quite high stability that can be regarded as peak community; while, the community whose Ea is lower than or approach D has higher biodiversity and is in the prophase of peak that can be regarded as sub-peak community in the aspect of the community succession dynamics.

On the basis of the research data that observed in 1965, 1983, 1994 and 2000, we compared the biodiversity variety and the living forms table of the species in sub-alp meadow of Dongling Mountain. The results show that the species biodiversity has assumed downtrend in the sub-alp meadow of Dongling Mountain in these years, especially among 1983~1994, the descend speed accelerated *obviously*. Using the important value as parameter to compare the live type table in the sub-alp meadow of Dongling Mountain of different periods, we get the results that from 1980's the mushroom of separated herd of horses which comes along with the development of tourism has created serious effect to the appearance of sub-alp meadow community: diminution of community height, change of specie composition, decline of vegetation cover degree and so on. All these show that excessive browse is an important effective factor that leads to degradedness of sub-alp meadow in Dongling Mountain. According to the questions existed in sub-alp meadow of Dongling Mountain tourism spot, we suggest that the governmental department involved should assess the tourism capacity of Dongling Mountain tourism spot scientifically. First and foremost, separated herd of horses should be limited extremely, and hippodromes and browse tend that are in the tourism spot should be closed. At the same time, the department should strengthen the public communication, management and infrastructure in the tourism spot. In this way, the service function of ecosystem can function sufficiently, and the sustainable utilization of resource can be realized in the precondition of protecting natural environment (Gao etc., 2002).

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23

Ecological Processes, Mechanism for the Degradation and Ecological Management of Chinese Fir Plantation over the Past Two Decades

Scientific research progress of CERN Huitong Research Station of Forest Ecosystem

Introduction of Huitong Research Station of Forest Ecosystem

Huitong Experimental Station of Forest Ecology, Chinese Academy of Sciences is located at Guangping, *Huitong* County, the southwestern part of Hunan province, N26°48′、E109°30′. This belongs to the up reach of Yuan River, a tributary of the Yantgtze.region, and marks transition from Yungui plateau to the hills along the southern bank of Yangtze River. The altitude ranges from 300 m to 1100 m above the sea level. The mother rock mainly consists of grayish green slate, metamorphic rock and sandy shale, the soils are Oxisols. This region has a typical climate of Central Subtropical Zone, with average annual temperature of 16.5℃. The annual rainfall and annual evaporation range from 1200 to 1400 mmm and from 1100 to 1300 mm, respectively, with average relative humidity of 83% and 300 days of frost –free period. The zonal vegetation is evergreen broad-leaved forest typical of subtropics, with the major species component of Castanopsis spp. And Cyclobalanopsis.

This Experimental Station was founded in 1960, selected as a member of Chinese Ecosystem Research Network (CERN) in 1989. In 2005, the station was approved by the academic committee *authorized* by the Ministry of Science and Technology of China to be a National Research Station of Forest Ecosystem. In the past two decades, Huitong Experimental Station of Forest Ecology, Chinese Academy of Sciences focused on the located research on Chinese fir plantation ecology. Scientists in this station have shown the basic law of changes in of the productivity of Chinese fir plantation on different space-time scales, and discovered nutrition mechanisms principally responsible for the decline in the site quality of the stand, and made an important progress in understanding the toxicity mechanisms. They also discovered the mechanisms for the inter-species interaction through mixed litter decomposition and fine root turnover. Research has also made a significant inroads in understands the characters of soil microorganism and flora in Chinese fir plantation stand and different structure of mixed stand of Chinese fir with broadleaf. Based on our research, we proposed the first connotation and technological system of the management for plantation ecology and provide the *important* theoretic support for sustainable management of plantation forest in subtropics.

1. Productivity dynamics at Different Space-time Scales

Cunninghamia lanceolata (Lamb.) Hook is a timber tree species distributed specifically in subtropical China, from southern bank of Huaihe river south to Leizhou peninsula, west to southeastern river vally of Qinghai-Tibeta Plateau, east to coastal Jiangsu, Zhejiang and Fujian. It covers 16 provinces, extending 800 km from north to south, 1000 km from west to east. On larger scale of its overall distribution, the growth of C. lanceolata plantation mainly relates to the climatic factors, such as solar radiation and rainfall. The productivity of the plantation stand with the same age changes in the order of the central zone > the southern zone > the northern zone. The pattern of biomass distribution differ significantly from zone to zone, with the biggest rate, about 60% of biomass allocated to bole in the central zone, the second in southern zone, the smallest in the northern zone, just 54.4% of biomass allocated to the bole. It can be inferred that the central zone is the major commercial timber production base in China based on the C. lanceolata plantation management for its largest bole biomass allocation.

In the same zone, the climatic factors are basically homogeneous. So the productivity of Chinese fir plantation is mainly related to site quality. For example, the standing biomass and net production changes in the order of foothill > hillside> ridge, and the difference is significant. In addition, the pattern of biomass allocation among different organs was also affected by the site quality, with the biggest rate of biomass allocated to stem on site with high quality. This suggest that the site with high quality be used to to cultivate C. lanceolata for the purpose fo timber production.

The changes in productivity of C.lanceolata plantation follow different rules on different time-scale. The processes of biomass accumulation and allocation differ at stand age and development stages. When we look at different stand age throughout the whole generation, we found that stand grows slowly at 3 years old (yough stage), with 3.46 t/hm2 of standing biomass, very fast from 6 to 13 years old (fast-growing stage) with standing biomass ranging from 34.0 to 97.0 t/hm2, and that the stand increment peaks at 18 through 26 years old (stem exclustion stage) with standing biomass ranging from 130 to 230 t/hm2, and that stand come into mature stage at 35 years old with standing biomass 284.0 t/hm2, aging stage at 56 years old with standing biomass 352.0 t/hm2. No matter what the stand age is, the tree layer biomass accounted for 93%-98% of total biomass, undergrowth vegetation only 0.1%-3.9%.

The accumulation and allocation of net production of Chinese fir plantation also vary with the stand age, and the net production increases from young stage and peaks at 15.93 t hm-2a-1 at the age of 26, the end of stem exclusion stage, and declines subsequently to 11.00 t $hm^{-2}a^{-1}$ at the age of 56, aging stage.

Based on the past survey and recent located observation and experiment research, we discoverd the mechanisms for the soil degradation and productivity decline after continuous planting of Chinese fir plantation and how to plant mixed Chinese fir plantation to reduce the soil degradation (Chen et al, 2000). These results provide an important theory for sustainable management of plantation forest in subtropics.

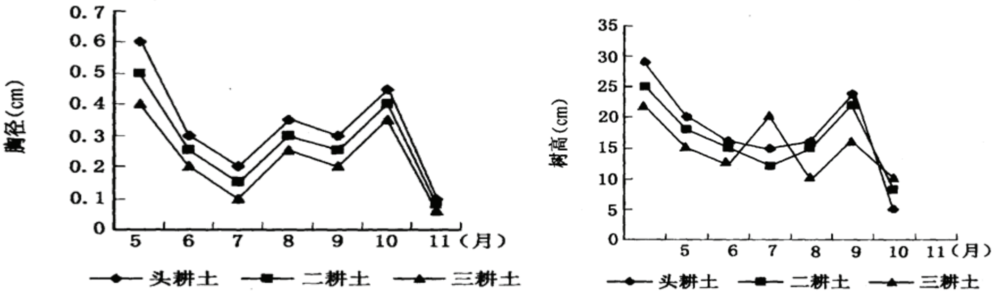

Fig. 23.1 Differences in DBH and tree height among different rotation of C lanceolata plantation

2. Chinese fir litter decomposition and nutrient cycling

(1) Dynamics of litterfall

Litter reflects the stand productivity to some extent. It functions as an extremely important nutrient pool in the forest and a key link to sustain the system itself. In terms of ecological management of the forest, it is imperative to obtain the data on the dynamics of the litterfall based on monitoring. However, these data are very rare. Based on our long term monitoring over 30 years, we analyzed the dynamics of litter fall in Chinese fir plantation, including year-round variation and rotation-round variation. In average, the monthly litter-fall peaks in April and in December. The annual litter fall is nearly equal to zero in the young stage (2-4a), gradually increases to 1333.5kg/hm^2.a at fast-growing stage, reaches 1917.4 kg/hm^2.a at stem exclusion stage, peaks at 4475.05 kg/hm^2.a at the mature stage, and dramatically decreases to 2073.20 kg/hm^2.a at the over-mature stage (54a).

The Chinese fir plantation has much lower litterfall than *Michelia macclurei* plantation with the age, especially at young and fast-growing stage. Ten years of observations showed that the total litterfall of Chinese fir plantation starting from age 4 through 13 was 19342.64 kg/hm^2, only 72% of the value for *M. macclurei* plantation (Liao et al.,2000). Dead fine roots are the major sources of underground litter. The total dry mass of dead fine roots of 15 year old Chinese fir plantation was 497.5 kg/hm^2.a, 36.8% of the aboveground annual litterfall. The standing dry mass of dead fine roots peaks in June and September respectively, basically coinciding with the dynamics of aboveground growth. Comparatively, the total dead fine roots of Chinese fir plantation is 83.5% of that of *M. macclurei* plantation with the same age.

(2) Litter decomposition and nutrient release

The litter-bag experiment showed that the decomposition rate of Chinese fir leaf litter was significantly lower than other broadleaved species within the region. The decomposition rate of Chinese fir litter for the first 420d was merely 43.3%, while that of *Alnus cremastogyne* and *Kalopanax septemlobum* leaf litter were 67.2% and 63.5%. The decay rate of fine root litter was also 32.78%, lower than that of *M. macclurei* fine root litter with a decay rate of 57.70%.The correlation analysis suggested there was a significant negative relationship between decay rate and C/N of litters.

Based on the litter-bag experiment and periodic fine root sampling on the permanent plots, we estimated the relative contribution of aboveground litter and underground dead roots to the nutrient return. The annual nutrient return from decomposing fine roots was 0.32、0.011、0.58、0.52 and 0.83 kg/hm^2, respectively for N, P, K, Ca and Mg. Although the total nutrient return from fine roots is just one fifth of the return form aboveground litter, it is much more than we expected (Table 23.1).

Table 23.1 Nutrient return from fine roots vs aboveground litter (kg/hm^2.a)

Stand type	Litter type	N	P	K	Ca	Mg	Total
C.lanceolata	Fine roots	0.32	0.01	0.52	0.58	0.83	2.26
plantation	Aboveground litter	4.05	0.51	0.78	3.93	0.78	10.05
M. macclurei	Fine roots	3.16	0.06	8.03	1.91	11.36	24.52
plantation	Aboveground litter	19.62	1.72	6.78	11.39	6.14	45.65

(3) Nutrient accumulation, allocation and cycling

Chinese fir plantation forest varies in its biomass accumulation, litterfall and fine root turnover, the nutrient accumulation, allocation and cycling also turn out to be different from stage to stage. Longterm study showed that the annual uptake of N, P, K, Ca and Mg was 41.89, 15.76, 19.65, 1.61 and 46.56 kg/hm2，the annual return was 18.71, 7.69, 5.79, 25.48 and 18.08 kg/hm2，and the ratio of return to uptake was 0.45, 0.49, 0.29, 0.35 and 0.39 respectively in Chinese fir plantation of 20 years old, and that the annual uptake of N, P, K, Ca and Mg totaled 398.89 kg/hm2，anuual return only 25.1% of uptake. It can be inferred that Chinese fir plantation forest either at stem exclusion stage or at aging stage deplete the nutrient all the time.

Nutrient accumulation and allocation of Chinese fir plantation differs from region to region. Accumulation of N, P, K, Ca and Mg by Chinese fir plantation in Huitong, the lower mountain region is 67%, 67%, 73%, 88% and 106% respectively more than that in Taoyuan, upland. Comparing the amount of nutrient required for 1 t of net biomass production, 1t of biomass production in Huitong region required N, P, K, Ca and Mg 0.42, 0.07, 0.35, 0.75 and 0.43kg more than that in Taoyuan region. In the sense of nutrient use efficiency, the value in Huitong is higher than in Taoyuan region.

Comparing the Chinese fir distribution zone, the nutrient accumulation was found to be the most in canopy in southern zone and northern zone, 46% and 53% of total, in stem in central zone, 43.9% of total, the nutrient accumulation by roots was found to be 20% of the total in central zone and in northern zone, 16% of the total in southern zone. If we look at the nutrient required for 1 t of biomass production, Chinese fir accumulate the most , about 10.25 kg, in northern zone, the second in southern zone, the least in the central zone, only 8.15kg.

In terms of nutrient use efficiency, 1 kg of nutrient consumption produced 123 kg of biomass in central zone, 119 kg and 98 kg of biomass. It suggest that the nutrient use efficency in central zone was high than that in southern zone and northern zone.

3. Stand quality variation of Chinese fir plantation

Chinese fir monoculture caused problems of soil degradation and yield declines, geneally speaking, less litter of low quality plus inappropriate management practices are responsible for problems. In detail, the soil nutrient, soil organic matter and associated physical, chemical and biological properties degraded with the increase in rotations. This type of variation in site quality is the key factors affecting the sustainability of Chinese fir plantation management.

(1) Nutrition mechanism

The monitoring of Chinese fir plantation of 34 year old on permanent plots confirmed that the growth and development of stand deplete the soil nutrition from planting all the way up to harvest. The reason partly lay in the higher C/N (generally >=70) ratio of litter and retarded decomposition (only 30% decomposition rate per year) of Chinese fir, and subsequent disturbed biogeochemical cycles and unbalanced input/output caused decline in soil fertility. The results also indicated that soil N， P and K concentration in 0-40 cm soil layer of the 20 year-old Chinese fir plantation decreased 47.1%, 78.8% and 62.2%. Located research on permanent plots across rotations showed that available N, P and K concentration of the soil decreased 40.5%, 47.5% and 42.3% respectively 30 years after the site turned into the second rotaion from the first rotation, and the values of the soil decreased 17.5%, 51.5% and 34.1% respectively 30 years after the site turned into the third rotation from the second rotation (Fig. 23.2).

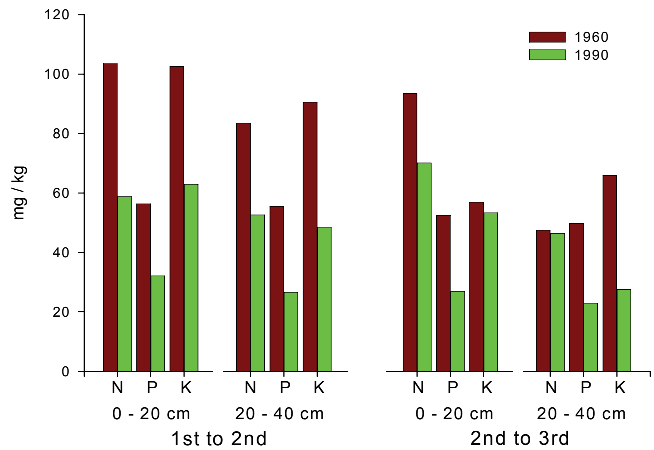

Fig. 23.2 Changes of soi nutrient concentration between rotations of Chinese fir plantation (mg/kg).

(2) Toxicity mechanism

Besides the nutrion mechanism, allelochemicals accumulated in soil by Chinese fir species and associated microbes are believed to be partly responsible for the soil degradation, eg. toxicity mechanism.

(3) Main resources of allelochemicals

The main resources of allelochemicals of Chinese fir plantation include the living organs, residues and associated soil fungi. The results showed that the water extracts of different Chinese fir tissues and organs had inhibiting effects on the seed germination and germinant growth, and the inhibition was in the order of root > leaf > branch > bark. The water extracts of fresh needle litter and half-decayed needl litter had significant inhibiting effects on the seed germination and germinant growth, and the fresh litter had stronger inhibitive effects than the half-decayed litter. Pot culture experiments showed that the Chinese fir stump also had significant inhibitive effects on Chinese fir germinants. The field survey confirmed that the growth of newly-planted saplings was negtively correlated with the density of stumps left on site. Bioassay of root exudates of Chinese fir showed that root exudates of 4-fold original concentration decreased the seed embryonic root by 16.7-21.4%, embryonic axes by 6.2-8.2% compared with the control. It can be inferred that root exudates of Chinese fir was also one sources of allelochemicals in the soil. Chinese fir associated microbes are believed to be another sources of allelochemicals. In our study, five toxic strains were isolated from soil fungal community (Chinese fir seedlings as the test material), two strains of all had higher toxicity, such as Fusa*rium oxysporum* f.sp. vasinfectum (SF2) and *Eupenicillium brefeldianum* (SF31).

(4) Isolation and identification of allelochemicals

Nine phenolic acids were identified from the water extracts of different tissues and organs of Chinese fir, including gallic acid,p-hydroxybenzoic acid, protocatechuic acid, vanillic acid, syringic acid, p-coumaric acid, m-coumaric acid, o-coumaric acid, and ferulic acid. The water extract of Chinese fir frest needle litter, half-decayed litter and stump-root contained all these phenol acids. Lately, traditional chemical analysis method was used for isolating allelochemicals from Chinese fir replanting soil. The isolating procedures basically follows: 1) extracting soil samples with ethanol, 2) to isolating ethanol extract with ehtyl acetate using column chromatography, 3) identifying crystal structure of isolated pure substance using NMR. Up to now, 3 allelochemicals were identified, including friedelin, dipeptide and stigmasterol.But their actual concentrations in the soil and effects on Chinese fir growth need to be studied further.

(5)Toxic mechanism of phenolic acids by bioassay methods

a)Bioassay results indicated vanillic acid and p-hydroxybenzoic acid had significant inhibiting effects on the chlorophyll content, photosynthesis, transpiration and root vigor of Chinese fir ($p<0.05$), and these inhibiting effects increased with the phenolic acids concentration.

b) The inhibiting effects on root vigor and soil nutrient availability may alter the nutrient uptake by trees. Using ^{15}N isotope tracing technique, we discovered that vanillic acid alone and combined vanillic acid to p-hydroxybenzoic acid (ratio=1:1) had significant inhibiting effects on nutrient uptake and allocation of N, and there was synergistic action between vanillic acid and p-hydroxybenzoic acid (Chen et al, 2005).

4. Located studies on ecological benefit from mixture

The mixed conifer with broadleaved had more amount of litterfall because the broadleaved tree species usually produce more residues especially in the early stage that easily decompose. In addition, litter-bag experiment of different combination of mixed litter decomposition results showed that the interaction between mixed species of litter differed significantly from species combination to combination. Due to the difference in their biological characteristics of tree species, the combination of Chinese fir litter with *Michelia macclurei* and the combination of Chinese fir litter with *Alnus cremastogyne* enhanced the mass loss rate significantly, indicating that the litter of M. macclurei and A. cremastogyne were of high quality being easy to decay. The controlled simulated experiment showed that soil nutrient-preserving capacity increased with the number of mixed litter species (Wang et al, 2005). Compared with single applying Chinese fir litter to soil, the soil enzymes (urease, invertase, dehydrogenase) activities enhanced significantly; however soil microbial metabolic quotient (qCO_2) values and soil polyphenol oxidase activities showed a decreasing trend (Hu et al, 2006). It can be inferred that the mixed litter species application improved soil ecosystem function.

The positive interaction between fine roots of two mixed tree species in planation was also found both in the increases of standing fine root biomass and in the enhancement of their decomposition. From the view of soil fauna, *M. macclurei* plantation significantly promoted abundance of the soil macrofauna compared with Chinese fir plantation, but the mixed Chinese fir with M. macclurei plantation had no effect on the abundance of soil macrofauna. The mixed Chinese fir with A. cremastogyne plantation mainly promoted abundance of diptera, tapinella bannan sp., nematode and enchytraeidae. From the perspective of biodiversity, *M. macclurei rotated* plantations and *A. cremastogyne* mixed forest plantations reduced soil fauna diversity. There is no significant difference in soil fauna biomass between paired sites. Our results stongly indicated that tree species was an important force to drive the succession of soil fauna community, and the estimated biomass suggested that it was a long-term process by transplanting to improve the soil quality.

5. Mechanism of SOM accumulation and forest plantation productivity formation

Soil organic matter accumulation was the key of soil nutrient status and allelochemicals accumulation in forest plantation. Forest soil organic matter was mainly from litter decomposition and fine root turnover. Two-year research results showed the mixed-decomposition between Chinese fir and broad-leaved species litter-fall improved itself decomposition, increased content of soil microbial biomass carbon, nitrogen and soluble organic carbon. The effect of the mixed litter decomposition of Chinese fir needle litter with alder leave litter on active soil organic matter was far stronger than that of Chinese fir needle litter with *Kalopanax septemiobus* leave litter, but there were no significant difference. Fine root decomposition was a main source of soil organic matter too. Incubation in 28℃ for 6 months showed soil microbial biomass carbon of fine root treatments of alder, Chinese fir and *M. macelurei* were as 1.40,1.28 and 1.46 times as compared with the control. The most increase in soil active organic carbon was found in the addition of *M. macelurei* fine root, but total soil organic matter content was not sensitive to the short-term incubation of litter or fine root.

Mineralization of soil organic matter was mainly related to the temperature, but for a specific forest, the mineralization rate was related to the tree species composition. In the same layer soil, we found that mineralization rate of soil carbon in Chinese fir was lower than in broad-leaved forest, but nitrogen mineralization rate was higher than in broad-leaved forest. This result is different with those from other research.

Using density fraction technique, we devided the soil organic matter from different rotation of pure Chinese fir plantation into three parts, free light fraction (fLF), occluded light fraction (oLF) and heavy fraction (HF). The results indicated the ratios of soil fLF to oLF trended to decrease with significant difference when evergreen broad-leaved forest turned into pure

Chinese fir plantation. Along with the the increase in times of pure Chinese fir being replanted, the above mentioned soil organic matter fraction decreased with no significant difference. Using AMS, we analyzed the ^{14}C abundance of soil organic matter for each fraction, and found that abundance of 14C varied in the order of top soil (0-10cm) > underneath layer (10-20cm), fLF > oLF > HF, the 4th rotation > the 3rd rotation > the 2nd rotation > the 1st rotation > evergreen broadleaved forest, indicating that management practices and human disturbacn increased the abundance of ^{14}C. Therefore the ^{14}C abundance in the scale range of ^{14}C half life period could reflect soil organic matter dynamic in Chinese fir plantation, and ^{14}C abundance could be considered as one of the indexes indicating the effects of human management activities on Chinese fir plantation site.

6. Quality evaluation system for plantation soil and ecological management

The core idea included three aspects, evaluation system of soil quality，stand structure management and soil management in Chinese fir planatation.

(1) Evaluation system of soil quality (ESSQ)

Based on site classification and the evolving process of site quality, we established ESSQ for plantation soil, in which the entire soil function were divided into three groups, eg. moisture availability, nutrient availability, and root suitability, 4, 6 and 5 indexs were selected for them respectively. Each index was given a weight, and the grades for a specific soil can be calculated using standardization grading equation (Huang et al, 2005). This ESSQ was of great theorical guiding meaning towards the ecological management of plantation soil in subtropics.

(2) Stand structure management (SSM)

The emphasis of SSM should be laid on the tree species selection, spatial arrangement of mixed species, and dynamics of species-interaction. Our results confirmed that planting mixed Chinese fir with broadleaved or alternatively enhanced the utilization of solar energy, improved soil physicochemical property, and increased stand productivity compared with pure Chinese fir plantation.

(3) Soil management (SM)

SM comprised of the management soil organic matter, soil nutrient and soil structure. The management of soil organic matter is the core of the SM. Our studies suggested that ecological management of soil organic matter, especially the aboveground litter, promoting the decomposition and nutrient release from litters is the key points during the development of stands. Furthermore, logging residues, stump-root management, and site preparation modes were the main measures in regeneration stage of stands, for protecting and disposing the logging residues may decrease the nutrient release in the process of silviculture and clearing stumps avert the release of poisonous allelochemicals from decomposing stumps.

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24

Successional Process and Patterns of Tropical Forest Ecosystems in South Asia

Scientific research progresses of Dinghu Mountain Research Station of Forest Ecosystem in Recent 20 Years

Introduction of Dinghu Mountain Research Station of Forest Ecosystem

Research work in Dinghushan Forest Ecosystem Research Station (hereafter referred to as DHS) is based on study of successional processes, patterns and functions in subtropical forest ecosystems, and to discuss its biodiversity mechanism of origin, maintenance and development thus to guide natural reserve management. Research goals of the station are to advance the basic understanding of the successional processes and dynamics of typical forests in lower subtropical region; to detect relationships between forest succession dynamics and environmental changes; to provide scientific references for evaluation and sustainable management of subtropical forests; to accumulate basic information on subtropical forest ecosystems for the national ecological research network; to enhance understanding of the ecological functions of subtropical forest ecosystems for policy makers.

DHS is located in Dinghushan Natural Reserve (112°30'39''-112°33'41'' E, 23°09'21''-23°11'30''N), with an area of 1,133 ha and an elevation ranging from 10 to 1,000 m above sea level. The region is characterized by a typical south subtropical monsoon climate, with annual average precipitation of 1,950 mm, of which nearly 70% falls from April to September and 30% from October to March. The annual mean temperature is 20.8°C, and relative humidity is 80%. The predominant soil types are lateritic red-earth in the lower altitude region and yellow earth in the higher altitude region. Favored by the subtropical monsoon climate and long history of protection, DHS has well protected monsoon evergreen broadleaf forest and its successional forests. Therefore, DHS is an ideal place to research successional processes and patterns of subtropical forest ecosystems, as well as to restore or rehabilitate the degraded forest ecosystems in subtropics of China.

1. Research progresses

The research goals of DHS are based study on forest successional processes, patterns and functions in subtropical forest ecosystems to advance the understanding of the relationships between forest succession dynamics and environmental changes; to find out carbon (C), nitrogen (N), H2O, and phosphorus (P) cycles and their interactions in subtropical forests in respond to global changes; to provide scientific references for evaluation and sustainable management of subtropical forests; to enhance understanding of the ecological functions of subtropical forest ecosystems for policy makers; to accumulate basic information on subtropical forest ecosystems for the national ecological research network. Research progresses in DHS experienced 4 stages with respect of research areas and goals showed as follows:

2. Background investigation

Background information including topography, geology, soil, mammals, birds, vegetation, floras, fungi, and soil microbes were investigated from 1978 to 1985. Investigations were accomplished by South China Institute of Botany (renamed as South China Botanical Garden in 2002) CAS, Zhongshan University, South China Normal University, Guangdong Institute of Soil Sciences, Guangdong Entomological Institute, and Guangdong Institute of Geography. Permanent forest plots, forest hydrological and meteorological observation systems were set up. Topographical map, soil map, and vegetation map were protracted. The first volume of "Tropical and Subtropical Forest Ecosystem Research" was published in this period. By 2006 nine volumes on this topic have been published.

3. Vegetation structure, dynamics, biomass and productivity research

Research areas from late 1980s to 1990 were focus on vegetation structure, dynamics, light use efficiency, biomass and productivity. Such researches filled the gap of knowledge on productivity in subtropical forest ecosystems in South China. Long term litter monitoring was carried out in the monsoon evergreen broadleaf forest and successional forests in this phase as well.

4. Ecosystem patterns and functions research

DHS became a member of CERN in 1991. Automatic observation systems with advanced facilities replaced manual observation with the aid of CERN. In addition to regular observations required by CERN, research projects on forest ecosystem patterns and functions were also carried out in DHS. Research projects in this stage include the following:

- Nutrient cycles in monsoon evergreen broadleaf forest ecosystem;
- Hydrological cycle mode in monsoon evergreen broadleaf forest ecosystem;
- Mechanisms of ecosystem structure and productivity in monsoon evergreen broadleaf forest ecosystem;

- Energy model of Soil-Plant-Atmosphere combo in monsoon evergreen broadleaf forest ecosystem;
- Human impacts on patterns and functions of Pinus massoninan forest in Dinghushan (International cooperation project);
- Mechanisms of ecosystem biodiversity protection and maintenance in Dinghushan (International cooperation project);
- Greenhouse gases (CO_2、CH_4、O_3、N_2O、CFC_5) monitoring in Dinghushan (International cooperation project).

These research projects improved research ability of DHS significantly. They also provided a all-round research platform for understanding C、N、H_2O、P processes, interactions and their responses to global environmental changes in forest ecosystems.

5. Ecosystem processes, interactions, and responses to global change research

Research goals from 2001 to 2006 was to advance understanding C, N, H_2O cycles in forest ecosystem, their interactions, responses and adaptions to global changes; to reveal carbon source-sink functions of subtropical forests; to illustrate contributions of subtropical forests in alleviating global environmental changes; to provide scientific references for international environmental negotiation and policy makers. Major research projects include following:

- Ecosystem patterns and functions respond to topographic elevation and oceanic-terrestrial patterns;
- Carbon fluxes in monsoon evergreen broadleaf forest ecosystem in South China;
- Human activities and global changes impact on ecological processes: a model research;
- Carbon cycles in typical subtropical forests in South China;
- Soil-atmospheric CO_2, N_2O, and CH_4 fluxes in subtropical forest ecosystems;
- Effects of nitrogen deposition on soil nitrogen processes in subtropical forests in South China;
- C, N, H_2O cycles and their interactions in subtropical forest ecosystems.

These researches were funded by CERN, national 973 programs, NSFC projects, knowledge innovations projects in CAS, and Natural Science Foundation of Guangdong Province. Research ability in DHS improved to a new level with longterm observations and successful implement of these projects. Research results were published on top journals on ecology such as ***Sciences, Ecology*, and *Global Change Biology***. Research results were awarded both by Guangdong Province and State Environmental Protection Administration of China. DHS was awarded as excellent station (2001-2005) by CERN. One of the research results "Old-growth forests can accumulate organic carbon in soils" was included as one of "Ten Basic Research News" in 2006. All these achievements demonstrated scientific research in DHS has already moved into the blooming stage, it also highlighted the importance of longterm ecological research. Scientific contributions made by DHS are summarized in the following three topics:

(1) Organic carbon accumulation in soils by old-growth forests

Based on analysis of soil organic carbon observation data in 25 years, Dr. Zhou Guoyi and his coworkers found soil organic carbon has been keeping increasing in old-growth forest. The result was published on Science (December 1, 2006). This result presented some convincing evidence contrary to the unproved perception that old forests are not a significant carbon sink. It is eroding an old doctrine in ecosystem ecology established several decades ago regarding forest carbon pool as a balance as forests matures. It also may fundamentally change our thinking about ecosystem processes and call for establishing a new, non-equilibrium conceptual framework to quantify carbon sequestration capacity. This result provided scientific references to debate on the contribution of tropical and subtropical forests in alleviating atmospheric CO_2 accumulation. The finding can also probably crack a current enigma confronting global scientific academia about carbon imbalance. More than 20 national and international media reported this finding including Nature News, BBC, the Associated Press in the United States, China Daily and Guangzhou Daily etc. More than 60 websites reported the finding as well. This result was one of major scientific achievements in CAS in 2006. The discovery would give developing countries where old-growth forests are widespread a strong evidence to negotiate compensation with developed countries in global carbon trade. Therefore, this finding was included as one of “Ten Basic Research News” in 2006.

(2) Notable influences of forest succession on hydrological processes through canopy structure dynamics

The mid-successional subtropical forest (coniferous and broadleaf mixed forest) in South China demonstrated better hydrological effects on reducing surface runoff and increasing water holding ability than forests at early- and advanced-successional stages. These results provide scientific references for managing ecological forests, restoring and rehabilitating degraded forest ecosystems in the subtropics of China.

(3) Systemical researches on C, N, H_2O cycles and their interactions in forest ecosystems

25 is the suggested critical C/N ratio of soil nitrification in subtropical forests in South China. It stressed the importance of interaction between C and N cycles in forest ecosystem, especially regarding nitrogen deposition became a global environment issues. This finding indicated that increasing nitrogen deposition resulted in accelerated soil acidification, triggering nutrient losing, changing nutrient balance, and finally leading forest degraded. Results found that runoff and soil erosion are major hydrological pathways of carbon losing

from forest ecosystems. Carbon losing through hydrological pathways varied with forest succession processes. Mature forest has relative high carbon losing through hydrological pathways compared with immature forests. This result illustrated mature forests are still a strong carbon sink even if net primary productivity is close to zero. This presented some convincing evidence contrary to the unproved perception that mature forests are not a significant carbon sink. More than 200 research papers including 38 SCI papers and two monographs were published on this topic by DHS. One of research results "C, N, H_2O interactions in tropical and subtropical forest ecosystems" was prized as the Natural Science Award in Guangdong Province in 2006.

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25

Model Development and Mechanistic Study of Ecological Restoration on Degraded Ecosystems in South China

Scientific research progress of Heshan Mountain Integrated Experimental Station of Hilly Land

Introduction of Heshan Mountain Integrated Experimental Station of Hilly Land

Heshan station (112 °54' E, 22 °41' N) is located in Heshan County, Guangdong Province, China. It is one of the core stations of the Chinese Ecological Research Network (CERN) of the Chinese Academy of Sciences (CAS.). The station was co-established by South China Institute of Botany (Renamed as South China Botanical Garden in 2002), CAS and Heshan Institute of Forest Science in 1984 based on the experience and knowledge of previous studies in a degraded costal ecosystem. The main focus of the station is ecological restoration. The missions of the station include: 1) to develop sustainable models of ecological restoration; 2) to illustrate the relationship between biodiversity and stability, and between ecosystem structure and function during the process of restoration. The station is located in the central part of Guangdong Province with a typical climate of south subtropical monsoon. The soil is laterite. The mean annual temperature is 21.7ºC, the mean rainfall is 1700 mm, and the mean evaporation is 1600 mm. The region is a hilly agricultural zone with 78.6% of hilly land, 17.1% of farming land and 4.3% of water body. The zonal vegetation is evergreen broad-leaved forest of typical subtropics. Since its establishment, the station has gone through the following three major developmental stages

1. Vegetation restoration on heavily eroded coastal land in tropical China (Since 1959)

With the rapid growth of human population and development of economy, the ecosystem stability and its resistance to adverse condition were severely affected by over exploitation of natural resources. Consequently, the ecosystem productivity and biodiversity were decreased, soil erosion was exacerbated and invasion of exotic species was more severe. In summary, the environmental degradation has severely threatened the sustainability of social and economic development. Therefore, the conservation of natural resources, the restoration of degraded ecosystems and the construction of sustainable ecosystems are of greatest concern on a global scale.

Since 1959, a pilot study of vegetation restoration on heavily eroded costal land in the tropics had been conducted by South China Institute of Botany, CAS in collaboration with Dianbai Institute of Soil Erosion Control. The objectives of the study were to explore the effective approaches of vegetation restoration and to set up the demonstration model of vegetation restoration in such ecosystem. In this study, we employed the "space-for-time substitution" chronosequence analysis. In other words, we considered that a series of vegetations, distributed at different locations, established at different time to be the same forest at different successional stages, and compared the aboveground and belowground structures and processes of the ecosystem in order to find out the restoration rate of biodiversity and ecological functions of the ecosystems during the restoration. The results showed that:

1) the diversity and abundance of native species increased continuously, so did the soil fertility with the increase of forest age. It would take about 40 years for vegetation restoration but much longer time for restoration of soil fertility;
2) the plantations would be eventually developed toward zonal vegetation regardless of the pioneer species;
3) the restoration of the degraded ecosystem should follow the "three steps" procedure: the construction of pioneer species, the formation of mixed forest by introduction of native broad-leaf species, and introduction of economic crops;
4) it was possible to restore the tropical rain forest with the help of human efforts.

Through this study, we edited the book " Vegetation restoration on degraded tropical and subtropical ecosystems", which was the first Chinese book on restoration ecology, and published more than 260 articles and 4 monographs in peer-reviewed journals in the field of restoration ecology. This study provided the solid scientific evidence and practical experience of vegetation restoration on degraded tropical and subtropical ecosystems, and it was awarded the first class prize of "Advancement in Science and Technology" by the Chinese Academy of Sciences in 1986 and the second class prize of "Advancement in Science and Technology" by the State Department of Science and Technology of China in 1989.

2. Development of sustainable model for subtropical hilly land (Since 1984)

Red-earth hilly land is the major type of land resource in South China, however, the soil erosion and degradation is very serious due to heavy rainfall and irrational land uses such as slash and burn. At present, the total area of degraded hilly land in South China is up to 117,000 km^2, accounting for 25% of the total area of land in this region. The total area of soil erosion is about 76,700 km^2 with a total soil loss of 2,300,000,000 m^3. Therefore, intensive studies on the mechanisms of soil erosion and on the development of sustainable model are imperative in the subtropical region of China.

Since 1984, Heshan station has carried out a series of projects on the model development of sustainable forestry and agroforestry on subtropical hilly land in collaboration with the Heshan institute of forestry. The ultimate goal of these projects was to develop optimized models, which should be sustainable in terms of economic value, and ecological effect, as demonstration for local residents in subtropical China. In this study, the “watershed” approach was employed because various hills and valleys are common in this region. In different watersheds, we constructed different plantations with various pioneer species (i.e. legumes vs non-legumes, conifers vs broad-leaf species) or agroforestry ecosystems with various combinations (i.e. forest-orchard-fish pond, forest-orchard-nursery). The objectives were to illustrate the relationship between the species diversity and ecosystem stability and to evaluate the sustainability of different forests and agroforestry ecosystems through monitoring the long-term patterns of the structure and functions of different ecosystems. The results showed that:

1) with the N-fixing trait, the legumes (i.e. Acacia) are good pioneer species because they can improve the quality of soil organic matter and increase soil fertility at the early stage of restoration, but the population productivity decreases during the late stage due to soil acidification. Therefore, it is necessary to change the species composition of the plantation at late stage;

2) with the ecto-mycorrhizae, the conifers (i.e. Pinus) are good candidates as pioneer species because they can grow on nutrient-poor conditions, but the population productivity also decreases because they are susceptible to diseases and insect pests. The introduction of broad-leaf species into coniferous plantations is a good practice to resist the forest diseases and to reduce the insect pests;

3) Eucalypts (i.e. Eucalyptus) are alternatives as pioneer species because they grow fast with huge biomass, which is good for soil erosion control and accumulation of soil organic matter at the early stage of restoration, but the diversity of understory species is usually low due to its strong competition capability over the other species through possible allelopathy. The replacement of eucalypts with other native species is recommended at late stage in order to balance the economic value and ecological effects of the ecosystems;

4) vegetation restoration is of great importance to mitigate the “greenhouse effect” because we found that half of the CO_2 emmision in Guangdong province is probably fixed by plantations

during the period of 1979-1998;

5) the agroforestry ecosystem of “forest-orchard-fish pond” is demonstrated to be a optimized model in terms of the balance of economic value and ecological effects, and this model has been widely accepted and practiced by local residents.

Based on our study, the local government established 19,000 hectares of pine and broad-leaf mixed forests, which not only greatly improved the quality of the air and water in the region, but also enhanced the resistance capability to forest diseases and insect pests, consequently, reduced the cost on forest disease and pest control. In the meantime, the application of the agroforestry model greatly increased the economic income for local residents. It was estimated that the application of our research findings greatly increased the regional GDP, up to 3 billion RMB during the period of 1979-1998. In addition, we published more than 240 research articles in peer-reviewed journals and 6 monographs in the field of ecology. The study on vegetation restoration and agroforestry model was awarded the first class prize of “Advancement in Science and Technology” by the Chinese Academy of Sciences in 1999. This project was listed as one of the three typical case studies on vegetation and soil restoration in hilly and mountainous area of China by the General Bureau of Environmental Protection of China in 2004.

3. Mechanistic study on vegetation and soil restoration of damaged lowland ecosystem in south China (Since 2005)

Although large scale plantations have been planted in south China in recent years to control soil erosion, which greatly improved the regional environment, the low quality of forest due to simple structure is still a big problem affecting the regional forestry and GDP. Therefore, how to improve the quality of the forests and to enhance the productivity and biodiversity of the ecosystems are of great importance to the sustainable development of the region.

In 2005, we started a project focusing on the mechanistic study on vegetation and soil restoration of damaged lowland ecosystems. In this project, not only the aboveground but also the belowground processes during the restoration were emphasized; not only the economic value but also the ecological effect of the forest were considered. By applying the ecological concepts of “biodiversity”, “edge effect” and “gap” into the experimental design, we aimed to find out the approach and its mechanism to enhance the quality and sustainability of forest ecosystems. The ultimate goal was to develop a good model for forest cultivation and management. The “complete randomized design” was employed for all the treatments in this project. There are 13 treatments in total with three random replicates for each treatment, and the area for each treatment is about one hectare, therefore, the total area of all treatments is about 40 hectares. The major experimental setups are:

1)"Biodiversity" experiment: the main idea is to construct a series of vegetation types along a gradient of species diversity either horizontally or vertically. In the horizontal direction, the tree species in the vegetation types are 0 (slash and burnt, but no trees planted), 1 (3 monoculture types), 10 (mixed forest of 10 native tree species) and 30 (mixed forest of 30 tree species). In the vertical direction of monoculture and mixed forests, the understory species was either removed, re-planted or unchanged. The objectives of this experiment are: (1) to illustrate the relationships between species diversity and ecosystem functions; (2) to find out how does the restoration of ecosystem functions couple with the restoration of community structure; (3) to illustrate how does belowground processes respond to aboveground processes.

2)"Edge effect" experiment: the main idea is to construct a series of forests mixed with slow-growing and fast-growing species, the ratios of slow-growing to fast-growing species are 2:8, 3:7, 4:6 and 5:5, respectively. Similar to "alley-cropping", the slow-growing and fast-growing species were planted with rows side by side. For example, two rows of slow-growing species were planted by the side of eight rows of fast-growing species was considered to be the ratio of 2:8. The objectives of the experiment are: (1) to find out the colonization rate of slow-growing species into the community of fast-growing species; (2) to evaluate both the economic value and ecological effects of the forests of different species combinations and to screen out the best model.

3)"Gap" experiment: the main idea is to adjust the species composition of the low-quality forest by selective thinning and seedling planting. The treatments include: (1) control (no thinning, no planting); (2) no thinning but with planting; (3) thinned but not planted; and (4) thinned and planted. The objectives of the experiment are to illustrate the relative contribution of thinning and planting to forest regeneration, or the relative effect of light and seed bank on forest regeneration, and to find out a good approach for quality-enhancement of the forests.

Currently, the research groups working in Heshan station are very strong with various disciplinary including landscape ecology, plant physiology, soil science, soil biology and ecological engineering. Since 2007, a key project funded by Natural Science Foundation of China (NSFC) and a key project funded by the Chinese Academy of China (CAS) are being carried out in Heshan station, respectively.

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26

Plantation Ecosystem and Degraded Vegetation in Eastern Margin of Qinghai-Tibetan Plateau

Scientific research progress of Maoxian Mountain Ecosystem Research Station

Introduction of Maoxian Mountain Ecosystem Research Station

Maoxian Mountain Ecosystem Research Station of Chinese Academy of Sciences (Hereafter abbreviated as Maoxian Station), being established in 1986, is located in the upper reaches of Minjiang River (E 103° 53′ 44″ N 31° 41′ 46″), northern Hengduan Mountains and eastern margin of Qinghai-Tibetan Plateau, with an altitude of 1826 m.

Climatic factors: annual sun shine hours 1373.8 hours, annual sunshine percentage 31%, annual mean temperature 9.3℃, annual extreme highest temperature 30.9℃, annual extreme lowest temperature -13.5℃, mean coldest monthly (January) temperature -0.9℃, the mean hottest monthly (July) temperature 18.6℃, ≥10℃ annual accumulated temperature 2579.1 ℃, ≥10℃ annual total active temperature 954.1℃, frost-free period 215days, annual precipitation 825.2mm, annual evaporation 968.7mm, annual mean relative humidity 81.1%, annual maximum depth of snow 19cm, annual maximum depth of frozen soil 65cm, annual mean wind velocity 1.5m/s, maximum wind velocity 10m/s, most wind comes from southeast.

Soil and Vegetation types: Main Soil types of the station region are brown soil and cinnamon soil. Plantation is the main vegetation. There are some typical mountain vegetation ecosystems, such as shrub forest of dry valleys, mixed broad-leafed and coniferous forest of middle part of the mountains, coniferous forest of subalpine, subalpine shrub, alpine meadows etc.

Main work of Maoxian Station: The station focuses its studies on restoration ecology, conservation ecology, plant ecophysiology, and forestry. Main research fields of the station include the theory and technology for restoration and rehabilitation of degraded forest ecosystems, plant resources and biodiversity conservation, ecophysiological mechanisms of underlying plant response to environment stresses, and ecosystem sustainable management strategies in the high mountain and deep valley regions of Southwestern China. Some projects are being carried out now as follows.

1) Located monitoring of structure and function change of mountain forest ecosystem

2) Ecological process and mechanism research of degradation and rehabilitation of mountain forest ecosystem

Nutrient cycling, energy flow and microclimate change in the course of mountain vegetation degrading or restoring are being done Based on the located monitoring in Maoxian Station areas. Important study as the physioecological process and mechanism of underlying species and dynamics of species component and community spatial structure characteristics in degraded environment or under environmental stresses are on the way.

3) Research of plant resources and biodiversity conservation

Collecting (conserving, filtrating) idioplasm resources, and research of propagation techniques and planting technique on a large scale; active constituents change and regulation research as environment change; endangered mechanism and conservation research of endangered species; mechanism research of the relationships between human factors and biodiversity etc.

4) Experiments and demonstrations of restoration and reconstruction techniques of degraded forest vegetation

5) research on Responses and adapting mechanism of growth and physioecological indexes of constructive species (Picea asperata, Abies faxoniana and some broad-leaved species) in subalpine forest ecosystem to global climate change (climate warming, UV-B radiation enhancing etc.).

1. Dynamics pattern and characteristics of *Pinus* plantation structure and function

First of all, comparative ecology was systematically used to study vegetation restored processes and their effects of Pinus plantation in eastern Tibetan plateau. The results have revealed the dynamics pattern of biodiversity, population structure (Liu et al., 2004), biomass, seeds rain and bank, litterfall (Lin et al., 2006), and macronutrients biochemical cycling and soil quality during Pinus forests succession.

Secondly, processes and mechanisms of restoration ecology were documented to plantation coniferous forests. Major phases and three turning points during Pinus plantation population growth, i.e. 0-30 forest age (before coverage), 30-50 forest age (coverage to self-thinning) and 50-70 forest age (rapid growing) were found. In the first stage, intensively changed environment and biodiversity, and weak similarity are observed (Table 26.1), although the Pinus population exhibits the first rapid growth stage between 20 and 30 forest ages. Comparatively, the plant develops slowly in the second stage, many characters as growth rate and biodiversity show a turning period in this stage (Table 26.1), and 40 forest ages is an important stage due to the minimums fertility. The second rapid growth period is observed in the third stage, which characterizes with separated forest structure, highly resources consuming rate, and displays degraded characters.

Table 26.1 Biodiversity index of different synusias in different restoration stages

Biodiversity index	**Layer**	**Different successional series of artificial forest (stand age)**						**Primary**
		10 a	20 a	30 a	40 a	50 a	70 a	**forest**
Number of species	Arbor	3	5	11	7	10	4	20
	Shrub	9	11	6	6	7	12	12
	Herbage	24	20	8	11	15	17	20
Simpson index	Arbor	0.3054	0.6438	0.7034	0.6655	0.6895	0.6490	0.8634
	Shrub	0.5430	1.0040	1.0544	1.0521	1.0330	1.0119	1.0098
	Herbage	0.8816	0.8715	0.7493	0.7164	0.7612	0.8917	0.8975
Shannon-Wiener index	Arbor	0.5854	1.1549	1.6361	1.3941	1.4244	1.1574	2.2365
	Shrub	1.1880	0.6260	1.6325	1.5680	1.5296	1.5470	1.5621
	Herbage	1.1053	1.0080	0.6907	0.7030	0.7954	1.0739	1.1168

Thirdly, relationships between soil characters and plantation forest structure were studied. The results indicates that soil organic matter, soil total N, total P and hydrolysable N has kept declining continuously, microorganism population and soil fertility have degraded during the 70 years developing period of *Pinus* plantation planted by traditional ways, and the minimum productivity and integration soil fertility were found in 30-40a forest. The soil physical and chemical characters in plantation forest are also significantly lower than which in primary forest and secondary *Birch* forest nearby. It suggests that *Pinus* plantation forest is degrading. 30-40a exhibited the most serious, indicating that 25-30a might be the key time to manage as thinning and partial-cutting. Additionally, decomposition of litter and material recycling evidences that inhibition of elements cycling is highly related with microclimate which formed during plantation forest succession (Fig. 26.1). However, studies of seeds rain and bank imply that higher potential regeneration is found in plantation forest comparing to natural forest. This conclusion provides scientific evidences to regulate forest’s plantation regeneration, and has also further developed the theory of forest regeneration as well as community succession.

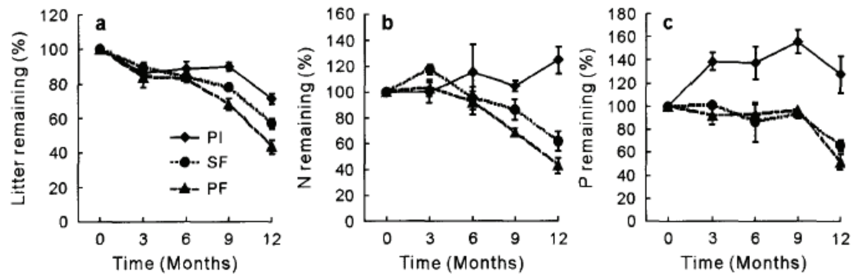

Fig. 26.1 Losses relative to the initial amounts for leaf litter mass (a), nitrogen (b), and phosphorus (c) in the leaf litter during forest litter decomposition in the three subalpine coniferous forests studied: plantation (PL), secondary forest (SF), and primitive forest (PF).

2. Transforming technique system of low-quality and low-benefit forest and observation and valuation of its ecological effect

Technique systems of ecological function restoration have been put forward and applied in the upper reaches of Minjiang River based on analysis of type and characteristic of low-quality and low-benefit forest. Secondary shrubs and high density plantation forest with lacking hiberarchy and low natural regeneration capacity are the main types of low-quality and low-benefit forests in the middle mountain regions of the upper reaches of Minjiang River. Human-induced disturbances are found to be the fundamental reason for formation of low-quality and low-benefit forests. Which indicates that control of human-induced disturbances, creating condition of natural restoration, regulations of the structure and changing the species composition are fundamental approaches of the transformation and ecological function restoration of low-quality and low-benefit forest.

Technique systems of the transformation and ecological function restoration of low-quality and low-benefit forests are applied Based on system research of natural regeneration of indigenous species. These technique systems are based on artificial adjustment of secondary shrub ramets. The ecological effects before and after transforming of low-quality and low-benefit forest are investigated. The results shows that growth rate of remaining sprouts increased 1-2 folds and the growth of basal diameter and highness also significantly increased compared with control treatment. At the same time, the structure of shrub stand became better, capacity of reproduction and resprouting (Meng et al., 2006), diversity in herbage and moss layers also increased after the transformation. Ecological function of forest floor and soil has also been improved in a year after the transformation. Compared with control treatment, soil bulk density decreased, porosity and capacity of water-holding in surface soil layer significantly increased (Fig. 26.2), as well as the increases in nutrients cycling and storage and capacity of water-holding in forest floor (Pang et al., 2005).

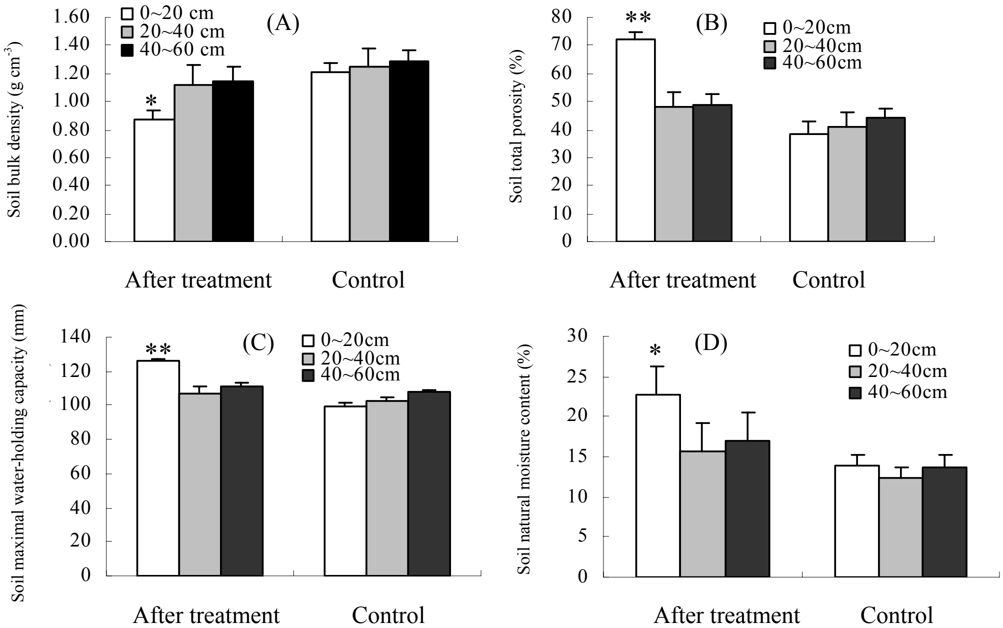

Fig. 26.2 Changes of bulk density(A), total porosity(B), the maximal water-holding capacity(C) and natural moisture content in soil after the transformation of low-quality and low-benefit forest

* $P<0.05$; ** $P<0.01$

Meanwhile, we made use of large areas of shrub remaining after deforestation and developed the technique systems of forestation zone and shrub remaining zone deploying along contour for forest restoration and rehabilitation. The ecological effects in forestation zone and shrub remaining zone were investigated (Bao et al., 2003). The results shows that soil physical properties (i.e. soil bulk density, soil porosity, non-capillary porosity, volume of soil gravity water-holding， soil permeability， soil ventilative porosity) have been significantly improved; The effect of the interception and redistribution of precipitation by Chinese pine plantation are also quite evident; Loss of soil and water has been controlled by the Chinese pine plantation; The soil temperature also decreased significantly in forestation zone of the Chinese pine plantation.

Through the investigation and research of ecological benefit on artificial adjustment of secondary shrub ramets, the forest restoration, rehabilitation technique systems of forestation zone and shrub remaining zone deploying along contour, the ecological reasonability and feasibility of technique application have been estimated. We also compiled the manual of technique application, confirmed the appropriate range and guarantee condition of technique application. At the same time, demonstration areas of 1.8×10^3 hm^2 and application areas of 3.0×10^4 hm^2 have been already established.

3. Using bryophyte as the indicative function group on ecological restoration

Domestically, we take a lead to carry out making use of bryophyte as indicating function in study of ecological degradation and restoration, expounded that restoration and development of understory bryophyte's diversity is highly correlated with growth process of plantation; and found that the higher arbor density and coverage are, the lower the diversity of understory species is and the poorer development is. This indicates that high density forest hinders restoration and reserve of bryophyte. Traditional forestry management is difficult to satisfy the aim of biodiversity. Thinning and pruning can stimulate restoration of bryophyte diversity and development of understory vegetation. Function changes of bryophyte can act as long-term monitor index on forest function restoration.

Bryophytes on the ground under six types of plantation forests (i.e. *Picea balfouriana* forest (P), *Pinus tabulaeformis* forest (Y), *Pinus armandii* forest (H), *Larix kaempferi* forest (L), *Picea balfouriana- Pinus tabulaeformis* forest (P-Y) and *Pinus tabulaeformis-Pinus armandii* forest (Y-H)) were investigated in the upper reaches of Minjiang River in order to understand the bryophyte composition and synusia structure of these different forest types We have also compared the differences among them and analyzed the factors which affected species composition and structure. The results shows that number of species in mixed forest is higher (except *Picea balfouriana* forest) than plantation coniferous pure forests; species composition is similar among plantation forests. Differences in average density and average thickness between understory bryophyte under different plantation forests were also observed (Fig. 26.3). As implies that bryophyte has indicative function on ecosystem health and environmental quality, as the same as vascular plant. In forest ecosystem, bryophyte synusia structure and species composition directly reacts to "naturalness" of understory environment and stand status. So bryophyte is used as one of the most indexes which estimated the ecological restoration and healthy condition of low-effect forest. The low bryophyte diversity and limited structure development (density, coverage, thickness) which are under all six plantations indicate that these are poorly developed bryophyte communities generally. Results show that the best bryophyte community has developed under the spruce forest with a relatively open canopy and low tree density and tree thinning or canopy pruning are the effective measure for improving bryophyte development under dense forests. Meanwhile ecological effects of these measures on biodiversity of bryophyte and synusia structure still need more careful and specific look into.

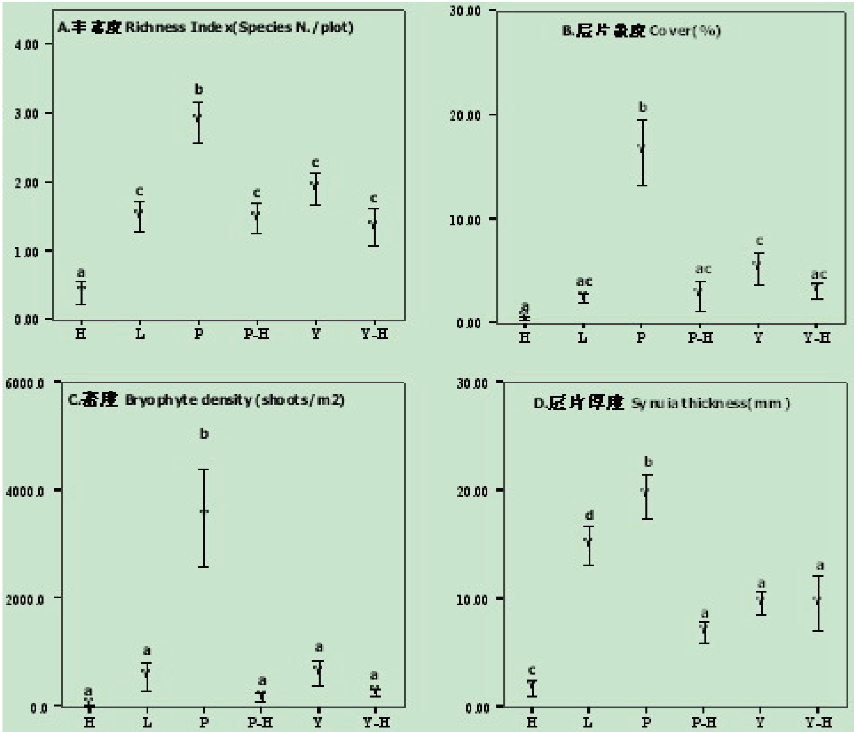

Fig. 26.3 bryophyte species richness, diversity index, synusia structure and variance under six types of artificial forests. A species richness index; B bryophyte density; C bryophyte cover; D synusia thickness. Different figures show significant difference (p<0.05).

4. New pattern of subalpline forests restoration

The collocation pattern of Multi-mosaic community of restoration of subalpline forests was proposed based on the succession theory of mosaic pattern. We've also framed some technique regulations to solve the problem of simple structure in traditional plantation forests, and thereby rationalized the community structure, facilitated the restoration of ecological function by accelerating revegetation. These works have proposed a new technique system and mirror for improvement of the ecological serving function of the subalpline forests in south-west China. A series of nurseries have been established including idioplasm resources nursery, refined nursery, field nursery and economic woods nursery for ecological restoration in different ecological areas. We have screened out 43 trees adapting to restoration based on the comparative experiments on 200 native broad-leaved trees, and successfully compiled some new technique regulations of seedling reproduction. 30 million cultivated seedling has widely applied some national ecological construction such as natural forest conservation and returning farmland to forest in the upper reaches of Minjiang River. These measures have changed the community structure of simplex conifers in the past and now, enriched species applying revegetation in the upper reaches of Minjiang River, and make it possible that new restoration pattern would improve the benefit of species diversity, restoration speed and water and soil conservation.

5. Sustaining agriculture pattern using chemosensory potential

Systematical study on the chemosensory potential, the chemoreception effect in soil of Zanthoxylum woods, the contradictory-compatibility of the Zanthoxylum-Medicago agriculture-woods pattern has originally carried out . The active substances (Linalool and so on) and their amount of chemoreception in plant and soil of Zanthoxylum have been identified, and moreover self-poisoning has been proved to exist in Zanthoxylum woods. Further more, we have found the contradictorily-compatible effect of the Zanthoxylum-Medicago pattern, and considered that self-poisoning of Zanthoxylum restricted planting this plant in the same area for several times and have also shortened life-span of this plant, thereby proposed a new view of construction sustaining agriculture pattern by chemoreceptive potential.We correlatively studied the effects of ruderals on the diversity of herbivorous, meat-eating and parasitical insects, the infection ratio of plant diseases and insect pests and soil water content. The results indicates that ruderals increased the diversity of herbivorous, meat-eating and parasitical insects the soil water content, at the same time decreased the infection ratio of plant diseases and insect pests and the mortality of Zanthoxylum subsequently. The results show a spark of a new idea improving the vegetation cover rate of high slope infield ,which is different from the conditional management notion of removing ruderals completely in Zanthoxylum woods of the upper reaches of Minjiang River.

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27

Mountain Environment Change and Forest Ecological Effects

Scientific research progress of Gongga Mountain Observation and Experimental Station of Alpine Ecosystem

Introduction of Gongga Mountain Observation and Experimental Station of Alpine Ecosystem

Mt. Gongga is located in the eastern edge of Qing-Tibetan Plateau; its summit is 7556 m above sea level. Gongga Alpine Ecosystem Experiment Station (called Mt. Gongga Station) is established within Hailuogou Valley on the east slope of the Mt. Gongga, approximate 60 km away from Luding county, and 360 km western away from Chengdu, the Capital of Sichuan province, China. The Station consists of Moxi base (at the elevation of 1600 m, 29º 39’ N, 102º07’E), sub-alpine experimental site (3000 m elevation, 29º 35’N, 102º00’E) in the Valley, and the Chengdu center for chemical analysis.

Mt. Gongga is a transition region between Sichuan basin and Qing-Tibetan Plateau, and is of a typically alpine landform with obvious horizontally and vertically changes in climate, biology, hydrology, soil and environmental factors, resulting in the multiple landscapes of subtropical farming zones, mountainous primary forests, and maritime glacier etc. The famous Hailuogou glacier has the area of 25 km^2. The glacier tongue stretches into primary forest 6 km at the elevation of 2900 m, and the grandiose glacier fall is 1080 m tall. Within 16 km horizontal distance, alpine glacier, biosphere and human activity interact with each other. It is an important area of ecosystems and biodiversity and an ideal site for alpine ecosystem studies in the eastern edge of Qing-Tibetan Plateau.

The terrain of the Mt. Gongga is highly changeable. Within 29 km horizontal distance, the elevation difference is up to 6500 m from valley to peak. Sequentially, 7 belts of subtropical, warm temperate, cool temperate, sub-frigid, frigid, ice-snow climates are distributed with the elevation gradient. For the Station, the central area of the studies is set up in primary forests from 1900 to 3600 m elevation in the Valley. There, broadleaf forests, mixed broadleaf and coniferous forests, conifers, dark coniferous forests and alpine shrubs distribute from 1900 to 2200 m, 2200 to 2800m, 2800 to 3600 m, and above 3600 m altitude respectively. Around the sub-alpine experimental site, major tree species in the forest are fir, spruce, birch, and rhododendron etc. Additionally, changes in the climates and ecosystems of the farming zone below 1900 m and the nival belt above 4000 m height are also concerned as one of potential research fields for the Station.

In the research area, the topography diversity and integrity of vertical vegetation distribution are unique in China and in the world. The mountain is the glacier-forest distribution region resulted from oceanic monsoon climatic. There are various ecological landscapes, abundant of biological resources, and well-grown primary forests. Since Quaternary Period, the movement of geological structure has been active. The relics of four-times glacier movements in Holocene Epoch are integrally kept. The glacier areas are large and their effects to ecosystem are directly.

The region is also called a natural museum of topography, geography and biology.

In the Station, many important and valuable scientific achievements about in the mountain environment and ecological effects of forest have been accomplished. These achievements play a key role in solving ecosystem construction, functions and evaluation of ecological effect, and produced wideinfluences in China and abroad.

From 2000 to 2006, more than 80 research projects with the total of 20 million yuan were . Among them, there were 6 national natural scientific foundations, including one key project of 1.8 million yuan, 5 special subjects of “973” programs with the sum of 1.7 million yuan, and 5 innovation programs with the sum of 7 million yuan. More than 170 research papers, including 13 SCIs and 21 EIs, were published. 17 academic monographs were also published. Total 9 prizes of state and provinces are awarded. The important achievements in carbon recycle of forest ecosystem, nutrient and water cycles, and water conservation mechanism of forest are listed as follows.

1. Soil carbon emission in the alpine forest

Soil fluxes of greenhouse gas vary with vertical distribution of forest types. Soil CO_2 emission rates in evergreen and deciduous broad-leaved forest are the highest in the region and their seasonal variation is little. In Abies fabric mature forest, soil CO_2 emission rate is higher, but the seasonal variation is the obvious. Soil respiration rate is high in the growing season, but significantly reduces in non-growing season. Soil CO_2 emission rates in coniferous and broad-leaved forest are the lowest and the seasonal variation is very little.

Soil N_2O emission rates in evergreen and deciduous broad-leaved forest are the lowest and seasonal variation is the least, in coniferous and broad-leaved forest are the lower and variation is less. Soil N_2O emission rate in Abies fabric mature forest is the highest and the variation is the largest. That in the growing season is very high but in winter significantly reduces and rapidly rises at the beginning of next year. Seasonal variation of CH_4 absorption and emission rates in Abies fabric forest are not significant and vary with different soil types. Soil CH_4 absorption and emission rates vary with vertical forest belts, but the seasonal variations are also not significant.

Table 27.1 Carbon emission of typical forest land in Mt. Gongga (kg C/ $hm^2 \cdot d$)

Date	Mean temperature	Mid-age forest	Mature forest	Maked land
1998	7.980	29.753	93.959	49.903
1999	7.700	27.733	87.526	45.813
2000	7.060	26.749	83.099	42.998
2001	6.840	27.525	86.499	45.160
Mean	8.170	27.940	87.770	45.970

The effect of increasing soil temperature on soil respiration is the strongest in clear-cutting forestland, followed by mid-aged forest, and matured *Abies fabric* forest. Furthermore, in the forest ecosystem, variation of carbon storage and the quantity of nitrogen fixation at the initial stage during primary succession of vegetation were analyzed. Carbon and nitrogen cycle model in different tree intensity and different vegetation restoration stages was developed. Carbon flux at different altitudes and the relationship between glacial decreased rate and environment changes were also determined.

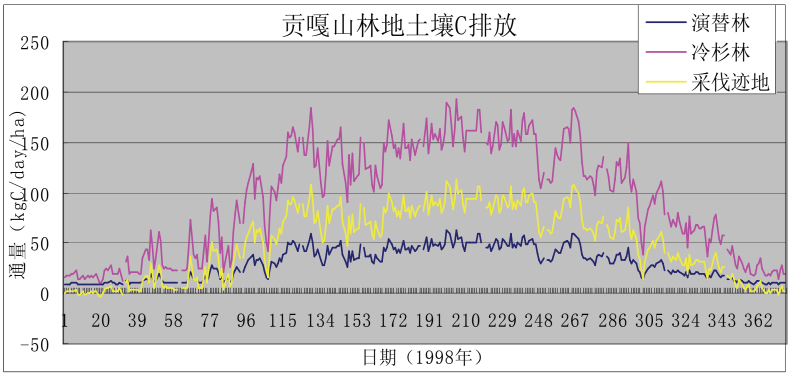


Fig. 27.1 The Carbon emission process of forest soil in Mt. Gongga

2. Nutrients and water cycling in forest ecosystems of Gonga Mountain

The litter-fall from arboreal layer of natural forest shows a strongly declined trend with variations of moisture and heat conditionin the east slope of the Gongga Mountain from altitude 2200m to 3580m. While the annual litter-fall from broad-leaved components gradually disappeared, the needle components from scratch and the proportion of shrub litter-fall gradually increased. The proportion of lichen, moss and detritus gradually decreased. The amount of annual litter-fall shows an increasing trend during *Abies fabric* forest succession. The quantities of N, P, K annual return are not high. Parent material in soil is mostly moraines with lower N content in dark coniferous forest. N reserve in the ecological system of dark coniferous forest is not high, but the utilizing efficiency and cycling intensity is the strongest. P reservation is very low, but the utilizing efficient and cycling intensity is stronger. K stored in the soil is higher and the accumulation of the forest ecosystem is more. Due to that K was easily to be transferred to other parts of tree before branches and leaves falling due to its mobile character, the utilizing efficiency and cycling intensity of K are the lowest in nutrients cycling. Compared with other forest, the efficiency and intensity of nutrients in *Abies fabric* forest are quite lower but retention rates are higher.

In the dark coniferous forest, biomass is higher and turnover rates of nutrients are lower, showing that the good ability of maintaining nutrients and reducing ecosystem nutrients loss, so it can maintain a higher forest biomass and productivity, and the cycling mechanism of nutrients can help it compete with other species and maintain stability. In natural forest protecting engineering in upper Yangtze River, in order to restore and renew mountain vegetation, we must focus on the ecological characteristic of dark coniferous forest.

Meteorological factors (including radiation) and hydrological cycle have been systematically observed in Gongga Mountain inferior alpine forest district and in the low mountains and hills area of middle reach of the Jialingjiang River. A fixed meteorological observation plot located in the forest district. Some facilities of runoff observation in three small forested basins have been built. An observation plot of the runoff under matured forest has also been set up. We carried out the benefit quantitative assessment of the inferior alpine forest hydrology, investigating and observing the soil erosion and rivers sediment in middle part of Sichuan Province. The ecological restoration process is also demonstrated from farmland to forest.

We comprehensively researched on meteorological factors, characteristic of radiation, hydrology trends and ecological change of forest in inferior alpine forest field, and the characteristic of the distribution of moisture under forest, and obtained a set of observed materials and data. During this period, we investigated and observed forest on large scale in the field, and studied forest evapotranspiration on the basis of observing work. We have not only mainly collected and set up a database of different conserving source of water ability for itself in the upstream area of the Changjiang River, but also quantitatively analyzed the effect of land use on hydrological processes in the catchments of Suomo River that is a branch of Dadu River. A model of soil evaluation and the mechanism of hydrodynamics lwere developed by studying micro-structure of the forest soil t, and an adopted SWAT distributed hydrological model was improved to simulate hydrographs, this study explores the relationship between flood frequency and percentage of forest cover.

The main environmental factors which influence evapotranspiration are tested by using the gradient observed data of meteorological radiation from the station. The key parameters of plant evapotranspiration were determined by using porometer to measure leaf moisture conduction. The evapo-transpiration process in dark conifer leaf forest zone was calculated with Penman-Monteith formula, and contrasted with observing results of local water surface evaporation. At last, an evapotranspiration calculating model that is suitable for inferior alpine dark coniferous trees was developed.

sing SWAT model, we simulated multiyear precipitation-runoff relationship under different land use covers (S1: no vegetation on the basin surface, S2: land cover of 1999, S3: The best land cover in the future, S4: the basin surface covered by forest totally) in Suomo River basin in the upstream area of Dadu River, and quantitatively assessed influence of land use changes on runoff, evaporation and flood flow in Suomo River basin. The results indicate that with improvement of land cover, runoff depth reduced, evaporation capacity increased, runoff depth reduced less in low flow season than that in rainy season apparently, and runoff depth reduces more at the beginning of rainy season than at the later stage. Flood flow reduced by 31.2% when whole basin covered by forest compared with non-vegetation at the same flood reoccurrence. These entire indexes have little difference between current and the best future land cover for large flood process, and they have a little more difference to the small flood reoccurrence.

3. Water conservation physical mechanism of forest ecosystems

We have compared structure and nutrient characteristic of soil in artificial forest field in the Yanting county with natural forest of Gongga Mountain. The relationship between the soil structural characteristic and mechanics of water conservation are analyzed. The main aim of those researches was to deeply understand the mechanism of preserving runoff in forest ecosystem. We have obtained several inventive achievements as following:

Soil structure characteristic: we analyzed the soil structure in natural forest in the mountain, and found that this kind of soil layer has thick forest humus and high colloidal content, which favor to form soil aggregate body with much large grains. Therefore, the porosity and permeability of forest soil are very high, which favor groundwater to store and move. However, the soil structure in Yanting is relatively compact with lower porosity and permeability, as shown in the table below:

Table 27.2 Comparison of structural characteristic of forest soil from different sites

Studied area	Forest type	Soil type	Soil structure	Colloidal content	Organic content	Aggregate	Porosity
Station of Gongga Mountain	wildwood	dark brown soil of the conifer leaf	thick	high	many	big, good	high 65%
Station of Yanting	artificial forest	lime purple soil	thin	low	few	small, good	low 45%

Water preserving mechanics of soil: Because of great differences of soil structure in two forest regions, hydraulic properties of forest soil are obviously different, which mainly lie in different storage capacity, delivering and transmitting capacity of water due to soil structures. The preferential water flows of soil caused by thick composition and large grains, and micro-structure with the preserving moisture ability play some important role in water preserving in forest area, as shown in the table below.

Table 27.3 Moisture function of soil structure and composition

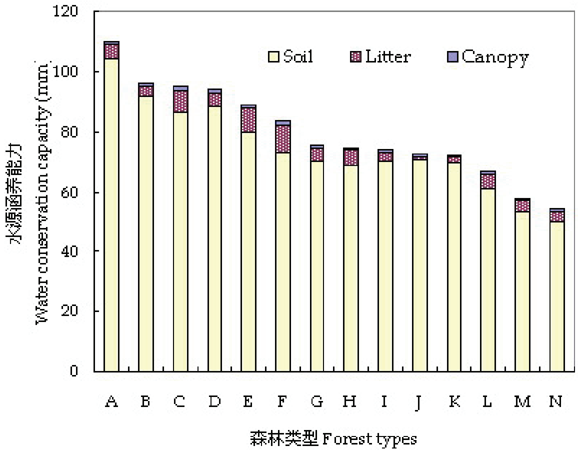
Soil structure	Great structure	Medium structure	Micro-structure	Macro-crack	Micro-crack	Penetration
Hydraulic property	preferential water flow of soil	offering water	holding water	non-capillary pondage	capillary pondage	permeability
Two stations compared	GG>YT	GG=YT	YT>GG?	GG>YT	YT>GG	GG>YT

The proposed soil moisture characteristic equation in the studying area has quantitatively described the forest soil structure characteristic, particle composition and bulk density which influence on soil property of holding water and saturation permeability. The results indicated that they have prominent functional relationship and laid certain foundation for further studying forest hydrology.

The forest ecosystem's comprehensive capacity of water retention is the summation of the capacity of water retention by the forest canopy, litter layer and soil layer. Such mechanism is one of the most important hydrological functions of ecosystem. The figure 27.2 shows the comprehensive capacity of water retention of all kinds of forests in the upper reaches of the Yangtze River. The difference of the structure among different kinds of the forests and soil result in the difference of hydrological function.

The comprehensive capacity of water retention of different forest type in the upper reaches of the Yangtze River is: subtropical evergreen broad-leaf forest (110.1mm) > subtropical evergreen and deciduous broad-leaved forest (96.3 mm) > fir forest (95.3 mm)> evergreen rigid high mountain Quercu (94.2 mm) > hemlock, maple and birch mixed forest (88.8 mm) >

spruce forest (83.6 mm) > temperate deciduous Quercu (75.3 mm) > aspen and birch forests (74.5 mm) > subtropical deciduous broadleaf forest (73.9 mm) > bamboo forest (72.5 mm) > Sabina przewalskii (72.3 mm) > temperate conifer forest (66.8 mm) > subtropical conifer forest (57.9 mm) > Larix chinensis forest (54.6 mm). The mean value of the comprehensive capacity of water retention of all kinds of forest in the upper reaches of the Yangtze River is 79.7mm, and its change range is 54.6～110.1mm.



A: subtropical evergreen broad-leaved forest, B: subtropical evergreen and deciduous broad-leaved forest, C: fir forest, D: evergreen rigid high mountain Quercu, E: hemlock, maple and birch mixed forest, F: spruce forest, G: temperate deciduous Quercu, H: aspen and birch forests, I: subtropical deciduous broadleaf forest, J: bamboo forest, K: Sabina przewalskii, L: temperate conifer forest, M: subtropical conifer forest, N: Larix chinensis forest

Fig. 27.2 The comparison of the comprehensive capacity of water retention for main forest types in the upper reaches of the Yangtze River

The capacity of water retention of litter layer is closely related to the litter existent quantity. The correlation analysis on moisture-holding capacity of litter layer and litter existent quantity in the upper reaches of the Yangtze River (Fig. 27.3) shows that they have a significant linear correlation (p<0.001).

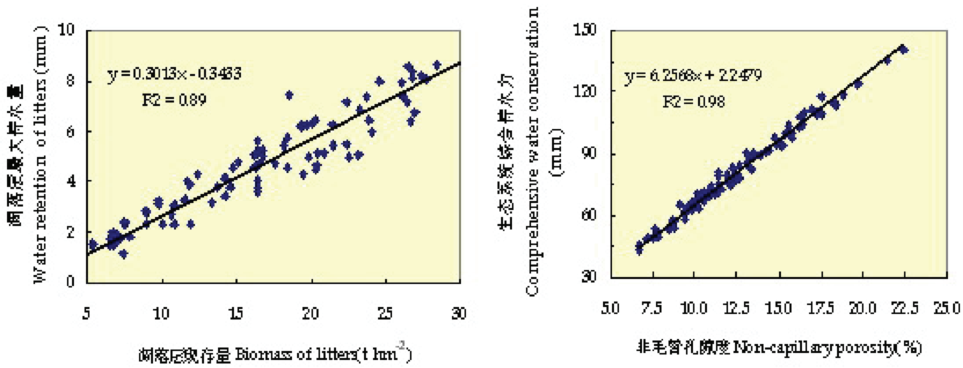


Fig. 27.3 The relation between water holding capacity of the litter layer and the litter quantity, and the relation between comprehensive moisture-holding capacity of ecosystem and non-capillary porosity

Because the water holding capacity of canopy in a precipitation event is less than that of litter layer, the maximal water holding capacity of ecosystem is mainly determined by non-capillary porosity of litter layer and soil. Figure 4 shows that the capacity of comprehensive water retention of all kinds of forest ecosystems and the non-capillary porosity of soil in the upper reaches of the Yangtze River have a significant linear correlation ($p<0.001$). Therefore, the water holding capacity of forest ecosystems was estimated by the non-capillary porosity of litter and soil.

The water holding capacity of soil system in different period, and the change in accumulation of soil and litter of the branches in the upper reaches of the Yangtze River were estimated by the statistic analysis on various forest areas. The trend of the total water holding capacity dynamic change in the upper reaches of the Yangtze River was determined. Because the Jinshajiang River and Yalongjiang River catchments are the most important wood production area in the southwest China, the decrease of the water holding capacity of forest is most noticeable due to the most seriously destructed forest ecosystem in the past decades.

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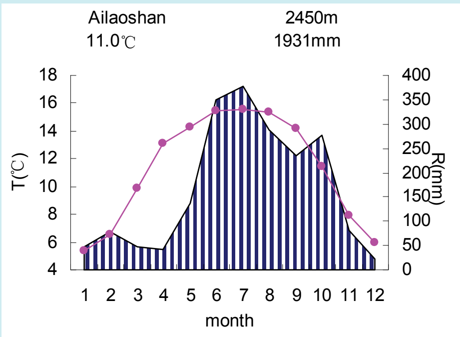
28

Sub-tropical Forest Ecosystem Research in Ailao Mountain

Scientific research progress of Ailao Mountain Research Station of Sub-Tropical Forest Ecosystem

Introduction of Ailao Mountain Research Station of Sub-Tropical Forest Ecosystem

The Ailaoshan Station for Forest Ecosystem Studies (ASFES) was established in 1981. In October 2002, it became a member of CERN (Chinese Ecosystem Research Network). In December 2005, it was approved to be one of the national field stations for scientific research and observation. ASFES is located in the north of the Ailaoshan National Nature Reserve in Jingdong County of Yunnan Province, at 24°32′ N，101°01 E. 2450 meters above sea level. ASFES is located at the south-west monsoon climate zone. This area is controlled by north-west monsoon showing typical sub-tropical climate characteristics. The annual temperature is 11.0℃. The coldest monthly temperature of 5.0℃ occurs in January and the hottest of 15.3℃ occurs in July. The accumulated growth temperature (>10℃) add up to 3420℃, frost period amounts to about 190 days. The area receives an annual rainfall of 1931.1 mm and experiences a distinct rainy season(May to Oct) holding 85% of total rainfall alternating with a dry season (Nov to April) sharing other 15% of rainfall. Annual relative humidity is 83%. The percentage of sunshine in a year is 28%, and annual sunshine



reaches 1239 hours. The climatic characteristics of this area are long winter (5 months), no summer, spring and autumn are as long as 7 months. In a word, the climate of this region is warm, humid, rich in water and moisture resources, and less sunshine. The soil of this area is mountain brown soil and yellow-brown soil.

With abundant rainfall, this nature reserve has the largest areas of subtropical primary evergreen broad-leaved forests in China (34483 hm^2), in which complex structures, abundant woody vines and vascular epiphytic plants flourish. It still keeps a complete forest structure, and presents characteristics of subtropical forest ecosystems. The forest is characterized with large number of endemic plant species of Yunnan and dominated by Fagaceae, Theaceae, Lauranceae and Magloniaceae. This type of forest has distinct four layers with relative rich inter-layer species mainly being of lianas and epiphyte. Tree layers are dominated by Lithocarpus xylocarpus，Lithocarpus jingdongensis and Castanopsis wattii from Fagaceae, Schima noronhae, Hartia Sinensis and Camellia forrestii from Theaceae, Machilus viridis and Litsea elongata from Lauranceae and Manglietia insignis and Michelia floribunda from Magloniaceae. Epiphytes, like fern and moss, form unique sights around the trunks and branches. The flora shows a complex origin with high species diversity. ASFES is an ideal place to carry out forest ecosystem research.

1. Species composition and community structure of montane evergreen broad-leaved forests in west China

A number of pilot inventories on the flora, fauna and community structure were conducted in the evergreen broad-leaved forests in the north part of Ailao Mountains. The results indicated that this forest type is dominated by the floristic elements of the Sino-Himalayan distribution, together with some plants from the north of tropical Southeast Asia, although it also includes a large proportion of species endemic to southwest China. These patterns suggest an affinity between the floras of the Sino-Himalayan distribution and that of montane forests in the north of tropical Southeast Asia. The physical environment (e.g. climate, soil and geographical features) and community structure of the forests.

2. Nutrient and water cycling in the forest ecosystem

The nutrient turnover time in montane evergreen broad-leaved forest in Ailao Mountains was 69a(C), 29a(N), 46a(P)、48a(K), 38a(Ca), 31a(Mg), 19a(Mn), 60a(Al), and 184a(Fe), respectively. Thick moss layer on trunk greatly changed chemistry of stem flow. Compared with trunk without moss layer, moss increased N, NH_4+, Mg^{2+}, Na^+ and SO_4^{-2} concentration in stem flow, but detained almost all NO_3^-，K^+, PO_4^{-2} and Ca^{2+}. One third of the rain fall was returned to atmosphere by evapotranspiration process, while the other two thirds were distributed in different components of forest ecosystem. Canopy interception accounted for 12.95% of rain fall, through fall 81%, and stem flow 0.2%. Water held in forest flour and in soil was 66 t/hm^2 and 6762 t/hm^2, respectively. The maximum moisture capacity of the soil, the ordinary moisture capacity and the non-capillary water capacity was 4523.2 t/hm^2, 711.7 t/hm^2, and 87.7 t/hm^2, respectively. The study showed that water flux was very high in this forest ecosystem, which functioned as a big reservoir.

3. Ecological effects of epiphytic plants in the montane moist evergreen broad-leaved forest

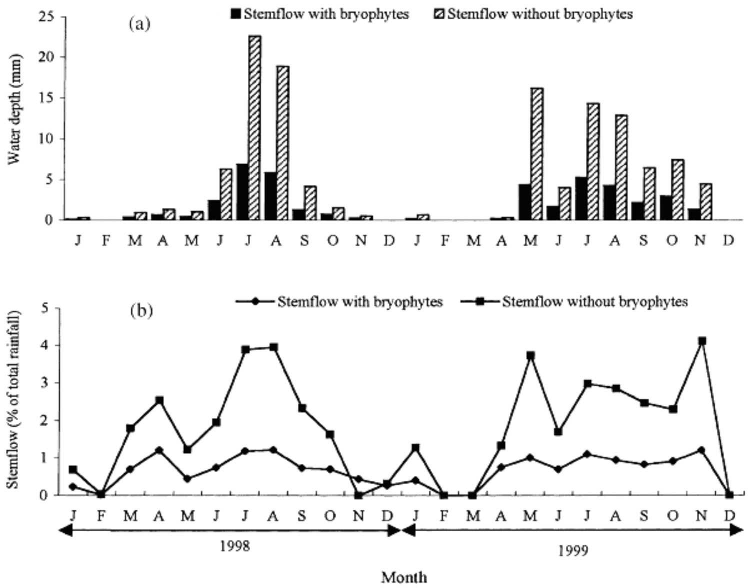


Fig. 28.1 Monthly distributions of stemflow from stems with and without bryophytes in natural Lithocarpus-Castanopis forest at Xujiaba, Ailao Mountain NNR. (a) stemflow water depth (mm); (b) stemflow rate (% of rainfall).

This research has systematically studied the species composition, biomass distribution, nutrient traits, litter rhythm and decomposition rates, as well as the hydrological function of epiphytes in a montane moist evergreen broad-leaved forest, which set up a new arena in studying the ecology of canopy dwelling epiphytes in China. This study found out a huge temporal and spatial variation in epiphytes' litter fall, and there was a clear correlation between the ratio of lignin to P in the epiphytes and their decomposition rates. Besides, canopy dwelling epiphytes not only trap water and nutrients in the atmosphere, but also absorb and release certain nutrients selectively. These findings revealed the ecological effects that epiphyte had functioned in the montane evergreen broad-leaved forests, and explained the mechanisms behind. These works have been appreciated innovative in recent years in the canopy ecology by foreign scholars for it turned out to be of significant scientific and application value in studying the relationship between the structure of montane forest ecosystem and its function, in understanding the patterns of biodiversity forming, and in conserving and managing forest resources. This research program has already attracted attentions from academic organizations such as "Global Canopy Programme- GCP", and scholars world-wide.

4. Characteristics of phenology in the montane evergreen broad-leaved forest

In the mid-montane humid evergreen broad-leaved forest, plants blossom and bear fruits almost all year round. However, for nut trees and Schima noronhae, their fruits do not mature in the year of their flowering and fruiting, instead, they become mature in the next summer and autumn. In addition, some deciduous trees show winter dormancy, whereas all the evergreen tress do not demonstrate evident leaf-shedding period. The phenology events are obviously related to the environment of the Ailao Mountain. For example, Light and temperature induce flowering, and rainfall and light are important to bud breaking and leaf expanding. According to the relationship between phenology and climate variables, the phenology events can be classified into three groups, i.e. warmer phenology, warm phenology and cool phenology. Warmer phenology is dominant type in this forest. In general, the phenology pattern in the montane evergreen broad-leaved forest is different from that of in the temperate forest, but similar to the tropical forest.

5. Characteristics of soil seed banks, seed rain and seedlings

Studies on the soil seed bank, seed rain and seedling were carried out in a montane evergreen broad-leaved forest, a dwarf mossy forest and three secondary forests respectively dominated by Alnus nepalensis, Pinus yunnanensis and Populus bonatii in the Ailao Mountains. The results revealed that the seed storage in the soil seed bank of the three secondary forests was much more abundant than that of montane evergreen broad-leaved forest. Herb dominated life form spectra in the soil seed banks of the 4 forest types. However the proportion of herbs reduced along with the forest succession. In contrast, the proportion of trees and lianas increased. The dwarf mossy forest apparently maintained more abundant seed storage than others did, although its soil seed bank was poor in species composition. The annual seed input in the dwarf mossy forest was more than those of the montane evergreen broad-leaved forest and Populus bonatii forest. More species were trapped in dry season. A peak of seed germination occurred at the beginning of the rainy season in the montane evergreen broad-leaved forest, but most of the newly germinated seedlings died soon after germination because of the continued raining and predation, etc. The heights of many seedlings remained almost unchanged within 1 year of observation. The density and species diversity of tree seedlings in the gaps were much higher than those under forest canopy, of which many species were only found in gaps. These results have shown the most recent advances in the research of forest ecosystem dynamics.

6. 16S rRNA gene analyses of bacterial community structures in the soil of evergreen broad-leaved forests in southwest China

Using sequence analysis and terminal restriction fragment length polymorphism (T-RFLP) analysis of 16S rRNA genes, bacterial community structures in the soils of evergreen broad-leaved forests at Ailaoshan and Xishuangbanna in southwest China were investigated. Clone sequences affiliated to Acidobacteria were retrieved as the predominant bacterial phylum in both forest soils, which is a recently identified group covering a broad phylogenetic spectrum. Other major members were Proteobacteria, Planctomycete and Verrucomicrobia. Bacterial communities in humus and mineral soils of the two forests were well-differentiated based on 16S rRNA phylogeny, and correlations were found between the bacterial T-RFLP community patterns and the organic carbon and nutrient (notably N) contents of the soil samples. Our study demonstrated the retrieval of new bacterial phylum in the soil of evergreen broad-leaved forest and the correlation of bacterial community structure to soil carbon and nutrients level.

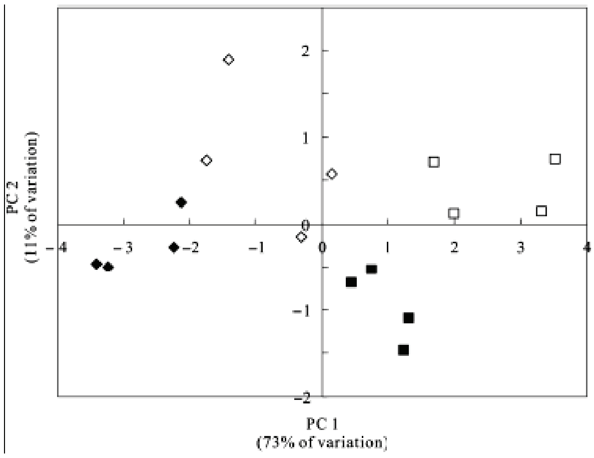


Fig. 28.2 Principal component analysis of terminal restriction fragments (T-RFs) data retrieved from individual samples. Open and closed diamonds denote humus and mineral soil of the evergreen broad-leaved forest at the Ailaoshan study site, respectively; and open and closed squares humus and mineral soil at the Xishuangbanna study site, respectively.

7. A new method, the Sequential Fumigation-Incubation Procedure for estimating soil labile organic carbon

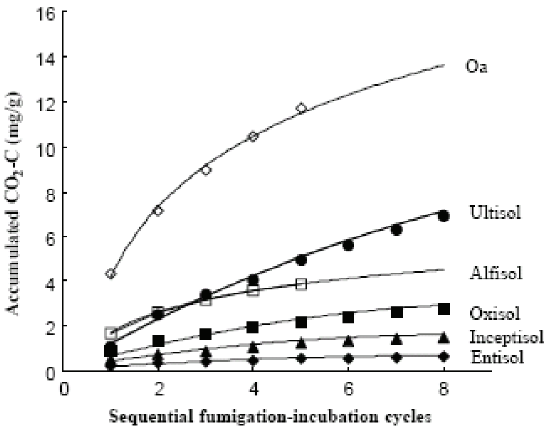


Fig. 28.3 Accumulated CO_2-C (M_t, mg/g)released from the sequential fumigation-incubation cycles (*t*) as fitted to the equation $Mt = C(1-e^{-kt})$, where C_{labile} is the estimated pool size of soil labile organic carbon, and *k* is the potentian turnover rate.

A new method, the Sequential Fumigation-Incubation Procedure, for estimating soil labile organic carbon was developed using data collected from forest soils of the Ailao Mountain (published in Soil Biology and Biochemistry, 2005). This new procedure provides a new means for studying carbon cycling and anthropogenic influence. Data show that the evergreen broad-leaved forest soil contains high levels of soil labile organic carbon (5.5 mg/g) with rapid turnover rate whose turnover time is only half that of a tropical Oxisol in Puerto Rico. Research papers have been published by Journals.

8. Inconsistency of vegetation types and climatic zones

The evergreen broad-leaved forest in the Ailao Mountains is considered as a warm temperate zone according to the indexes for the climatic division. However, it belongs to subtropical according to zonal forest vegetation type. Studies show that such inconsistency was caused by the reason that the climate of the Ailao Mountains was clearly characterized by warm winter and cool summer, and there was a climatic difference between montane vertical zone and latitudinal zone. In addition, the higher soil temperature of this area is one of the reasons that caused the inconsistency of vegetation types and climatic zones of this area. (mean annual soil and accumulated temperatures were 2.55 - 3.03℃ and 900 – 1100℃ respectively, higher than that of the air temperatures in the area).

9. Altitudinal patterns of vegetation and upland climatic characters

Vegetation types in eastern and western sides of the Ailao Mountains differ from each other remarkably. The vegetation types can be divided to the vegetation of dry and hot valley (910-1300m), semi-humid evergreen broad-leaved forest and Pinus yunnanensis forest

(1300-2400m), montane evergreen broad-leaved forest (2400-2600m), and montane mossy evergreen broad-leaved forest (2600-2700m) on the eastern slope and monsoon evergreen broad-leaved forest and Pinus kesiya forest (1140-2000m), montane evergreen broad-leaved forest (2000-2600m), and montane mossy evergreen broad-leaved forest (2600-2700m) on the western slope. The Ailao Mountains lie in the southwest monsoon climatic zone and range from northwest to southeast. As it makes a vertical angle between the direction of the Ailao Mountains and the direction of southwest monsoon, the climatic characters on different slope of the Ailao Mountains also differ from each other distinctly. The climatic character is warm and humid on the west slope and it's dry and hot on the east slope due to the foehn effect. The transformation of vegetation types along altitudinal gradients is controlled by the climate.

10. New species or subspecies found and published in journal

Until now, six new species or subspecies (Vibrissaphora ailaonica, Orcolalax jingdongcnsis, Lepiolalax alpinus, Lepiolalax ventripunciaius, Chiropodomys jingdongensis, sp. Nov., Typhlomys cinereus jindongensis, subsp. Nov.) were found and published in journal.

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29

Tropical Rain Forest Ecosystem Studies

Scientific research progress of the Xishuangbanna Research Station of Tropical Forest Ecosystem

Introduction of Xishuangbanna Research Station of Tropical Forest Ecosystem

Xishuangbanna Station for Tropical Rain Forest Ecosystem Studies (XTRES) is based at Menglun Township, Mengla County, Xishuangbanna Dai Autonomous Prefecture, Yunnan Province, SW China. It is geographically located at 101°16’ E, 21°55’ N, alt. 570 m, on the northern edges of tropical Asia. The climax forest types in this area are tropical seasonal rain forest and monsoon forest, representing an important distribution area of tropical rain forests in continental China. Due to the botanical transition between the Paleo-Tropic floristic region and the Holarctic floristic region from the south to the north, and the East-Asian floristic region and the Himalayan floristic region from the east to the west, the area harbors affluent flora and fauna, evolving a high biodiversity complex.

XTRES was founded in 1959. Its scientific research is focused on the ecology of tropical forests. The missions of XTRES are to measure long-term ecological change in terms of community structure, ecosystem processes and their dynamic patterns; to understand biological mechanisms of important ecological phenomena, and the interactions between organisms and physical environments; to investigate biodiversity pattern and its ecosystem functioning; to increase the scope of the research to include developing new theories and techniques in the restoration of degraded forest ecosystems; to establish and demonstrate multi-storey and multi-species agroforestry systems with high productivity and ecological benefits. All those scientific efforts are oriented to monitoring the environmental change in the tropics of western China and serving for the sustainable use of biological resources.

1. Biogeography and tree species diversity of the tropical seasonal rain forest in Xishuangbanna

Integrated investigations on the species composition, community structure and successional processes of the local tropical forests were conducted. And a number of LTER plots were set up in the major forest types (including tropical seasonal rain forest, secondary forest and plantation) with the purpose of monitoring long term dynamics of local forest ecosystems. We argued that the tropical seasonal rain forest in Xishuangbanna is a northern type of tropical Asian rain forests based on the conspicuous similarities in ecological and floristic characteristics, although it occurs at the altitudinal and latitudinal limits and displays some transitional features (e.g. a small proportion of deciduous tree species in forest canopy). The predominance of tropical monsoon in this area enhances the regionalized traits of the forest in terms of both ecosystem structure and functioning. Tropical seasonal rain forest of Xishuangbanna maintains high tree species diversity. The tree species diversity of single-dominant rain forest is not significantly lower than that of mixed rain forest, because the dominant species of some single-dominant rain forests are principally in the emergent layer. This is composed of sparse and huge trees of one species and, consequently, creates unique canopy architecture and more heterogeneous microenvironments for the more diversified species composition under the emergent layer. The occurrence of tree species with small population sizes, particularly of species represented by only one individual, is highly correlated with the tree species diversity of the local forest vegetation. They are crucial elements in the richness of local biodiversity. The biomass estimation for the tropical seasonal rain forest in Xishuangbanna suggests a similarity to those of Southeast Asia and the Neotropics.

2. Breeding systems and the pollination biology of genus Alpinia (Zingiberaceae)

The breeding systems and the pollination biology of genus Alpinia (Zingiberaceae) were studied. Among the observed species, A. kuangsiensis and A. galanga were intensively studied, including their floral characteristics, flowering behavior, pollination processes, self-compatibility, and inbreeding depression degrees. Through these studies, a new stigmatic behavior was found and nominated as "flexistyly". Flexistyly is a new plant outcrossing mechanism which is distinguished from other known floral mechanisms. Plants with flexistyly have two phenotypes, namely "anaflexistylous morph" and "cataflexistylous morph". These findings were published in academic journals such as Nature, American Journal of Botany, Plant Systematics and Evolution, and Annals of Botany etc. The project won the First-Grade Award for Annual Yunnan Provincial Natural Sciences in 2002.

Nectar robbing by squirrels was reported for the first time in the striped squirrel, which was found robbing nectar from ginger plants in tropical forests. The study indicated that fruit set in inflorescences robbed by squirrels was 5.9% and was significantly lower than that of 34.8% in non-robbed inflorescences, because 78.56% of styles had broken in the robbed flowers. This finding enriches our knowledge about plant - animal interactions and enhances our understanding on the diversity of pollination mechanisms in the tropical forest ecosystems.

3. Soil seed banks and vegetation restoration potential

Studies on the soil seed banks in tropical and subtropical forests of Yunnan revealed that there were large proportions of seeds of herb/grass species in the soil seed banks of disturbed forests, which deceased with forest growth. However these species did not dominate the above-ground vegetation in the sampling sites, indicating an asynchronous rhythm between the developments of above-vegetation and soil seed bank, and vise versa. Anthropogenic disturbance and forest fragmentation resulted in the infection of exogenous herb/grass to the soil seed banks under the forests. Based on the findings mentioned above, we hypothesized that the species composition of the soil seed banks could serve as indicators for quantifying the disturbance forests suffering, and estimating the potentials of vegetation restoration. And a technological system for detecting the species patterns of soil seed banks was also developed. By comparing the soil seed banks in three small forest fragments and one large tract of subtropical forest in Yunnan, we identified and nominated a new functional group of species, which is "nonconstituent species", referring to the plant species that occur in a natural landscape but are not native to it.

4. Forest fragmentation and edge effects

Edge effects of forests were firstly studied in China, in terms of gradient changes in microclimate and plant species composition. A reverse double-circulation was found below and above 2/3H (H = tree height) nearby forest edge. Forest edge as a wall was an important active interface leading to the formation of heat effect and microclimate in edge zones. The interior habitat of a fragmented forest trended to be drier and hotter, and the buffer resistance to climate change was decreased after forest fragmentation. The pattern of species composition was also changed due to fragmentation. Some shade-tolerated species, e.g. Barringtonia machrostachya, disappeared from the fragmented forests. This process resulted in an increase of heliophlous vines and microphanerophyte species, and a decrease of epiphyte, megaphanerophyte and mesophanerophyte species. The forest species diversity was reduced.

5. Micro-climate in forest gaps

Studies on the light environment in canopy gaps of a tropical seasonal rain forest and secondary forests showed that solar radiation, leaf temperature, air temperature and soil surface temperature had the phenomena of "spatial-asymmetry distribution" and "dynamic displacement of peak values". Usually, the peak values of these factors appeared at the north edge of actual gaps and extended edge and the east edge of actual gaps in the cool-dry season (Nov. – Feb.), but these values peaked at the center and the east edge of the gaps in the hot-dry season (Mar. – Apr.). The ratio of daily gross radiation for different light wavelengths within the canopy gap to clearing and the distributive proportion of infrared radiation, visible light to total solar radiation within the gap had significant differences in time, season, location and forest structure, which made the distribution of radiation heterogeneity within the gap. The characteristics of radiation heterogeneity were embodied by "multiplex influence by multi-factors" and "temporal-spatial variation" in the ratio of different wavelength radiations in gaps to clearings. In addition, canopy gaps adjusted the distributive proportion of infrared radiation and visible light to total solar radiation. Compared with clearing and interior of forest, the ratios of infrared radiation to total solar radiation in the centers of gaps were greater than those of clearings, but smaller than those of interior of forest in the dry season (Nov. - Apr.). The direction of heat transferring of soil-plant-atmosphere continuum in gaps varied with time and season. At the same time, the directions of heat transferring could be inversed in different parts of gaps, showing a phenomenon of minor circumfluence of heat within gaps.

6. Carbon flux in the tropical seasonal rain forest of Xishuangbanna

Annual variation of carbon flux in a tropical seasonal rain forest of Xishuangbanna was investigated. We carried out two-year measurements on above- and below-canopy carbon fluxes by eddy covariance and soil respiration of three treatments (bare soil, soil + litterfall, soil + litterfall + seedling) by static opaque chamber and gas chromatography technique. And photosynthesis of dominant tree species and seedlings, leaf area index, litter production and decomposing rate, temperature, solar radiation and photosynthetic photon flux density within the forest were monitored concurrently. Data from January 2003 to December 2004 were used to present annual variability of carbon flux and relationships between carbon flux and environmental factors. The results showed that carbon flux of this forest presented distinct tendency of annual variation. Above-canopy carbon flux was negative in the dry season (Nov. – Apr.), performing a carbon sink. However, it was slightly positive in the rainy season (May – Oct.). On the other hand, the carbon flux of the forest demonstrated diurnal variation. It acted as carbon sink in the daytime, but carbon source at night. And the absolute values were larger in daytime of the dry season than that in the rainy season. Canopy tree species had greater photosynthesis capability in daytime, making a great contribution to above-canopy carbon flux. There was a significant correlation between above-canopy carbon flux and rate of photosynthesis of tree species. There was also a significant correlation between above-canopy carbon flux and carbon flux of forest floor. Soil respiration of the three treatments displayed a markedly seasonal variation. Above-canopy carbon flux correlated well with soil respiration, litterfall production, the rate of litterfall decomposition, precipitation, soil moisture and soil temperature. Preliminary statistical analysis indicated that above-canopy carbon flux in this forest presented carbon sink and source effects in different seasons. Overall, this forest functions as carbon sink at the scale of an entire year.

7. Radiation fog and fog drip in the tropical seasonal rain forest of

Xishuangbanna

The importance of radiation fog to the tropical seasonal rain forest of Xishuangbanna, SW China was studied for four years (1999–2002). Results showed that fog events and fog drip mainly occurred during the dry season, suggesting that the hydrological and ecological consequences of fog could be significant for this rain forest ecosystem during this time. Observations indicated that higher fog drip during dry years further implied that fog water was important in sustaining the rain forest vegetation in dry years. Fog not only inputs water and nutrients into the forest, but also partly reduces the drop intensity of air temperature at night. During the sampling days in the dry season, three understory species obtained between 10–75% of their stem sapwater from fog drip, while two canopy species obtained only between 0–25%. This demonstrated that fog drip could be critical to the growth and survivability of shallow rooted species, such as most understorey species and seedlings, especially at the end of the dry season. In addition, fog drip input into the rubber plantation was quite lower than those of the rain forest, suggesting that the stripping ability of fog moisture by the canopy of the rubber plantation was greatly reduced.

To identify the possible sources of fog drip in a tropical seasonal rain forest of Xishuangbanna, rainfall, throughfall, stemflow, fog drip, stream water, river water, pond water and soil water were sampled for three years (2002–2004) for stable isotopic analysis. We found that radiation fog is produced mainly through evaporation from pond, river, soil, and through forest evapotranspiration. In addition, radiation fog produced during the dry season contained more terrestrially recycled water than fog produced during the rainy season. Although the relative contribution of the different sources of fog could not be quantified, forest evapotranspiration appears to be the largest fraction. These results indicated that the dense rain forest played not only as an important source of its own moisture but also triggered the fog producing process dynamically since it continued to transpire throughout the year. However, converting large-scale multilayer rain forest into rubber tree plantation and other farmland in this region would reduce fog formation and duration, and might have far-reaching negative impacts on this forest ecosystem.

8. Nitrogen cycling pattern in the seasonal rain forest in Xishuangbanna

Based on small catchment approach and input-output budgets, we investigated the nitrogen cycling of a seasonal rain forest in Xishuangbanna. The nitrogen stock in the seasonal rain forest ecosystem was 6481.2 kg/ha, of which 970.9 kg/ha (15.0%) was maintained in the above-ground vegetation, and 5481.2 kg/ha (84.4%) in the soil (0-30 cm). The nitrogen stock in this system was higher than that of tropical montane rain forest on Hainan Island, China, but lower than those of lowland tropical rain forests in Papua New Guinea, Brazil, and Ghana. Soil organic matter, total nitrogen, total phosphorus and available phosphorus in the seasonal rain forest were much higher than those in soils of forest gaps. These results provided evidence for the habitat heterogeneity in forest succession.

9. Tropical man-made plant communities

By simulating the multi-layer and multi-species structure of the tropical rain forest, more than ten new models of man-made plant communities were established in Xishuangbanna, for the purpose of increasing bio-productivity and improving ecological, economic and social benefits of tropical plantations. Of which, rubber-tea man-made plant community is widely extended to the tropical areas of Yunnan, Guangxi and Hainan provinces. This model achieves more than 13,000 ha and makes significant economic incomes in Hainan Province (Fig. 29.1). This project won the First-Grade Award for Advances in Science and Technology of Chinese Academy of Sciences

Fig. 29.1 Man-Made rubber-tea community

10. Cultivation of Amomum villosum under the tropical seasonal rain forest canopy

The plantation of Amomum villosum in the understorey of tropical seasonal rain forest seriously influenced the biomass and productivity of the forest, and resulted in the decrease of the biomass and productivity by 53.21% and 22.5% respectively. The fruit yield of A. villosum in the rain forest was affected by the water supply of its habitat and water deficit in the dry season. With the altitude increasing from 650 m to 950 m, the time of florescence of A. villosum was delayed for ca. 20 days, from the end of hot-dry season (Mar. to Apr.) to the beginning of rainy season (May), which was favorable to the growth of flowers and fruits. Thus the fruit yield of A. villosum increased with increasing elevation. The difference between the yields in the secondary forest and primary rainforest was not significant. In the sampled rain forest plots, soil pH value, organic matter content, soil mineralization and nitrification rate increased after planting A. villosum, while the contents of other soil nutrients did not change significantly. We suggest that the cultivation of A. villosum could be moderately developed in the secondary forest at elevation higher than 800 m, because this could overcome the water shortage and light deficiency as in the understorey of rain forest. And it can also alleviate the biodiversity loss and the degeneration of forest structure and function resulting from the cultivation of A. villosum in rain forest.

11. Demonstration of optimized models of tropical mountain agriculture

Shifting cultivation is a traditional farming system in southern Yunnan. However, its sustainability is greatly reduced with the rapid population growth. The project “Reformation of arable upland in tropical and subtropical regions of south Yunnan” aimed to reducing soil erosion and increase productivity by setting up different rotation, intercropping systems, and man-made plant communities, and applying advanced agricultural technology. This project greatly contributed to the local economy development, poverty alleviation and the protection of natural environment.

The establishment of organic tea gardens, and prevention of tea green leafhopper are major challenges to the tea production in Yunnan Province. After a long term observation, the population dynamics of tea green leafhopper was identified. Based on this study, we developed a pest control system for the tea gardens, in order to increase tea productivity and improve tea quality. This system consists of the establishment of multi-layer and multi-species ecological tea garden, introduction of spiders praying on tea green leafhoppers, rotation of green manures, application of organic fertilizers and biological pesticides etc.

Yunnan shares a long boundary with Myanmar. Golden Triangle area is famous for the plantation of opium poppy, from where drug is smuggled to other parts of the world. In order to promote the substitution of opium poppy cultivation in this area, the Ministry of Science and Technology of China, and Department of Science and Technology of Yunnan Province launched a project to reform the farming system of opium puppy with other tropical cash crops and fruit trees. We demonstrated a couple of new upland agricultural systems with high ecological and economic benefits. On the other hand, some training courses on the application of new agricultural technology were held for local farmers. The economic income of the local farmers was significantly improved after the implementation of the project. The cultivation of opium poppy was reduced in this area.

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30

Biodiversity and Ecosystem Functioning in Typical Steppes

Scientific research progress of Inner Mongolia Research Station of Grassland Ecosystem

Introduction of Inner Mongolia Research Station of Grassland Ecosystem

The Inner Mongolia Grassland Ecosystem Research Station (IMGERS) of the Chinese Academy of Sciences, which is located in the typical steppes of Xilingol, Inner Mongolia (43°26′N，116°04′E, 1100 m a.s.l.), was established in 1979. It became one of the key stations of the Chinese Ecosystem Research Network (CERN) in 1992 and one of the national field monitoring and scientific research stations in 2005. The work of the IMGERS is focused on (1) long-term monitoring of the key biotic and abiotic factors driving the typical steppe ecosystem processes, (2) studies on the structure and function of the ecosystems, the biodiversity and ecosystem functioning, and the ecosystem responses and feedbacks to global change, and (3) developments of practical techniques and methods for grassland ecosystem management, especially for sustainable resource utilization, grassland restoration, and artificial pasture planting.

The latest research efforts have been mostly concerned with vegetation structure and succession, biogeochemistry, ecophysiology and greenhouse gas (GHG) dynamics of the region. Major findings of scientific significance in IMGERS research include: (ⅰ) improved knowledge on structure and function of the temperate grassland ecosystems, (ⅱ) understanding the impact and mechanism of grazing on typical grassland ecosystem, (iii) elucidation of life-history strategies and diapause characteristics of the native grasshopper species as one of the key grassland pests, (ⅳ) development of effective management strategies for controlling rodent pests in grassland ecosystem.

1. Structure and function of grassland ecosystems

(1) Ecosystem stability and compensatory effects in grassland

Numerous studies have suggested that biodiversity reduces variability in ecosystem productivity through compensatory effects; that is, a species increases in its abundance in response to the reduction of another in a fluctuating environment. But this view has been challenged on several grounds. Because most studies have been based on artificially constructed grasslands with short duration, long-term studies of natural ecosystems are needed. Based on a 24-year study of the Inner Mongolia grassland, Bai et al. (2004) presented three key findings. First, January–July precipitation is the primary climatic factor causing fluctuations in community biomass production (Fig. 30.1); second, ecosystem stability (conversely related to variability in community biomass production) increases progressively along the hierarchy of organizational levels (that is, from species to functional group to whole community) (Fig. 30.2); and finally, the community-level stability seems to arise from compensatory interactions among major components at both species and functional group levels. From a hierarchical perspective, our results corroborate some previous findings of compensatory effects. Undisturbed mature steppe ecosystems seem to culminate with high biodiversity, productivity and ecosystem stability concurrently. Because these relationships are correlational, further studies are necessary to verify the causation among these factors. Our study provides new insights for better management and restoration of the rapidly degrading Inner Mongolia grassland. For example, as the precipitation regime and dry period pattern are altered, a shift in dominance of species and functional groups may occur. For restoring the vast areas of degraded grasslands in Inner Mongolia, it is important to establish and maintain grassland communities with a high diversity of dominant species and functional groups, such that compensatory mechanisms can enhance long-term ecosystem productivity and stability in the face of climatic fluctuations.

Moreover, the community may also rely on constantly regulating the structure to maintain the functional stability in grassland ecosystems under long-term mowing disturbance. Using 17 yr field experimental data of mowing succession in L. chinensis steppe, Bao et al. (2004) analyzed the dynamics of community composition based on plant functional groups (PFGs), explored the relationship between changes of the PFGs proportion in community and the community annual net primary production (ANPP). The results showed that changes in both community structure and function took place during 17 yr of mowing succession. The roles of different PFGs varied apparently with mowing succession, and the dominance of rhizome grasses were replaced successively by annuals and biennials, tall bunch grasses, and short bunch grasses. Following 17 yr of mowing, the community became co-dominated by rhizome grasses, tall bunch grass, and short bunch grass. ANPP correlated significantly with annual precipitation in control plot, but not in successive mowing plot. Annual precipitation explained more than 62% of the annual variability in ANPP of control plot, whereas annual variation of ANPP in mowing plot was mainly driven by successive mowing disturbance. The community

ANPP showed resilience to mowing disturbance and kept relatively stable initially through internal regulation of PFGs, and declined to a lower level with structural changes of the community after about 5 yr, and then maintained at a stable level through structural regulation. Therefore, the community structure (PFGs) changed gradually in mowing succession while the community function (ANPP) declined abruptly. The community relied on constantly regulating the structure to maintain the ANPP stability. The community ANPP would decline after its structure changed to certain degree.

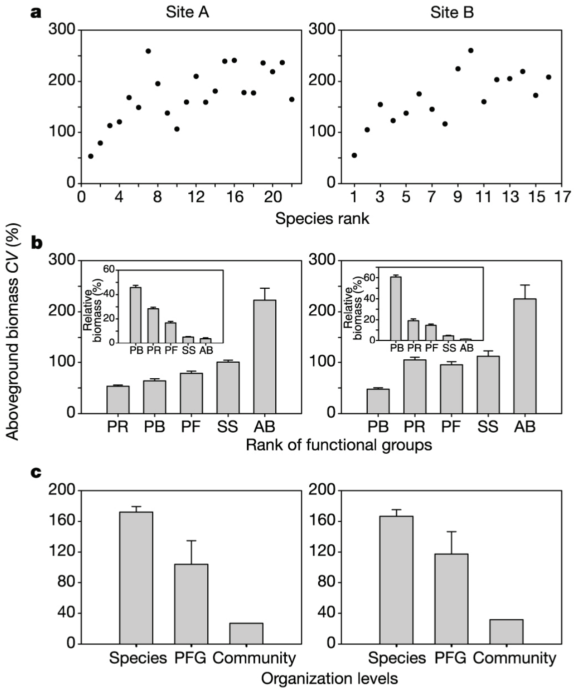

Fig.30.1 The relationship between January-July precipitation and total community aboveground biomass for the *L. chinensis* (site A) and *S. grandis* (site B) steppe ecosystems of the Inner Mongolia grassland, using data from 1980 to 2003

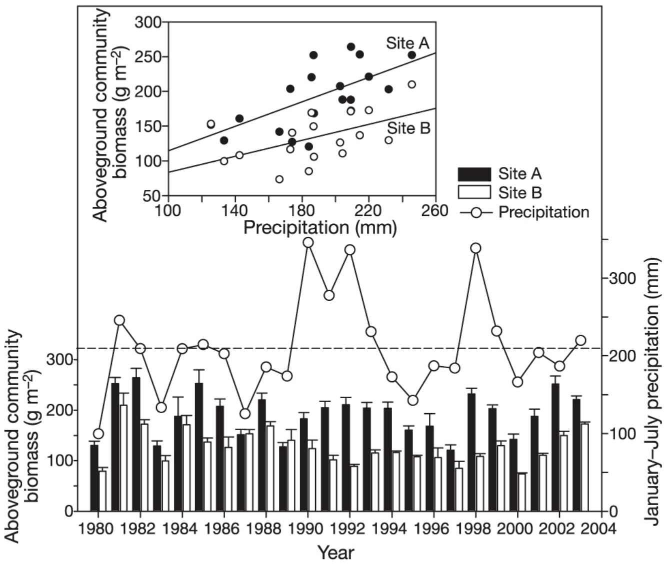

Fig. 30.2 Coefficients of variation (CVs) in aboveground biomass for the *L. chinensis* (site A) and *S. grandis* (site B) steppe ecosystems at different organizational levels in the two study sites

(2) Impact of land-use change on the relationship between species diversity and productivity

Land use affected the relationship between species diversity and ANPP in this semi-arid steppe ecosystem, and the mode and severity of disturbance are important factors for interpreting the relationship between species diversity and productivity in semi-arid steppe ecosystems. Zhou et al. (2006) examined the relationship between species diversity and aboveground net primary productivity (ANPP) over two consecutive growth seasons (2004 and 2005) in a semi-arid steppe ecosystem of northern China, that were subjected to different land uses. The results showed that exclusion of grazing without or with biomass removal by mowing increased ANPP, species richness and species diversity compared with free grazing; the effect was reflected mainly as enhanced importance of the perennial forbs functional group in terms of their relative contributions to ANPP, plant cover and plant abundance (Fig. 30.3). Many mechanisms regulate the relationship between species diversity and productivity. Differential effects of anthropogenic activities on biodiversity and ecosystem functioning greatly complicate the analysis of such relationships. On grazing-exclusion sites the relationship between ANPP and species richness can be best described as an exponential growth function ($R^2 = 0.99$, $P < 0.001$, $n = 24$); whereas on the free-grazing site the relationship takes the form of exponential decay (R2 = 0.96, $P < 0.001$, $n = 24$). The study concludes that the mode and severity of disturbance are important factors for interpreting the relationship between species diversity and productivity in semi-arid steppe ecosystems.

(3) Biogeochemistry

Energy and matter flows among components of ecosystems and exchanges with atmospheres are the central function of ecosystems. Factors affecting those processes regulate ecosystem productivity and functional services. Apart from climatic factors such as temperature and precipitation, soil nutrients are the most likely limiting factors to the productivity of the temperate grasslands in northern China. Researches to date on biogeochemistry in the grasslands of Inner Mongolian Plateau have been predominantly concerned with the elements of biogeochemical significance, e.g. N and P. Field fertilization experiments and N:P stoichiometry have both been used to identify the most limiting nutrient elements at the species level in typical steppes with and without livestock grazing, using L. chinensis and Carex korshinskyi as model plants. It has been found that L. chinensis is N limited on sites free of animal grazing for only a brief period, whereas P is likely to be a limiting factor to growth of C. korshinskyi on sites where animal grazing are excluded for a prolonged period. There exists a significant synergistic relationship between tissue N and P concentrations of grassland plants. Growth of L. chinensis is generally N limited in typical steppes of Inner Mongolian Plateau. Using ^{15}N-labelled technique, we were able to identify the N acquisition and allocation patterns of major dominant and minor species in the typical steppe ecosystems. Increased N deposition due to anthropogenic activities combined with increasing precipitation, as predicted to occur for the arid and semiarid regions, may likely accelerate plant litter decomposition, hence facilitating faster N transfer from the plant to soil pools in the grassland ecosystems of northern China. Many studies demonstrated significant growth response to N addition at the plant community level on the typical steppes of the Inner Mongolian Plateau, indicating a great potential for increased grassland productivity with increasing N deposition as a result of global change.

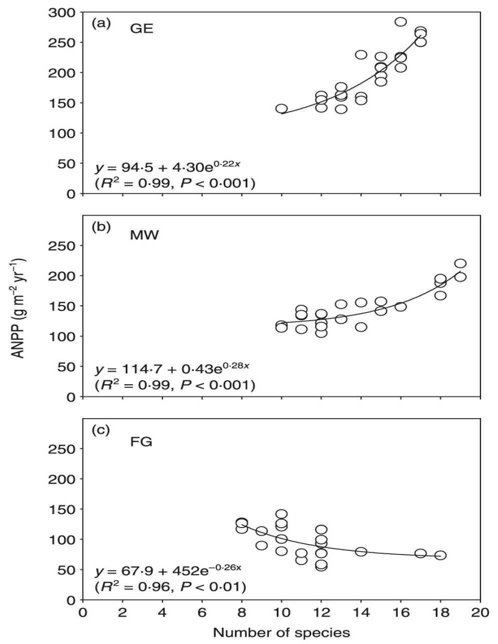

Fig. 30.3 Relationship between ANPP and species richness in three different land-use types in a semi-arid steppe ecosystem of northern China. GE, grazing exclusion without biomass removal; MW, grazing exclusion with biomass removal by mowing

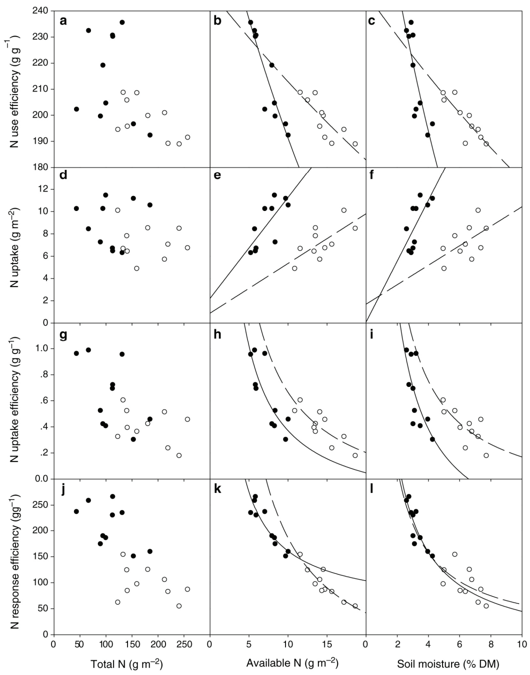

Fig. 30.4 Plant N use and soil conditions in Inner Mongolia, China (filled circle *S. grandis*, open circle *S. Krylovii*)

(4) Plant nitrogen use efficiency

The concept of nutrient use efficiency is central to understanding ecosystem functioning because it is the step in which plants can influence the return of nutrients to the soil pool and the quality of the litter. Nitrogen use efficiency (NUE) is the product of nitrogen productivity (NP) and the mean residence time of nitrogen (MRT). Nitrogen resorption efficiency (NRE) and proficiency of 28 plant species belonging to five different life-forms were studied in a semi-arid region of northern China. NRE in these species ranged from 29.8% to 76.1% and averaged about 48.0%, depending upon the species and the life-forms. Most of the 28 species examined in this study can be categorized as low N proficiency plants. The lower nitrogen concentration in living tissues and the greater nitrogen resorption during senescence could have contributed jointly to the leaf-level NUE of the species. It was noted that NRP was negatively correlated to NRE, while a positive correlation between the leaf-level NUE and NRE was found for all the species. The results showed that a significant positive relation between NRE and the N concentration in green leaves for all the species pulled together, suggesting that green leaf N content might have partially controlled the leaf N resorption. Moreover, resorption of nitrogen (N) from senescing leaves is an important conservation mechanism that allows plants to use the same N repeatedly. N resorption from senescing leaves in S. gordejevii was correlated to soil characteristics and higher N resorption on poor soils is a phenotypic adjustment by this species to maximize N-use at low availability.

Theory suggests nutrient efficiency increases unimodally with declining soil resources, but this has not been tested empirically for N and water in grassland ecosystems, where plant growth in these ecosystems is generally thought to be limited by soil N and moisture. We tested the N uptake and the N use efficiency (NUE) of two Stipa species (S. grandis and S. krylovii) from 20 sites in the Inner Mongolia grassland by measuring the N content of net primary productivity (NPP). The results showed that NPP increased with soil N and water availability. Efficiency of whole-plant N use, uptake, and response increased monotonically with decreasing soil N and water, being higher on infertile (dry) habitats than on fertile (wet) habitats. The N productivity (NP) and NUE of S. grandis growing usually in dry and N-poor habitats exceeded those of S. krylovii abundant in wet and N-rich habitats. NUE differed among sites, and was often affected by the evolutionary trade-off between NP and mean residence time (MRT), where plants and communities had adapted in a way to maximize either NP or MRT, but not both concurrently. Soil N availability and moisture influenced the community-level N uptake efficiency and ultimately the NRE, though the response to N was dependent on the plant community examined. These results show that soil N and water had exerted a great impact on the N efficiency in Stipa species. The intraspecific differences in N efficiency within both Stipa species along soil resource availability gradient may explain the differences in plant productivity on various soils, which will be conducive to our general understanding of the N cycling and vegetation dynamics in northern Chinese grasslands.

Theory suggests that there should be a trade-off between both components (NP and MRT). To test this hypothesis, we analyzed the effect of varying nitrogen supply levels on NUE and its two components (NP, MRT) in Helianthus annuus L., an annual herb. The plants investigated were subjected to six nitrogen levels (0, 2, 4, 8, 16, and 32 g N/m2). Total plant production increased substantially with increasing nitrogen supply. Nitrogen uptake and loss also increased with nitrogen supply. Nitrogen influx (r_{in}) and outflux (r_{out}) were defined as the rates of nitrogen uptake and loss per unit aboveground nitrogen, respectively. Both r_{in} and rout increased with increasing nitrogen supply. In addition, r_{in} was far higher than rout. Consequently, the relative rate of nitrogen increment ($r_{in} - r_{out}$) also increased with nitrogen supply. There were marked differences between treatments with respect to parameters related to the stress resistance syndrome: nitrogen pool size, leaf nitrogen concentration, and NPP increased with nitrogen supply. Plants at high nitrogen levels showed a higher NP (the growth rate per unit aboveground nitrogen) and a shorter MRT (the inverse of r_{out}), whereas plants at low nitrogen levels displayed the reverse pattern. Shorter MRT for plants at high nitrogen levels was caused by the abscission of leaves that contained relatively large fractions of total plant nitrogen. We found a negative relationship between NP and MRT, the components of NUE, along the gradient of nitrogen availability, suggesting that there was a trade-off between NP and MRT. The NUE increased with increasing nitrogen availability, up to a certain level, and then decreased. These results offer support for the hypothesis that adaptation to infertile habitats involves a low nitrogen loss (long MRT in the plant) rather than a high NUE per se. The higher NUE at the plant level was a result, in part, of greater nitrogen resorption during senescence. A long MRT (an index of nitrogen conservation) is a potentially successful strategy in nitrogen-poor environments.

(5) Ecophysiology

Ecophysiological characteristics reflect both the genetic control and the environmental modification of plant performance. Research into the ecophysiology of grassland plants on the IMGERS has focused mostly on photosynthesis and water relations at individual levels in various habitats. Photosynthetic gas exchange and plant water potential have been the most commonly studied traits of plant performance in response to environmental constraints such as drought and high temperatures. Generally, C_4-photosynthetic-pathway plants display more negative values of leaf osmotic potential compared with C_3 and crassulacean acid metabolism plants. Studies with 104 plant species by Liu et al. (2003) showed that leaf osmotic potentials became more negative with increasing rooting depth and decreasing leaf water content across different habitats. Such findings may explain the long-term adaptation strategies of various plants to frequent droughts on the temperate grasslands of northern China.

In recent years, the stable isotope technique has become a popular tool for studying carbon cycle and water relations of grassland plants. The $\delta^{13}C$ values of 51 plant species selected from eight plant communities along a moisture gradient were measured. The results showed that different habitats support dominant species with different water-use efficiencies and a trend in the community-level ^{13}C values was observed， which is as followed, typical steppe (−23.0‰) > degraded steppe (−23.5‰) > sand dune (−25.0‰) > restoring degraded steppe (−25.8‰) > meadow steppe (−26.4‰). Promising outcomes may be achieved in the future on the response and adaptation strategies of grassland plants and plant communities to changing climatic conditions.

(6) Soil respiration

Soil respiration is an important component of the carbon cycle, the quantification of which has significant implications in models to predict anthropogenic carbon emissions resulting from land-use and land-cover changes. In the typical steppes of Inner Mongolia, soil respiration displays clear seasonal patterns, driven most probably by seasonal patterns of primary production as found in other ecosystem types in temperate climates. The peaks of soil respiration often occur in summer corresponding to the maximal temperature of the season. The daily average of soil respiration during growing seasons has been found to be in a range from 565 to 1350 mg C m^{-2} d^{-1} for different plant communities.

Temperature and soil water are both important in determining seasonal variations in soil respiration of the grassland ecosystems. Generally, soil respiration increases with temperature; exponential, power law and linear functions can be used to describe the temperature function of soil respiration in the grassland ecosystems of Inner Mongolia. Q_{10}, the amount of CO_2 exchange due to a 10 ℃temperature rise, can indicate the sensitivity of soil respiration response to changing environmental conditions. A positive relationship between Q_{10} and soil moisture has been detected along a soil water gradient in the grasslands of the Inner Mongolian Plateau, which indicates severe water limitation effects on carbon cycling of the grassland ecosystems in this region. Moreover, interaction between temperature and soil water can better explain the seasonal variation in soil respiration than each of the factors alone. In addition to abiotic factors, live-shoot biomass dynamics could contribute greatly to the seasonal variation in soil respiration in the L. chinensis and S. grandis community, but a significant functional relationship between soil respiration and total aboveground biomass or root biomass is lacking.

(7) CH_4

Temperate oxic soils usually exhibit low levels of atmospheric CH_4 oxidation, which are estimated to consume about 10% of the atmospheric CH_4. The range of methane and diurnal variation in meadow steppe of Inner Mongolia were investigated with static-chamber and GC methods. The meadow steppe can act as a sink of CH_4 in which the fluxes CH_4 has obvious diurnal variation. There is significant for the diurnal mean uptake rates of methane which varied from 27.20 to 126.05 μg CH_4-C m^{-2} h^{-1}. Grazing exerts a considerable negative impact on CH_4 uptake in semi-arid steppes. Total CH_4 uptake during the growing seasons (May–September) 2004 and 2005 at no-grazing grassland since 2001(NG01) and no-grazing since 1999 (NG99) was quantified as 1.15 and 2.15 kgC ha^{-1}, respectively. Annual rates of CH_4 uptake were approximately 1.91 (NG01) and 3.58 kgC ha^{-1} (NG99), respectively. Winter-grazing of steppe significantly reduced atmospheric CH_4 uptake by 47%. The winter-grazing practice may have inhibited CH_4 uptake by (a) increasing the likelihood of physiological water stress for CH_4-consuming bacteria during dry periods, (b) decreasing gas diffusion into the soil because of soil compaction, and, (c) reducing the populations of CH_4 oxidizing bacteria. These three mechanisms could have collectively or independently facilitated the observed inhibitory effects.

Small wetlands greatly contribute to the CH_4 budget in semiarid regions, where wetland contributions are often assumed to be insignificant. Small riparian mires of the Xilin River basin in Inner Mongolia were selected as a case study for weekly measurements of in situ CH_4 flux. Average CH_4 fluxes were 234.3 and -1.9 mg CH_4 m^{-2} d^{-1} for the riparian mires and the upland grassland, respectively, during July–October 2003. Although the riparian mires cover only 0.4% of the Xilin river basin, their total CH_4 emission was about half of the amount of CH_4 consumed by the upland grassland with 89.7% land cover ratio. The results indicate that estimated CH_4 budgets for semiarid regions should include an assessment of small wetlands.

2. Grazing ecology

The experiments were conducted at IMGERS since 1989. The results mainly are as follows

(1) Effect of grazing on vegetation

There are significant effects for grazing intensities on plant composition，life type and population characteristics of grassland. L. chinensis and S. grandis steppes are converged to A. frigida under sustainable heavy grazing. Under moderate grazing, ANPP and p1ant diversity index are maximized and there is compensation or overcompensation for plant production.

Under different grazing rates (0.00, 1.33, 2.67, 4.00, 5.33, 6.67 sheep/hm^2), aboveground standing biomass decreased linearly with the increase of stocking rate, but ANPP did not correspondingly decrease, suggesting a compensating growth occurring under the optimal stocking rate 1.33 sheep/hm^2-2.67 sheep/hm^2. The belowground biomass decreased with increasing stocking rate. Comparing with L. chinensis and S. grandis steppes, the belowground biomass in surface soil increased apparently. The ratio between belowground and aboveground biomass increased with increasing stocking rate, but the ratio between belowground biomass and aboveground net primary productivity (aboveground biomass + intake by sheep) decreased with increasing stocking rate. Stocking rate imposed obvious impacts on the spatial patterns of plant species. L.chinensis and S.grandis which were native species had less random spatial occurrences and larger spatial autocorrelation scales according to the increasing stocking rate. Contrarily, A. frigida and P. acaulis which were invading species had more random spatial occurrences and smaller spatial autocorrelating scales while the grazing pressure increased.

(2) Behavior ecology of grazing sheep

Under relatively low stocking rate, the parameters of the daily grazing time (min), the rate of intake (DM g/min) and the amount of daily intake (DM kg/sheep/day) were basically stable through the grazing season. The number of bites per day and the biting rate decreased while the size of a single bite increased with the elapse of the grazing season. The size of a single bite (mass per bite) was negatively correlated with the number of bites per day. However, the biting rate and the number of bites per step walked by the sheep, the biting rate and the number of bites per step were highly positively correlated. There were 3 peaks in daily grazing activity of the sheep, which were maintained every day through the grazing season, the amount of morning intake only made up 1/3-1/2 of the total daily intake in early phases of the grazing season, but accounted more in the later season. The forage species of L. chinensis, Medicago ruthenica, Allium bidentatum, Kochia prostrata, C. squarrosa, etc. were most preferred by grazing sheep, while others such as S. grandis, Carex duriuscula, and P. acaulis were usually avoided.

3. Ecology of grasshoppers as grassland pests

Grasshoppers have been the subject of particular research emphasis in China because of their importance to the grassland ecosystem processes and function. Grasshoppers, as the primary consumers, affect grassland productivity and compete with domestic animals for food resources. The biogeography of grasshopper fauna including some 150 species on the Inner Mongolian Plateau has been studied, of which 10-15 species are considered as grassland pests. Long-term studies of grasshopper ecology have been conducted at the IMGERS since 1979, with earlier work mainly focused on the fauna and food selections, and on the economic thresholds as controlling guidelines for major grasshopper species of the region. During the latest two decades, more research efforts were directed at understanding the life history strategies, chemical ecology, niche differentiation, and community dynamics in response to grazing in grasshoppers. Notable progress has been made in understanding the grasshopper ecology of the grassland ecosystems in northern China. Such knowledge is fundamental to developing alternative methods to pesticides for controlling outbreaks of grasshopper populations in the grassland ecosystems.

(1) Life-history strategies and diapause characteristics

Understanding life-history strategies and diapause characteristics is useful for improving predictive models and developing management guidelines for grasshopper control. In the grassland ecosystems of Inner Mongolia, nearly all the grasshopper species have only one generation per annum, but occur in different seasons and form sequential development cohorts. In the latest research on grasshoppers, life-history strategies and diapause characteristics are used in an attempt to explain the seasonal patterns of egg diapause and over-wintering in response to temperature variations. Temperature has been identified as one of the key controlling factors of the life-history and diapause characteristics of grasshoppers. The diapause and nondiapause eggs of different grasshopper species have been found to respond and adapt to seasonal temperature fluctuations. Irrespective of their seasonal occurrence, all species of grasshoppers on the Inner Mongolian Plateau overwinter as eggs and enter diapause in embryo stage 19, but eggs deposited by adult grasshoppers in different seasons enter the winter at different embryological developmental stages. Therefore, the over-wintering eggs can be either diapause or non-diapause.

Interspecific differences have been found in the over-wintering embryonic stages, developmental rates, survival curves and cumulative hatching probabilities of six grasshopper species, including one early-season hatching species (Omocestus haemorrhoidalis), three mid-season hatching species (Oedaleus decorus asiaticus, Angaracris barabensis and Calliptamus abbreviatus) and two late-season hatching species (Chorthippus dubius and Chorthippus fallax). Great variations have been observed in the embryonic stages of over-wintering eggs in grasshopper species of the Inner Mongolian grasslands. Generally, the early-season hatching species are able to reach a much more advanced stage of development (embryonic stage 19) before the onset of winter than the late-season hatching species due primarily to cumulative growth temperatures; the developmental stage at which the eggs of a species over-winter varies greatly within the mid-season hatching species such that both diapause and non-diapause eggs are found during the winter season. The late-season hatching species over-winter as eggs at early embryonic stages. Although differences have been found among the above six grasshopper species in the low developmental threshold temperature and sum of effective thermal units for the post-diapause development of eggs, they are insufficient to explain the seasonal sequence of the grasshoppers.

Research by Hao and Kang (2004) revealed species-specific adaptation to different temperature ranges for egg hatching in grasshoppers of the Inner Mongolian grasslands. The egg development of the early-season hatching species tends to adapt to a lower temperature range, the mid-season hatching species to a middle temperature range and the late-season hatching species to a higher temperature range. The late-season hatching species have a wider adaptive temperature range than the early- and mid-season hatching species for egg development. The springtime temperature has not been found to be an obvious factor affecting the differences in hatching time among grasshopper species. In fact, the timing of diapause determines the sequential development of grasshopper species through growth seasons. It was postulated that the temporal separation of niches, as a result of adaptation to prevailing environmental conditions over a long period of evolutionary history, could eliminate severe competition for the food supply among different grasshopper species.

Eggs are the only form of over-wintering strategy known in the Chinese grasshoppers. Therefore, cold tolerance is a critical trait in the life history of grasshopper species in the grassland ecosystems of China. Using C. fallax as a model insect, Hao and Kang (2004) demonstrated that within the same grasshopper species the cold tolerance of individual eggs could differ. Their study showed that supercooling points (SCP) of the C. fallax eggs could vary from -6 to -32.48 ℃, apparently separating them into higher and lower SCP groups. The supercooling capacity differed among the pre-diapause, diapause and post-diapause embryonic stages. Studies of cold hardiness and supercooling capacity in eight grasshopper species showed that the pre-diapause and diapause eggs could survive to temperatures as low as -27℃. Considering the local climate on the Inner Mongolian Plateau, the pre-diapause and diapause, low SCP eggs can safely survive the severe winter seasons, but not the post-diapause, high SCP eggs. C. fallax has been empirically proven to be a true cold-tolerant insect having low SCP eggs.

Although the grasshopper eggs over-winter as diapause and non-diapause or in different embryonic stages, most eggs can safely survive the winter season. Differences in cold tolerance have no apparent influence on the sequential development of cohorts of grasshoppers. Post-diapause eggs are sensitive to low temperatures, especially the abrupt decline in temperature heralding spring. Therefore, for monitoring and predicting grasshopper populations, particular attention should be paid to the temperature and the mortality of post-diapause eggs the following spring. Photoperiod is also known to be an important factor influencing diapause characteristics of grasshopper eggs. Further insights could be gained into understanding mechanisms of the occurrence and termination of diapause of grasshopper eggs based on genomic studies of the locust.

(2) Ecological niche and its divergence

Ecological niche and divergence determine species distribution and composition in ecosystems both spatially and temporally. For grasshoppers, physical habitats and food sources are likely determinants of their ecological niche. Kang and Chen (1992) studied the spatial and temporal heterogeneity of grasshoppers in two grassland types of the typical steppes, L. chinensis and S. grandis, on the Inner Mongolian Plateau using multivariate analysis and diversity indices, and categorized 11 grasshopper species based on guild or assemblage. They found that three dominant grasshopper species, Dasyhippus barbipes, Myrmeleotettix palpalis and C. dubius, were temporally separated into early-, mid and late-season hatching species with distinct temporal developmental sequences. The richness of grasshopper species in the temporal dimension has been found to be greatest during the mid-growth seasons for plants and lower in the early and late seasons.

Microscopic dietary analysis of grasshoppers identified 31 species of vascular plants, one species of fungus and mites as food sources in the typical steppes of the Inner Mongolian Plateau. On the basis of dietary partitioning and utilization, grasshopper species can be categorized into five feeding groups: graminivorous, mixed graminivorous, mixed forbivorous, forbivorous, and phytocarnivorous. In the grasslands of the Inner Mongolian Plateau, the grasshopper species from Pyrgomorphinae and Pamphaginae are mainly forbivorous, whereas those from Gomphocerinae and other groups are graminivorous. The grasshopper communities on the Inner Mongolian grasslands are mainly dominated by Gomphocerinae and are principally graminivorous. The differentiation of spatial, temporal and trophic niches avoids interspecific competition for resources.

(3) Livestock grazing and grasshopper population dynamics

Because of the impacts of grasshoppers on grassland vegetation, understanding the relationships between population dynamics of grasshoppers and grazing is vitally important. Studies of about 34 species of grasshoppers from 16 types of habitats in the Xilin River Basin of the Inner Mongolian Plateau have suggested that both vegetation types and moisture condition are the main factors influencing the distribution of the grasshoppers in the region.

Livestock grazing can alter the environmental conditions for grasshoppers by affecting their food resources and the spatio-temporal heterogeneity of their habitats. Changes in plant community resulting from livestock grazing directly affect the species composition and community structure of grasshoppers. Species composition of grasshoppers has been found to relate largely to plant biomass rather than species diversity and evenness of plants. For example, species diversity of plants was found to be higher on moderately grazed sites, whereas higher species diversity of grasshoppers tended to occur on non-grazed or lightly-grazed sites. Species-specific relationships between grasshoppers and plants have been found in the grasslands of the Inner Mongolian Plateau. Kang (1995) found that the biomass of grasshoppers in the subfamily Catantopinae was positively correlated with the biomass of tall grasses and negatively with the biomass of forbs and short grasses; whilst the biomass of grasshoppers in the subfamily Oedipodinae was negatively correlated with the biomass of grasses and total plants and positively with the biomass of forbs and legumes. Soil compactness and water content also significantly affected grasshopper density and community composition. Grazing in moderate intensity tended to maintain the highest plant diversity and more diverse grasshopper community with lower proportion of the pest species. With increasing grazing intensity, the xerophytous grasshopper species become more abundant, but those of the mesophytous and hydrophytous would markedly decline. Overgrazing often results in decreased species richness and density of grasshoppers. There also exists a species-area relationship in grasshopper assemblages, and the relationship is affected by grazing. Therefore, effective grazing management can minimize the outbreaks of xerophytous grasshopper species.

4. Rodents and grassland ecosystems

(1) Damage to grassland

Population outbreaks of rodents frequently occur in the grassland ecosystems of China. It is estimated that 10-20% of grasslands are heavily infested by rodents causing 20 billion kg losses of grasses every year. It has been found in the grasslands of the Inner Mongolian Plateau that, each vole can eat 40 g of fresh plant material per day, and in high-density years with up to 1384 individuals ha^{-1}, 15-44% of grass production can be consumed by voles. In the

Qinghai-Tibet Plateau, the available area of the natural grasslands is about 1.4 million km^2, and the area of the degraded grassland is up to 0.71 million km^2 among which 0.37 million km^2 are damaged by rodents. The average density of the plateau pika (Ochotona curzoniae) is greater than 4.29 individuals ha^{-1}, and the density of plateau zokor (Myospalax baileyi) is about 1.07 individuals ha^{-1}. Their eating and excavating activities cause degradation of grasslands and turn the infested area into black sandy earth. So far the area covered by blank sandy earth is estimated to be about 40000 km^2 due to infestation by plateau pika and zokor. One plateau zokor can produce about 240 moulds each year, covering 22.5 m^2 of grasslands.

(2) Impact of livestock grazing

Over-grazing by livestock and the irrational reclamation of the grasslands have been identified as important factors in worsening rodent and weed infestations in grasslands. Over-grazing facilitates rodent infestations through providing suitable vegetation and foods. Many rodent species in grasslands prefer to live in open habitats and avoid high grasses. The plateau pikas prefer open habitats, and avoid dense shrubs or thick vegetation. Grazing with high intensity can severely reduce the height and cover of vegetation and produce habitats more suitable for Brandt's vole and Mongolian gerbil (Meriones unguitulus). The substantially increased livestock numbers over the last 50 years have increased the frequency of outbreaks of Brandt's vole. Under conditions of over-grazing by livestock, the succession of the degraded grasslands can be changed into a vicious circle as shown below: Overgrazing → grassland degeneration → rodent infestation → further grassland degeneration. In the grasslands of the Xilin River Basin of Inner Mongolia, the dominance of plant species changes from L. chinensis and S. grandis → A. frigida, L. chinensis, and C. squarrosa → A. frigida, P. acaulis, and C. squarrosa→ Planta annua under lightly, heavily, and excessively over-grazing by livestock. Accordingly, the dominance of rodent community changes from Cricetulus barabensis, Citellus dauricus, and Ochotona daurica, O. daurica, C. barabensis, and C. dauricus → Microtus brandti → Meriones unguiculatus under lightly, heavily, and excessively over-grazed treatments.

(3) Pest management

Controls of rodents are very critical for restoring degraded grassland. In the grasslands of the Inner Mongolian Plateau, controls of over-grazing reduced the population density of Brandt's vole by 78% and increased the grass production by 40% from 1987 to 1989. Because rodent population can recover quickly after chemical control, fertility control of the rodents has been recommend as an alternative method. As mating system alters the effect of fertility control, extra effect can be produced for monogamous or polygynous rodent species if both sexes are sterilized due to mating interference. Simulation by modeling indicates that fertility control offers great potentials for managing population of Brandt's vole in the grasslands of the Inner Mongolian Plateau. A mixture of contraceptive compounds of levonorgestrel and quinestrol has been demonstrated to be effective in reducing fertility of some grassland rodents like Brandt's voles (M. brandti), gray hamster (Cricetulus migratorius), striped hamster (C. barabensis), Phodopus sungorus, and mid-day gerbils (Meriones meridianus).

5. Future research outlooks

Currently, some multi-factor experiments in temperate grassland ecosystem, viz. biodiversity and ecosystem functioning, nutrient addition, burning, and stocking rates, have been established in IMGERS. The experiments brings together a large team of scientists in the research fields of soils, vegetation, insects, grassland animals, and provides a unique platform for increased international collaborations and multi-national research projects led by Chinese grassland ecologists.

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Note: Most of the abovementioned Information comes from a recently published synthesis paper by Kang L, Han X G, Zhang Z B, Sun O J. 2007. Grassland ecosystems in China: review of current knowledge and research advancement. *Phil. Trans. R. SoC. B*, doi:10.1098/rstb.2007.2029, and other published papers is cited in this summary material.

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31

Alpine Meadow Ecosystems in Qinghai-Tibetan Plateau

Scientific research progress of Haibei Research Station of Alpine Meadow Ecosystem

Introduction of Haibei Research Station of Alpine Meadow Ecosystem

Haibei alpine meadow ecosystem research station, as a field station has been in operation since 1976. The research station is located in the northeast of Tibet, in a large valley oriented NW-SE surrounded on all sides by the Qilian mountains, at latitude 37°29′~37°45′N and longitude 101°12′~101°23′E. The average altitude of the mountain area is 4000 m a.s.l. and 2900-3500 m for the valley area. The landscape is characterized by large mountain ranges with steep valleys and gorges interspersed with relatively level and wide inter-mountain grassland basins. The climate of Haibei research station was dominated by southeast monsoon and high pressure of Siberia. It has a continental monsoon type climate, with severe and long winters and short cool summers. The average air temperature is -1.7ºC with extremely maximum 23.7ºC and minimal -37.1ºC. Average annual precipitation ranges from 426 to 860 mm, 80% of which falling in the short summer growing season from May to September. The annual average sunlight is 2462.7 hours with 60.1% total available sunshine, and the total annual radiation is 58556×10^5 J/cm^2.

There are two main vegetation types, alpine meadow and alpine shrub, in the region of the research station. With respect to the general biogeography of the region, the alpine meadow, dominated by Kobresia humilis and various grasses and forbs are widely distributed along the alley floor. The shrub, Potentilla fruticosa joined by shrubby Salix species, are located on the northern slopes. Both types of vegetation are characterized by dense plant community structure, short growing period and a low productivity. The soil types are dominated by alpine shrub soil, alpine meadow soil and bog soil, rich in nitrogen, phosphorus and potassium. They are characterized by high organic matter, under development, thin soil layer. For nutritional substance exists in organic state with weak process of mineralization, the available elements are low, especially a lack of available nitrogen and phosphorus, the soil condition can not meet the needs of plant growing.

The station was qualified as an opened filed research station of CAS in 1989 and became one of the leading stations of Chinese Ecosystem Research Network (CERN) in 1992; to be a member of International Tundra Experiment (ITEX) in 1999, and became the field observation station of the ministry of science and technology of the People`s Republic of China in 2001.

The Haibei research station has been formed based on CERN which was initiated to evaluate the effects of climatic change and human activity on the alpine meadow ecosystems of the Tibetan Plateau. The research station address the fundamental relationships between climate, and aspects of the plateau environment such as ecology and vegetation dynamics over a grange of time scales. Archives of past environments and biotic communities preserved in productivity, plant community structure, soil nutrients and major animal populations have being investigated since the research station was established in 1976. The experimental and analytical approaches will be used to unravel current climate effects on ecological process. The basic understanding of the dynamics of climate and the alpine landscape and its ecology will be employed to assess the likely impacts on Tibet of predicted future climatic changes. Working on the ecosystem structure and function, global warming, biodiversity, long term ecosystem monitoring as well as sustainable pastoral animal production, the station has become a research, demonstration and extension center.

1. Impacts of climate warming on the alpine grassland ecosystem

The Qinghai-Tibetan plateau, well known as the "roof of the world", has an average altitude over 4,000 m above sea level. With its peculiar topography, the Qinghai-Tibetan Plateau has a unique climate system that is very sensitive to these environmental changes, with air temperatures increasing at a rate of 0.16 ℃ every ten years. Due to its high species richness and unique evolutionary mechanisms, Qinghai-Tibetan Plateau, along with southeast China, the Himalayan biodiversity hotspot, is not only designated as one of World's 34 most important centers of biodiversity, but also considered the hotspot of adaptive evolution research. Little information is available by which we can assess how the grassland on the plateau will react to this change, thus simulated warming experiments have been performed in this region in order to understand the possible effect of ongoing climate warming on the vast grasslands on the plateau.

(1) Independent and combined effects of simulated warming on plant diversity

Within each of OTC's experimental plots, a complete factorial experimental design was established where warming was simulated using fiberglass OTC's. Simulated warming decreased total species richness by five to 14 species (depending on the habitat and the grazing history) in 1999, and by 9 to 15 species in 2001. This represents a 16-30% decline in species richness in 1999 and a 26-39% decline in species richness by 2001. Averaged across all sites, warming decreased the Shannon diversity index by four species (34%) in 2001 (Fig31.1). This is a preliminary study to explicitly examine the effects of experimental warming on the rangelands of the Qinghai-Tibetan Plateau, and its results suggest that the future of species diversity in this region will depend on both climate change and grazing management.

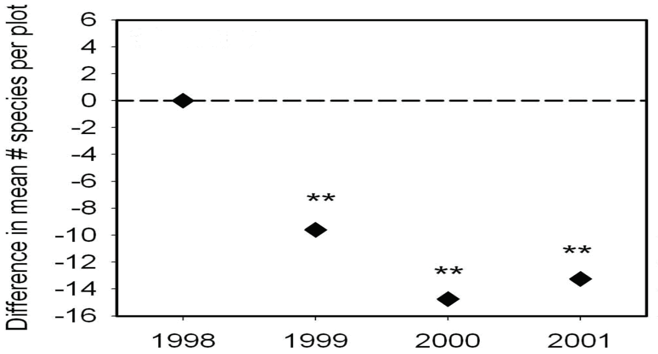

Fig. 31.1 Effect of warming on total species richness at the low grazing intensity history shrub

(2) Impacts of simulated warming on the above-ground biomass

Open Top Chambers (OTC) are commonly employed to study the effect of climate warming on ecosystems. Almost all alpine meadow species could be categorized into graminoids, sedges, and forbs. The aboveground biomass of most gramineous plants such as Koeleria cristata, Festuca ovina, Festuca rubra, Poa sp., Stipa aliena, Elymus mutans increased. The aboveground biomass of most sedgy plants such as Kobresia humilis, Carex sp., Scirpus distigmaticus also increased. However, the contrary is true for forbs such as Gentiana straminea, Saussurea superba, Thalictrum alpinum, Gueldenstaedtia diversifolia, Gentiana farreri, Taraxacum sp., Potentilla bifurca and Potentilla nivea. Consequently, the aboveground biomass of graminoid and sedge species inside OTC's increased by 12.3% and 1.18% over the control, respectively. However, in contrast, the aboveground biomass of forbs decreased by 21.13%. Numerous impacts on the phenology, growth, and physiological state of the vegetation in the plots have been observed. For example, forbs in heated plots show significant reductions in aboveground biomass. However, in our study, a simulated experiment on the alpine meadow on the Qinghai-Tibetan Plateau, forbs in heated plots showed a significant increase in aboveground biomass.

(3) Effects of simulated warming on the phenology

The phenological phases of the alpine meadow are affected significantly by increased temperatures. The growing phase of plant populations inside the OTC's was delayed, on average, by 4.95 days. Beginning times for all phenological phases advanced, but ending times were delayed. This was especially true for the beginning of the fruit-bearing phase, which was advanced by 2.84 days, while the end of the vegetative phase, after the bearing of fruit, was delayed 5.74 days. However, the contrary was true for the florescence phase, with its beginning time delayed, and its ending time advanced. Perhaps this is due to the fact that the energy obtained during the sunlight hours, and the amount of sunshine available, was reduced by the fiberglass of the OTC's.

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(4) Impacts of simulated warming on herbage nutrition

Four sites with differing temperatures were selected at different altitudes of Daban Mountain in order to investigate the potential effect of climate warming on alpine herbage nutrient content. There are negative correlations between the temperature and CP contents of the herbage; as for ADF and ADL contents, there were positive correlations between temperature and ADF and ADL contents of the herbage. In this study, we selected sites that showed similar topography, soil type, and vegetation conditions, but that were located at different altitudes. Temperature differences, resulting from different altitudes, were the determining factor for all kinds of environmental elements. Thus, in this study, differences in the nutrient contents of herbage grown at different altitudes can be deduced as the response of herbage nutrients to differences in temperature. Therefore, differences in herbage CP, ADF, and ADL contents were primarily influenced by temperature, and the warming trends seen in the climate of the Tibetan Plateau over the last 40 years would enhance herbage respiration. This is especially true of increases in nighttime temperatures. This tends to work against the accumulation of some soluble matters such as protein, ether extract, and nitrogen free extract, and is better suited to the accumulation of insoluble lignin.

2. Carbon cycling in the alpine grassland on the Qinghai -Tibetan plateau

(1) Carbon balance of the alpine grassland ecosystem

Despite the large difference in time between carbon uptake and release (carbon uptake < release time), the Kobresia humilis meadow and shrub meadow were carbon sink (78.5～192.5gC·m^{-2}yr^{-1}and 58.5～75.5gC·m^{-2}yr^{-1}, respectively), while swamp meadow's annual atmospheric release is16.10～76.73gC·m^{-2}yr^{-1}. This is probably because the ecosystem respiration at our site was confined significantly by low temperature and small biomass and usually soil moisture was not limiting factor for carbon uptake. This proves that the Kobresia humilis meadow and the shrub meadow have relatively low potential for CO_2 uptake and release compared to C4 grasslands, a number of lowland grasslands, and forests. Moreover, swamp meadow has relatively high release potential.

(2) Various characteristics of CO_2 flux over the alpine grassland

In this alpine grassland, temperature is apparently the dominant factor controlling gross primary production (GPP) and ecosystem respiration (Reco) dynamics, but the relationship between temperature and GPP or Reco changed, depending on seasonal variations. Monthly net ecosystem CO_2 exchange (NEE) variations are extremely prominent, with CO_2 release having two annual peak periods (April between May and October, respectively), carbon uptake was mainly attributed from June, July, August, and September of the growing season. In July, NEE reached seasonal peaks(Kobresia humilis meadow:3.9 $gCm^{-2}day^{-1}$; Potentilla fruticosa shrub meadow: 4–5 $gCm^{-2}day^{-1}$; wetland meadow:3.9 $gCm^{-2}day^{-1}$). the Kobresia humilis meadow, the shrub meadow and the swamp meadow's highest CO_2 uptake rates are 16.78, 10.42 and 16.57 $\mu mol \cdot m^{-2} \cdot s^{-1}$ respectively, while their highest CO_2 release rates are 8.22, 7.73 and 18.67$\mu mol \cdot m^{-2} \cdot s^{-1}$ respectively.

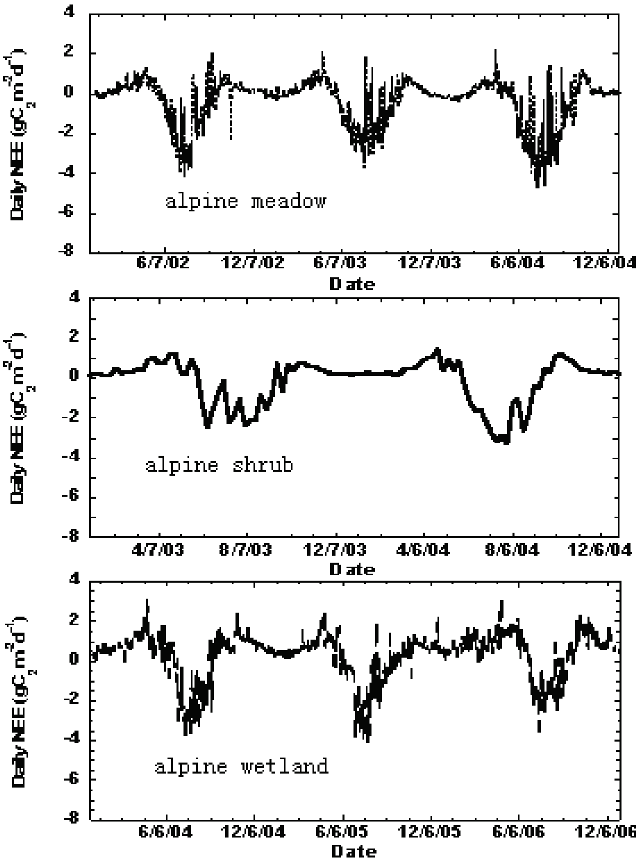

Fig. 31.2 The seasonal variations of net ecosystem CO_2 exchange over the alpine meadow, alpine shrub and alpine wetland

(3) Relationship between CO_2 flux and environmental factors

For the same photosynthetic photon flux density (PPFD), GPP was significantly higher on cloudy days than on clear days. However, mean daily GPP was higher on clear days than on cloudy days. Before 14:00 hours (Beijing time), light response increases with rise of PPFD values, and then starts to decline. In the afternoon, the values of NEE responded linearly to PPFD during every month, with small intercept. The differences between before noon and afternoon indicated there apparently no PPFD saturation in afternoon. With high PPFD, NEE decreased as air temperature increased from 10℃ to 23℃. The greater the difference between daytime and nighttime air temperatures, the more the sink was strengthened. Daytime average water use efficiency of the ecosystem (WUEe) were 8.7 mg (CO_2) (g H_2O)$^{-1}$ and 6.5mg(CO_2)(g H_2O)$^{-1}$ in the Kobresia humilis meadow and the shrub meadow, respectively; WUEe values ranged from 5.8 to 15.3 mg(CO_2)(g H_2O)$^{-1}$. WUEe increased with the decrease in vapor pressure deficit. Daily albedo was negatively correlated with daily NEE. In general, Reco was an exponential function of soil temperature, but with season-dependent values of Q_{10} (rate of change in soil flux with a 10℃ change in temperature). Soil temperature was the major environmental factor controlling soil respiration rate, low temperature limited ecosystem respiration. Soil water availability was high in the alpine meadow. The high soil water might reduce the ecosystem respiration. It seems to be difficult to separate the effects of the temperature and soil water contents on the ecosystem carbon budget. However, soil water content varied sharply during periods as short as a week or so, while temperature varied less and more gently at similar temporal scales. We, therefore, tentatively conclude that high soil water content is correlated with low ecosystem respiration at nighttime for this alpine ecosystem.

(4) Effects of grazing on CO_2 flux

Grazing intensity markedly altered the soil respiration rate of an alpine grassland ecosystem. Soil CO_2 efflux decreased by about 50% when grazing intensity was approximately doubled. The soil respiration rate was lower at the heavy grazing (HG) site than at the light grazing (LG) site at the same soil temperature. The HG site had a significantly lower root biomass and a lower soil organic carbon content at the surface soil from 0 to 10 cm than the LG site. The results suggest that the lower proportion of root biomass at the HG site is mainly responsible for the low soil respiration rate.

(5) Control process

The current CO_2 sink strength seems small and is comparable with many other subalpine ecosystems reported so far. This dependence seemed to be related to the accumulated biological effects that resulted from previous temperatures, that is, cumulative temperature and consequent plant growth. The annual NEE in the alpine grassland was comprehensively controlled by the temperature environment, including its effect on biomass growth; the timing of rain events had more impact than the total amount of precipitation on ecosystem Reco and NEE. The carbon cycle of the Qinghai-Tibetan plateau is controlled by the following two approaches short-term control including day and night difference in temperature, precipitation, season length and leaf area and long-term control including biota, time and human functional on temporal scale; it is controlled by the following two approaches top-down climate factor (temperature and precipitation) and down-top biology factor (leaf area and grazing) on spatial scale.

3. Biological evolution and adaptation on Qinghai-Tibetan Plateau

For further understanding and elucidating what have triggered the high levels of biodiversity and molecular adaptive evolution, it is essential to investigated phylogenetic relationships and evolutionary patterns of organisms endemic to Qinghai-Tibetan plateau from morphological to molecular level.

(1) Molecular phylogeny and historical structure of fishes endemic to the plateau

The molecular phylogenetic relationships among the schizothoracine fishes, coupled with the morphological analyses revealed that the subfamily Schizothoracinae forms a well-supported monophyletic group having close relationship with species of subfamily Barbinae. The divergence of major clades within the subfamily Schizothoracinae happened during 11.7~10.9Mya and 10.1~9.4 Mya, and the main speciation events occurred largely 6.1~0.4 Mya, suggesting the major cladogenetic events and speciation of the subfamily Schizothoracinae are mostly correlated with the geological tectonic events and intensive climate shift occurred in the course of uplifts of the Qinghai-Tibetan Plateau. These species are endemic to the Qinghai-Tibetan Plateau, a region with a history of geological activity and a rich diversity of habitats that may have resulted in the parallel and reversal evolution of some morphological characters used in their taxonomies. A significant genetic variation was observed among populations within drainage systems and among drainage systems, indicating significant geographical structuring of Schizopygopsis pylzovi. The contemporary population structure and differentiation of Schizopygopsis pylzovi may be consistent with the historical tectonic events occurred in the uplifts of the Qinghai-Tibetan Plateau. The fluctuations of ecogeographical environment and major hydrographic formation might have promoted contiguous range expansion of freshwater fish population, whereas the geological barriers among drainages have resulted in fragmentation of population and restricted gene flow among populations. In addition, the significantly large negative Fs value (-24.91, $P<0.01$) of Fu's Fs test and the unimodal mismatch distribution indicate that the species Schizopygopsis pylzovi have undergone a sudden population expansion after the historical tectonic event of Gonghe Movement (0.11Mya).

(2) Genetic characteristics and domestication history of the yak

The divergence time of these two recovered lineages was estimated taking place more than 100,000 years ago, far earlier than the possible colonization of human beings in the Qinghai-Tibetan Plateau. Most interestingly, we found that these two deeply divergent maternal lineages occur in a single, small, wild population. This finding suggests that the deep genetic lineages of the domestic yaks are not from the discrete wild populations. Despite the highly diversified morphology, each breed contains the haplotypes of the two main lineages and smaller identified clades, suggesting no maternal genetic differentiation between these breeds. Basing on it, we deduced yaks are derived from a single wild gene pool (possibly from the same wild population) and the diversified breeds have no genetic correlation with the population differentiation of the wild yaks. The morphological diversification of breeds resulted from the recent artificial selection since the domestication. Furthermore, the earliest domestications probably occurred around Qinghai and Tibet—the current wild distribution because these two regions contained high genotype diversity. We further estimated the domestication probably took place between 8,000 and 10,000 years ago. This estimation is in agreement with the archeological record of yaks and the Qinghai-Tibetan Plateau ecosystem transformation from forest to grassland.

(3) Adaptation and evolution of functional gene under extreme environment

In order to elucidate the underlying mechanisms and adaptive strategies of the mammals living on Qinghai-Tibetan Plateau, we focus the work on two key genes. At first, cloned full-length cDNA of pika leptin, and examined the extent of leptin variations within the Ochotona family through evolutionary analysis, also compared its mRNA expression in different altitudes (3200 and 3900m). Results showed that the full-length pika leptin cDNA was 3015 with 504bp open-reading frame encoding the precursor peptide of 167 amino acids including 21 residues of signal peptide. The deduced amino acid sequence of the Pika leptin shared the identity of 70-72% with that of other species and its predicted molecular structure was similar with other species. There were unique genetic variations in pika leptin sequences, occurring at twenty sites of amino acid sequence. Further we identified them as the positive selection sites located in some key functional-constraint regions of leptin in other vertebrate lineages, that is to say, adaptive evolution happens in pika leptin. With the increase in altitude, the expression of leptin gene in mRNA level was enhanced, suggesting that leptin is sensitive to high-altitude cold and hypoxia environments and may play one important role in pika's ecological adaptation to harsh plateau environment. HIF-1α is evolutionarily conserved in plateau pika. HIF-1α protein had a high expression and was significantly present in cellular nucleus under physiological conditions, the molecular weight and localization of which are identical to plateau pika HIF-1α (ppHIF-1α) protein in vitro in different cell lines. The expression of HIF-1 α protein was significantly higher in plateau pikas than mice, and was tissue-specific in plateau pikas. There was a high expression in lungs, livers, spleens, kidneys and brains, among which, the expression in brains was the highest. Immunohistochemistry analysis revealed that ppHIF-1 α protein displayed tissue-specific localization and was present in cell nucleus. In brain neurons, ppHIF-1 α displayed dynamic cellular localization. Further, the expression of HIF-1α protein was related with the altitudes. As the altitudes increase, the expression of ppHIF-1 α was significantly enhanced in kidneys and lungs. The unique expression patterns of ppHIF-1α protein may be one way for plateau pika to adapt to high-altitude environments. All the data suggest that HIF-1α probably plays an important role in the physiological process that plateau pika adapts to high-altitude hypoxia on Qinghai-Tibet plateau.

4. Alpine grassland degradation, re-vegetation and sustainable development on the Qinghai-Tibetan Plateau

Recent years, the alpine grasslands on Tibetan Plateau are suffering from quite severe degradation. Serious grassland degradation is endangering eco-environment of this region. The degraded grassland occupied about one third area of the all investigated grasslands on the Tibetan Plateau, and the current productivity of plateau grasslands was about 30% less than the productivity measured only two decades ago. At the same time, the native fauna of the Tibetan Plateau has been greatly reduced, and nearly every medium-to-large mammal species is now classified as threatened. It has become increasingly clear that the alpine grassland ecosystem on Tibetan Plateau is in danger of losing much of its native species, breaking the balance of grasslands ecology, and its ability to support sustainable pastoralism, the region's primary economic activity.

(1) Alpine grassland degradation

Alpine grassland degradation is a process of reversing succession. It always has the sequence as follows: non-degraded grassland → lightly degraded grassland → moderately degraded grassland → heavily degraded grassland. According to the relative value of above-ground biomass, plant coverage, proportion of palatable herbage and soil hardness, all grasslands is divided into 4 phases as which are non-degraded grassland, lightly degraded grassland, moderately degraded grassland, and heavily degraded grassland, respectively. In summary, with the degradation extent from light to heavy, above-ground biomass, plant coverage, proportion of palatable herbage, and soil hardness will decrease as well as soil moisture, organic matter content of the soil. Plant diversity and richness index had decreasing trends from non-degraded grassland to heavily degraded grassland with the method of principal component analysis.

There was about 4251.10×10^4 ha degraded grassland, 32.69 % area of the all investigated grassland on Tibetan Plateau. Heavily degraded grasslands covered an area of 703.19×10^4 ha, about 16.54% of degraded grassland, and were also related to the winter and spring pastures, mainly at the places of Tibet, Qinghai, and Gannan. Grassland degrading speed in the past 10 years was increased from 3.9 % in 1970s to 7.6 % in 1990s at the headwater of three rivers. However, the degrading trend of alpine grassland is still not reversed.

(2) Degraded grassland re-vegetation

Alpine grassland degradation was caused by integrated effect of anthropogenic and natural factors. Anthropogenic factors include seasonal over-grazing, blind reclamation of grassland, mining, road construction, gold and sand collection, etc.. Natural factors include impact of climate warming and drying, rodent and insect pests, wind erosion, freeze-thaw striping of sod layers, etc..

Serious grassland degradation is endangering eco-environment of the Tibetan Plateau. Environmental degradation of the grassland is evident enough that it has captured the attention of not only ecologists but also government officials. Facing this serious situation, local government and the scientists from the Chinese Academy of Sciences, Qinghai Province, Tibet Autonomous Region, European Union Delegation, and United States of America have paid full attention to grassland degradation in order to restore degraded grassland, protect natural pasture and eco-environment. A series of experiments and integrated grassland management practices have been carried out on the degraded grassland since 1980s. Utilizing the principles of restoration ecology, some effective measures and integrated countermeasures for restoration of degraded grassland have been developed in the Haibei Station of the CAS and headwater of three rivers, such as Establishment of artificial and semi-artificial grassland, Rodent and ruderal control, Optimization of the ecological structure of livestock, Rational management of alpine grassland and livestock and Integrated restoration of degraded grassland.

(3) Sustainable development and management of animal husbandry on alpine grasslands

Since the productive capabilities of sheep and yaks differs by species and age group, there is an optimal structure of species age groups and gender ratio that maximizes the yield of the grassland - livestock ecosystem. This practice will decrease the grazing pressure of natural grassland and prevent grassland from degradation effectively. On a theoretic study, on a per capita basis, 30 % should be yaks, and 70 % should be sheep and goats. Female sheep with reproduction capability in one herd should reach 48 to 50 %. About 30% of the sheep should be slaughtered by the end of the each summer so that the herd undergoes a three to four years cycle. Now, some female sheep will reach five or six years of age because of cultural norms, i.e., Tibetans are reluctant to slaughter animals. Experiments indicated that this practice was a successful way on Tibetan income increase and grassland protection in the Haibei Station of the CAS and headwater of three rivers.

The failure of the utilization and management of grassland system can lead to grassland degradation. Rational management of alpine grassland and livestock can lighten grazing intensity and prevent grassland from degrading succession. 45% of utilization rate of herbage in each season was suitable for grassland and livestock production. Seasonal animal husbandry should be carried out according to the spatio-temporal characteristics of grass growth. The methods include making full use of pasture in warm season, converting the grass into livestock product quickly, protecting and enlarging the area of cold season pasture, and determining the livestock number based on the herbage yield. the development of seasonal animal production via improving species; building plastic greenhouse shelters to protect animals in winter thereby to reduce their energy consumption for maintenance; providing supplementary food in winter to increase the productivity of female and young animals; and applying artificial stimulants, regulators, and feed supplements in the growing season to accelerate the growth of animals in one year. Rational management of alpine grassland and livestock will make animal husbandry develop healthy in the headwater of three rivers. To acquire the goal of sustainable development and the optimal management of alpine grassland, all of these measures discussed above are necessary in future.

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32

Evolvement, Change of Primary Ecological Processes and Environmental Effects of the Marshes in the Sanjiang Plain

Scientific research progress of Sanjiang Plain Marsh Ecological Station

Introduction of Sanjiang Plain Marsh Ecological Experiment Station

The Sanjiang Mire Wetland Ecological Experimental Station was established in 1986, joined in Chinese Ecosystem Research Network（CERN）in 1992, and became the national field observation and research station in 2005. The Sanjiang Plain is one of the largest concentrative distribution areas for freshwater marshes in China. There are many kinds of herbaceous marshes and swampy meadows in the low plain whose altitude is 50-60 m, annual mean temperature 1.9℃ and annual total precipitation about 600 mm. The main crops of the plain are soybean and rice. The Sanjiang Plain is a typical distribution area representative for the marshes of the cold and wet low-plain with seasonal freezing and thawing in the middle latitude of our country. The Sanjiang Plain Mire Wetland Experimental Station（133°31′E，47°35′N）lies in the interfluve between Bielahong River and Nongjiang River. The station takes the marsh wetlands of Sanjiang Plain as the main objects and develops long-term field observation for the environmental factors and primary ecological processes of the marsh wetland ecology system. The station also provides basic data support and research platform for the ecological processes of mire wetland, regional mire wetland resources conservation and the management of regional ecology and environmental safety.

The station will become the important field base for the observations and researches on ecological environment and the basic station in the network researches on global changes in the future. The station faces the demands of national environment and resources and the long-term ecosystem researches, developing long-term field observation and comprehensive study on marsh wetlands, researching the natural environmental change and the marsh wetland ecosystem processes under human influences, the temporal and special characteristics of the variation, the mechanism and environmental effect and setting up the demonstration site for reasonable utility and sustainable management of marsh wetlands. The main research directions are as the followings: (1) wetland ecosystem process and evolution law; (2) wetland ecosystem structure, function and environment effect; (3) the recovery of degenerated wetland ecosystem and sustainable management.

1. Observation methods and techniques of wetland ecosystems

We analyzed the domestic and international history and development tendency of wetland ecosystems observation and then brought forward the principles on selection and setup of wetland observation site. After comparing the index systems of wetland observation, we put forward the index system fitting the field observation of domestic wetland ecosystem and then designed the detailed field observation methods and techniques.

2. Surface water flux and water balance of marsh wetland ecosystem

Through long term in situ observation, we investigated marsh evapotranspiration and the variation characteristics of surface fluxes, and then set up marsh evapotranspiration model and the model on precipitation runoff of marshy river (Fig. 32.1). After analyzing the water consuming characteristics of marsh water balance, we found that the amount of marsh evapotranspiration was 1~2 times of that of free water surface, while the amount of rice paddy evapotranspiration was 10%~28% higher than that of the marsh. The total marsh evapotranspiration during the growing season was 420~430 mm. All these conclusions provide the scientific basis for the water management of marsh ecosystem conservation.

3. Evolvement process and biodiversity dynamic of the Sanjiang Plain

Studies show that the landscape structure has changed dramatically in the Sanjiang Plain over the past 50 years. Longitudinal gradients of the wetland landscape tends to be simplified, and few of transverse gradients characteristics exist now; percentage of isolated landscape increases from 49% in the 1980s to 98% at present; landscape diversity index are decreasing, the species richness decreased by 13% and the height of the predominance species decreased by 24.4% compared to that of the 1970s.

Results indicate that wetland landscape fragmentation is the main reason endangering the survival of more than 50 vascular plants. Wetland plant community succession has taken on dramatically. C.angustifolia meadow community (density, 45%~65%) has replaced the C.lasiocarpa community (density, 29%~58%) and becomes the main vegetation types in the Sanjiang Plain. All of these researches can be taken as basis for wetland conservation and management in the Sanjiang Plain.

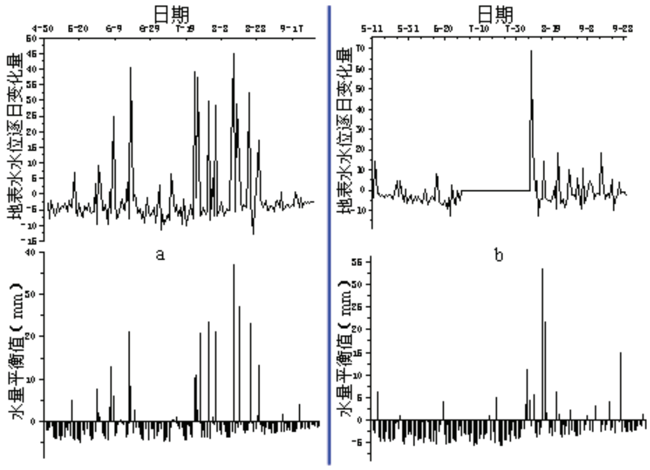

Fig. 32.1 The variation of water table and the water balance of marsh wetland

It is convinced that dynamics of predominant plant communities is related to the hydrological conditions of the marsh in the Sanjiang Plain. Water level is the key factor influencing the dynamics of plants densities and diversity indexes, and induces changes of the predominant communities. Species densities reduced as the water level increased; biodiversity index was higher in shallow water (0～20cm) and decreased significantly with the increase of the water level. Changes in water quantity determine the spatial distribution pattern of the plants. But responses to the hydrological dynamics varied with plants, and were most dramatic for C. lasiocarpa and C. meyeriana which are typical plants in the Sanjiang Plain.

The accumulation of N、P in the marsh has significant impact on species richness and diversity index. Exogenous nitrogen input, at some extent, can enhance wetland species richness. Lack of phosphorus produced more important impacts on species diversity than the accumulation of nitrogen in wetland. Excessive phosphorous input reduced species diversity while proper nitrogen input can increase it. Long-term exogenous nutrient elements input and accumulation can lead to interspecies replacement, and change the structure and functions of the wetland ecosystem.

Changes of nutrient elements impact the allocation of nitrogen and phosphorous and C/N in plants and marsh soil. The close relationship was found between the species richness and plant N/P (Fig.32.2). When the plant N/P of the marsh vegetation community was about 9.5, the species richness was the highest, when the plant N/P was between 2.0 and 9.5, the species richness increased with the increase of N/P and when the plant N/P was higher than 9.5, the wetland species decreased gradually. Therefore, the plant N/P can be taken as a sensitive indicator for nutrients restriction on plant growth. It was also concluded that the species richness increased with increasing soil pH value at pH of 5.6～6.8 (Xu et al., 2006).

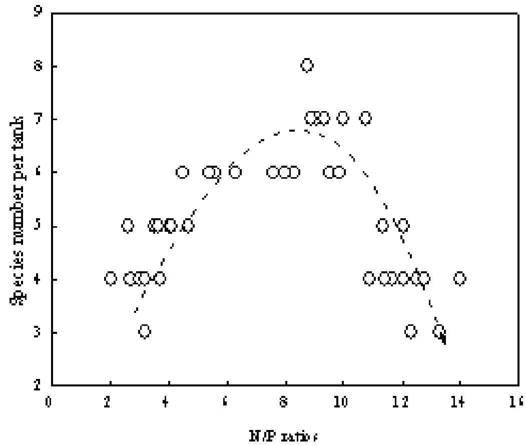

Fig. 32.2 The relationship between marsh plant N/P and species richness

4. Environmental changes of marshes under anthropogenic activities and its ecological effects

We studied the environmental effects caused by the changes of land surface during the past 50 years in the Sanjiang plain. After 4 times of large-scale reclamations（decreased from 5,345,000 hm^2 to 1,041,000 hm^2 ）and enormous changes on land surface characters in the Sanjiang Plain, the results revealed the climate change features and extents, the variation regularity of latent and sensible heat fluxes and their relationship with radiation balance.

We found that after the marsh was converted to farmlands, the proportion of sensible heat flux to the radiation increased from 20% to 65%, the average air temperature enhanced about 1.2-2.3℃ in local area, and the amount of precipitation reduced at the rate of more than 2.0mm a^{-1}, thus the regional water and heat balance regularities changed obviously.

We also studied the relationship between the marsh ratio and the time series of maximal flood peak flux in the up, middle and down of Naoli River in Sanjiang plain. Our results indicated that the time series of maximal flood peak flux in downriver area（higher marsh ratio）was about 50%, which was lower than upriver area, and we testified that marshes have the notable hydrological adjusting function and play an important role in flood equilibrium. Before 1970s, marshes were all in natural states in the drainage basin of Naoli River, and the frequency of drought and flood was 23.8% and 33.3%, respectively. However, when 96% of the lower wetted meadow was converted to farmland and 45% of marsh was converted to low moisture meadow, the frequency of drought and flood increased to 33.3% and 47.9%, respectively, and its disaster frequency increased by 10% ~ 15% （Fig. 32.3）. We also found that marsh has stronger water purification effect. Water and nutrition conditions were the pivotal factor which controlled the ecological process in marshes, and there were threshold values in the absorption of N and P in wetland ecosystem. However, only in a limited extent, marshes have purification effect which correlated with the growing process of plants. This is the pivotal parameter in the management of wetland ecosystem. We also put forward elementarily the optimized management mode on wetland ecosystem.

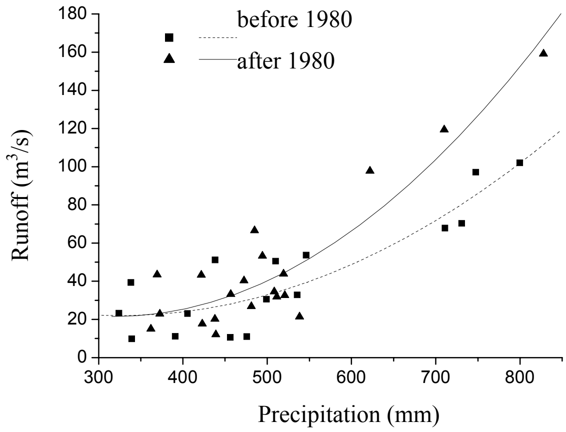

Fig. 32.3 The influence of wetland change on precipitation runoff in the Raoli River drainage area of Sanjiang Plain

5. Carbon and nitrogen biogeochemical processes of marshes

Our studies investigated the accumulating character and the distribution mode of carbon in typical freshwater marshes. We found that the seasonal dynamic of soil organic carbon was strongly correlated with the activity of cellulase, amylase and ß-glucosidase. We also found the peak-value contents of rhizosohere soil organic carbon were correlated with the growing phase of plants, and were identical with the seasonal variation of active organic carbon in rhizosphere soil. The studies indicated that higher plant productivity, over-saturation water condition, lower annual average temperature of soil and slower decomposition but longer turnover rates of organic matter were the main reasons that led to carbon accumulation in marshes. We also estimated the average deposition rate of peat in the Sanjiang plain, which was about 0.028 cm yr^{-1}～0.043 cm yr^{-1}.

It was found that water level fluctuation, topsoil temperature, plant growth and Eh condition are the major factors that influence the seasonal changes of carbonaceous gases emission, and the change of precipitation is the main factor that effect carbonaceous gases emission which is strongly related with the contents of dissolved organic carbon and dissolved organic nitrogen in marsh soil. Meanwhile, we found that the freezing and thawing was one of the key factor that influence carbon balance in marshes (Song et al, 2006), and had an important influence on the configuration and transference of phosphorus（Wang et al, 2007）(Fig. 32.4).

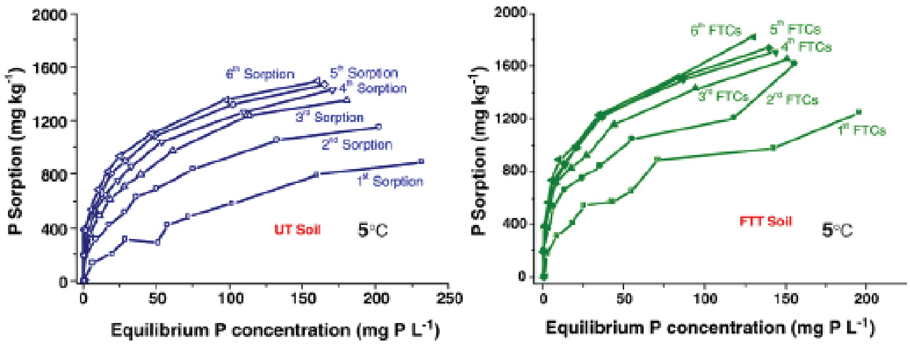

Fig. 32.4 The influence of freezing and thawing on the phosphorus cycle of marsh soil

We have testified that the changes of exogenous nitrogen and phosphorus import which caused by human activities have significant impact on the carbon processes in Sanjiang plain marshes. The results showed that too much or too little exogenous nitrogen or phosphorus import would produce negative effects on the bioaccumulation of carbon, and prevent the absorption of nitrogen and phosphorus by plants. The biomass of plant community decreased with the increase of nitrogen supply in submersed condition. However, the biomass increased with the increasing of nitrogen or phosphorus in meadow marsh. Meanwhile, there were obvious changes in the decomposition rate of organic matter, and too much exogenous nitrogen input could restrain the decomposition of organic matter in permanently inundated marsh.

6. Soil quality changes during marsh cultivation and restoration

Our results show that wetland cultivation leads to an increase of daily average temperature in rhizosphere by 3℃~4℃ higher than that in natural wetland, with melting date of frozen layer ahead of schedule 55~62 days, which notably affects mineralization of soil organic carbon and nitrogen, resulting in declines of their contents in soil. During the initial 5-7 years after cultivation, organic carbon in topsoil decreased rapidly and then slowed down in the following 15-20 years with a constant of 25 g kg^{-1}. The quantity of soil organic carbon decreased 60% in the first 5 years after cultivation, with a mean annual rate of 12%, decreased 15% for the following 10 years, and 5% for additional 20 years, which can be seen in the rising proportion of heavy fraction carbon as well as the falling proportion both in free-light fraction carbon and soluble carbon in soil. Simultaneously, the ratio of DOC to TOC fell at first, but then increased with the continuous cultivation afterwards. Long-term cultivation led to the increased proportion of soluble organic carbon to organic carbon in soil, which tends to accelerate the loss of soil organic carbon. After the cultivation of marshes, the soil microbial quotient and basal respiration rates decreased rapidly, however, qCO_2 increased obviously (Zhang et al, 2006) (Table 32.1).

Table 32.1 The variation of carbon fractions in different land utilization after the cultivation of marsh welands

		DOC		MBC		HWC	
Sites‡	Soil depth	June	Sept.	June	Sept.	June	Sept.
	cm	mg kg^{-1}					
C	0–10	153.4(10.1)^{d}§	183.9(16.6)^{c}	912.6(25.3)^{c}	1125.6(27.7)^{cd}	2075.8(103.9)^{d}	1787.4(112.1)^{d}
	10–20	150.4(9.2)^{d}	174.9(16.8)^{c}	873.9(25.7)^{c}	965.7(27.7)^{d}	1918.3(104.9)^{d}	1611.5(112.8)^{d}
	20–30	100.5(9.8)^{e}	126.4(10.2)^{cd}	338.1(14.7)^{d}	513.3(38.4)^{e}	1265.4(128.1)^{e}	1140.5(88.7)^{e}
	30–40	87.7(9.3)^{e}	83.9(8.1)^{d}	86.9(2.3)^{de}	248.9(7.7)^{e}	813.8(76.4)^{e}	793.5(45.0)^{e}
A	0–10	198.0(18.7)^{c}	203.8(18.2)^{b}	1272.1(109.9)^{b}	1682.8(154.7)^{c}	2548.5(241.3)^{c}	2302.6(207.1)^{c}
	10–20	164.6(17.7)^{cd}	171.8(19.2)^{c}	1246.8(119.9)^{b}	1365.4(158.7)^{c}	1931.2(239.3)^{d}	1725.7(217.1)^{d}
	20–30	95.3(8.9)^{e}	144.2(13.6)^{cd}	210.5(19.8)^{d}	476.1(44.9)^{e}	965.5(91.0)^{e}	1106.0(104.3)^{e}
	30–40	93.1(8. 8)^{e}	85.3(8.0)^{d}	37.6(3.5)^{de}	349.9(32.9)^{e}	754.7(71.2)^{e}	873.6(82.4)^{e}
U	0–10	229.1(21.6)^{b}	220.0(20.7)^{b}	854.6(80.5)^{c}	941.9(88.0)^{d}	2356.3(221.2)^{c}	2392.3(223.5)^{c}
	10–20	213.3(20.6)^{b}	196.9(20.7)^{b}	515.6(80.6)^{d}	675.8(88.8)^{e}	1235.3(202.2)^{e}	1741.4(225.6)^{d}
	20–30	89.3(8.42)^{e}	95.2(8.9)^{d}	104.3(9.8)^{de}	25.6(2.4)^{ef}	592.4(55.9)^{e}	754.8(71.2)^{e}
D	0–10	463.9(43.7)^{a}	415.9(39.3)^{a}	1528.6(523.7)^{b}	5566.1(143.1)^{a}	3561.4(325.8)^{a}	7114.5(671.2)^{a}
	10–20	430.2(42.7)^{a}	438.9(39.2)^{a}	2534.2(514.8)^{a}	3203.9(144.1)^{b}	4445.0(315.8)^{a}	5263.0(670.8)^{b}
	20–30	122.5(11.6)^{de}	174.9(16.5)^{c}	925.8(141.1)^{c}	1496.1(87.3)^{cd}	3074.9(289.9)^{b}	1771.4(167.1)^{d}
	30–40	109.3(1.9)^{e}	121.5(1.1)^{cd}	393.8(53.9)^{d}	571.7(37.1)^{e}	1210.9(114.2)^{e}	1226.4(115.6)^{e}

† HWC is hot water-extractable C; MBC is microbial biomass C; DOC is dissolved organic C.

‡ *C* is field cultivated, *A* is a field that was abandoned for 6 yr after being cultivated for 10 yr, *U* is upland forest, *D* is *Deyeuxia angustifolia* wetland. Soils at all sites were Hydric Medihemists.

§ Data shown are means with the standard errors in parentheses (n = 3). Values in a column with the same letter are not significantly different at $p < 0.05$.

After the cultivation of marsh, the soil physical properties changed significantly with the rapid decrease of water-stable macro-aggregate in surface soil. The decrease was most obviously in the initial 5~7 years after cultivation. After 3 years of cultivation, the water-stable macro-aggregate in surface soil decreased from 55% in natural marsh to 25% in cultivated farmland and further decreased to 15% after 5 years of cultivation. After 15~20 years of cultivation, it was stable at the level of 4%~6%. The amount of water-stable micro-aggregate in the range of 53-250μm increased from 26% before the cultivation to 47% after 3 years of cultivation and was stable between 55-60%. Soil bulk density reached an stable range of 1~1.2g cm^{-3} after 5 years of cultivation. Topsoil porosity decreased by 28% after 15-20 years of cultivation.

It would take 17~25 years for the organic carbon content in the cultivated surface soil to recover to the original level of Deyeuxia angustifolia dominated marsh. After 3~9 years of restoration of cultivated farmland, the content of microbial biomass carbon increased more rapidly than that of total carbon and thus can act as a index for the dynamics of soil organic carbon.

7. Carbon and water exchange between atmosphere and two ecosystems (marsh and rice paddy)

We found that marsh wetland was the sink of CO_2 and the source of CH_4. The CH_4 emission showed different temporal and spatial characteristics in different marsh wetlands. The CH_4 emission and soil respiration flux in the marsh of Sanjiang Plain were about 4.7~5.4 times and 3.5 times higher, respectively, than those of Ruoergai marshes. We also found that the seeper of spring thaw played an crucial role in annual CH_4 emission, and the CH_4 emission during this period was about 15%~23% of annual CH_4 emission. The greenhouse gas emissions increased significantly during the freeze-thaw period, however, the marsh wetland was a sink of N_2O during the snow-covered winter. The seasonal pattern of CO_2 flux in marsh and the rice paddy and soybean field reclaimed from marshes are similar, but the variation extent differed greatly. As far as the carbon sink effects are concerned, during the growing season, the carbon accumulation periods were from early-June to mid-September in marsh, early-June to mid-September in rice paddy and early-July to late-August in soybean field. Carbon emission occurred mainly in the other periods of the growing season (Yang et al, 2006).

After the additional input of nitrogen, the CO_2 emission, nitrification, denitrification and the CH_4 emission of plant-soil ecosystem increased, while the active organic carbon and soluble organic carbon in soil deceased significantly. Too much input of additional nitrogen caused the decrease of net ecosystem CO_2 exchange, however, the input of nitrogen did not change the carbon sink function of marsh but weakened the sink function (Fig. 32.5). Additional input of nitrogen lead to the increase of global warming potential, and the enhancement of the greenhouse effect of CH_4 and N_2O from both long and short time scales (Zhang et al, 2006).

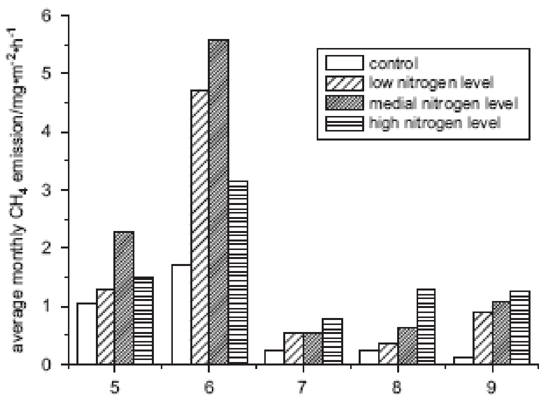

Fig. 32.5 The variation of greenhouse gas emission in the marsh wetlands after the additional input of nitrogen

In our research, we found that the marsh water flux had an important influence on carbon budget. When the water flux was minor (latent heat flux<100 W m^{-2}), the increase of water flux had significant influence on the increase of net carbon accumulation, and the extent of the influence differed during the growing season. When the water flux was higher (latent heat flux >100 W m^{-2}), with the increase of water flux, the increasing extent of net carbon accumulation decreased significantly, and the tendency was more obvious with the further increase of water flux.

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33

Desertification Process and its Reversion in the Agro-pastoral Area of Northern China

Scientific research progress of Naiman Desertification Research Station

Introduction of Naiman Desertification Research Station

NDRS is located at Naiman County (120o42'E, 42o55'N, 358m a. s. l.), eastern Inner Mongolia。It is subordinate to Cold and Arid Regions Environment and Engineering Research Institute (CAEERI), CAS. It is also affiliated to the Chinese Ecosystems Research Network (CERN), GTOS, Desertification Monitoring Network of State Forestry Administration (SFA), National Environment and Ecological Observation Network, and Natural Science Foundation of China (NSFC) as a Center for Youth Science Education in Horqin Sand Land.

The research orientation is desertification and its control in the semi-arid agro-pastoral transitional area in eastern China. It includes 1) process and mechanism of desertification and restoration; 2) function, structure and management of sand land ecosystems; 3) biological process and mechanism of degraded ecosystem restoration; 4) comprehensive utilization of sand land resources; 5) long-term monitoring on the changes of environment and resource and 6) organic C dynamics in relation to climate change.

The research goal is to reveal the causes, processes and mechanism of desertification, to predict the consequences and extent of ecosystem changes related to land use, to provide models and theoretic supports for efficient utilization of natural resources and environment protection, and to supply supports to the local and national decision making in environmental conservation.

NDRS has publishes six monographs, 500 research articles and won eight prizes by UNEP, Inner Mongolia Science and Technology Department, Gansu Sciences and Technology Department, Ministry of Science and Technology.

1. Introduction

According to UNEP (1997), 47% of the land surface of the earth is dryland, of which about 70% was degraded due to climate change and human activities, threatening about 1.2billion people in 110 countries and numerous plants, animals and microorganisms. The drought and starvation in late 1960s and early 1970s in Sahel triggered the research in desertification control and ecosystem conservation. The following UNEP conference on desertification in the capital of Kenya, Nairobi attached great importance to 'preventing desertification with a global united actions'. The global summit, conference of Environment and Development' in the capital of Brazil recapitulated desertification conservation as one of its important topics. In August 2005, UNEP and Chinese Academy of Sciences have jointly had a meeting in Beijing for 'Conservation and Development of Drylands'. These conferences have greatly pushed forward the research in protection of dryland, alleviation of ecological hazards and poverty in relation to desertification. Hence, research in the component, function and process of desertification-prone ecosystems in relation to climate change and human activity has become one of the top issues of dryland ecology, desert science, restoration ecology in dryland (John N. Thompson etc., 1999; Tim Flannery, 2001; NSFC，1997；2005).

China is one of the countries suffered from severe land degradation. In the past several decades, some countermeasures have been employed to increase vegetation cover, prevent land degradation and to alleviate poverty, such as 'Building shelterbelt in the northern part of Shanxi province, Gansu Province and Ningxia Hui Autonomous Region' in 1954. Following this project, the 'Three North Project' was put into action in 1978. Recently, the 'Natural conservation project', 'conversion cropland into woodland or grassland project' and 'Project for the protection of rivers' sources from degradation' have been implemented one after another. All of these projects have made some progresses, but desertification is still threatening the environment in China.

Horqin Sand land once was one of the grasslands in northern China. However, it became one of most severely desertified lands in northern China since the early of last century, particularly in 1950s, 1960s and 1970s. Annually, there was about 10 thousand ha of grassland and 7000ha of cropland engulfed by desertification and 30% of the cropland threatened by desertification.

Thus, as early as in 1966, some researchers from the former Desert Research Institute had carried out serious desertification survey in Horqin Sand Land, as a preparatory step for protection of Bejing-Tongliao Railway. After successful protection of the railway in the middle of 1970s and early 1980s, Naiman Station was established in 1985 for ecological research and monitoring. During the past 20 years, Naiman Station has made a great success in elucidation of desertification process, searching desertification control methods and disseminating its findings. However, the researchers in this station still face great challenge now and in the future.

2. Achievements

This part will focus on changes of soil, plants, water, land use in relation to desertification and desertification control to present the success stories of NDRS.

(1) Soil process of desertification

Soil is not only the carrier of plants, but also material provider to plants. Reversely, plant rewards soil with organic carbon (SOC) and nutrient imput (Li Yuqiang, 2006). Thus, it is valuable to monitoring the change in soil organic C and N for exploring the process and mechanism of desertification.

Research found that（Yongzhong Su, 2004a,b）SOC was decreased with fine particles, such as clay and silt, eroded away in the process of desertification（Fig. 33.1）. SOC was lost at the rate of 0.169 g kg-1with every 1% loss of soil clay and silt (Yongzhong Su, 2004c), while N reduced at 0.0215gkg-1. Changes of SOC and N could be expressed with formula (1) and (2):

SOC (g・kg-1)=0.169 (clay and silt %)+1.1484 (1)

TN (g・kg-1)=0.0215 (clay and silt %)+0.149 (2)

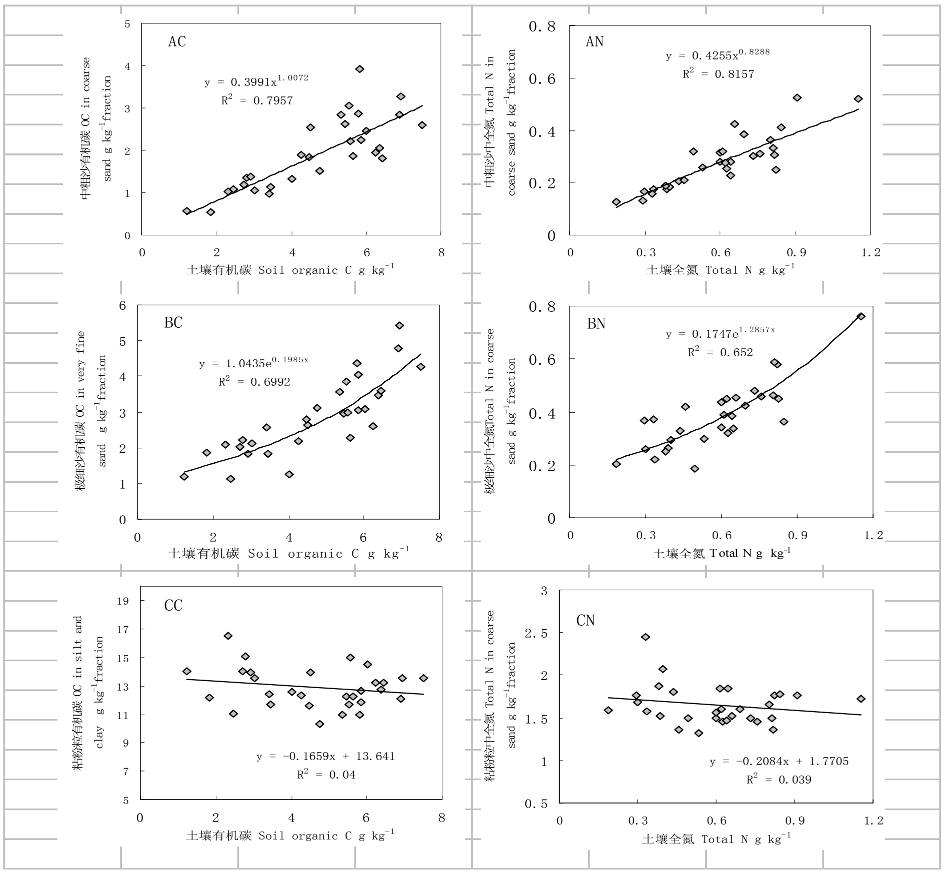

Fig. 33.1 Changes of SOC and total N in Horqin Sand Land (Yongzhong Su, 2004b)

From slightly desertified soil to severely desertified soil, SOC and N were lost by 91％的 and 95％, respectively (Zhao Halin, 2005). Loss of nutrient and destruction of soil structure due to loss of SOC are leading causes of desertification and biomass reduction (Halin Zhao, 2006).

(2) Biological process of desertification in Horqin sandland

Loss of nutrient and destruction of soil are essential characteristics and process of desertification (Zhu Z. D., 1994). When soil is degraded, the coverage is decreased at first, and then the decreases in species and bio-productivity of vegetaion.

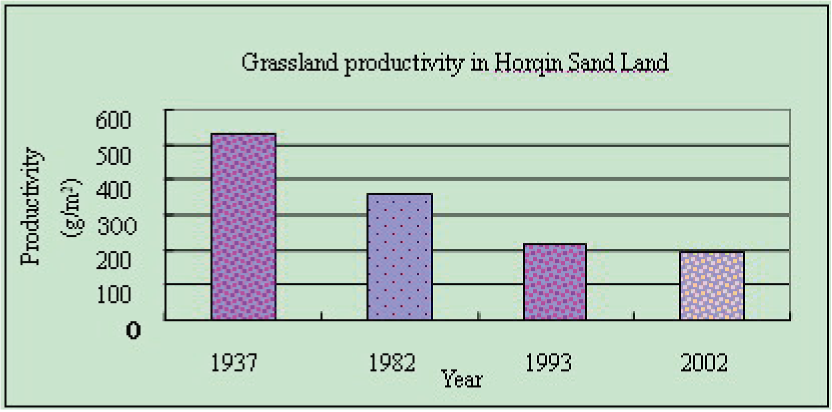

Fig. 33.2 Bio-productivity Change in relation to desertification

The original landscape in Horqin Sand Land is *Ulmus pumila* scattered *Leymus chinensis*（*Trin.*）*Tzvel. or Stipa grandis* grassland. The well preserved vegetation coverage found up to now is great than 50%, but it could be reduced to less than 10% within 5 years (Halin Zhao, 2001; 2003).

Concerning the composition of degraded vegetation, *Leymus chinensis*（*Trin.*）*Tzvel.* and *Stipa grandis* were retreated from succession, and then *Lespedeza davurica*, *Potentilla anserine* and *Leymus secalinus*. The species number was reduced from 10 -21 to 5-7, dominated with *Agriophyllum squarrosum (L.) Moq. , Salix gordejevii Chang et Skv., Caragana microphylla* and *Artemisia halodendron*., and some annuals in the last degradation stage.

Degradation has led to reduction of bio-productivity from 520g/m² in 1937, 350g/m² in 1982, 210g/m² in 197g/m² in 2002 in Horqin (Fig. 33.2). Vegetation degradation reduced the return of organic matter and nutrients to soil, and further more reduced the land productivity. This vicious circulation caused by vegetation destruction could be only eliminated with proper interference of human activity or improvement of natural condition.

(3) Water use of different vegetations

Water content of shifting sand is normally about 3%～4%，and 5%～6% immediately after rainfall. Seasonally, soil water pool in artificially reforested land is replenished in the period of May to September, and lost from October to April mainly due to evaporation. There is a layer of 0.2～1m in irrigated soil changed rapidly, denoted that this layer is affected by crop. According to the above soil water characteristics, annul property, water use by plants were calculated with water balance method and FAO Penman-Monteith foemula and measured with Lysimeter (Tonghui Zhao, 2004). The result showed that *Artemisia halodendron, Caragana microphylla* and *Hedysarum fruticosum* had a water sue rate of 190.4～394.3mg/g•hr，256.8～645.9mg/g•hr and 267.9～497.7mg/g•hr, respectively. *Pinus selvistris Var. Mongoliaca* and *Populus simonii Kitag.* has a water use rate of 133.7～284.7mg/g•hr and 186.6～387.6mg/g•hr.

Amount of water used by different communities in a growing season is ranged into Pinus *selvistris Var. mongolica*(452mm)>*Populus simonii*(419mm)>*Caragana microphylla*(412mm)> *Pinus selvistris Var. mongolica* + *Artemisia halodendron* (409mm)>*Hedysarum fruticosum* (396mm)> *Artemisia halodendron* (338mm) >control(shifting dune)(320mm), but annually, *Pinus selvistris Var. mongolica* (389mm)> *Caragana microphylla* (368mm) > *Populus simonii* (349mm)> *Hedysarum fruticosum* (352mm)> *Pinus selvistris Var. mongolica* + *Artemisia halodendron* > natural grassland (301mm) > *Artemisia halodendron*(296mm) > control(shifting dune) (289mm). The irrigated maize, wheat and rainfed millet consumed 496mm, 409mm and 331.2mm of water, respectively, in a growing season.

According to the above results and water carrying capacity, it is recommended that current tree density, 3000/hm^2 of *Pinus selvistris Var. mongolica*、3500/hm^2 of *Populus simonii*、4900/hm^2 of *Caragana microphylla* and 6500/hm^2 of *Hedysarum fruticosu, should be reduce to* 2140/hm^2， 2910/hm^2， 3770/hm^2 and 5410/hm^2, respectively. This adjusted density could bring no any harm to the ecosystems (Tonghui Zhang，2004Ph.D dissertation).

(4) Model of agro-pastoral compound ecosystem for sustainable use

In combination of the results in 2.3 and demonstration in the Yaoledianzi Villagge, it is found that the ration of Cropland: woodland: grassland should be around 1：1：4. It could not be the best proportion, but it is a better combination up to now (Fig. 33.3）(Zhao Xueyong, 2003; 2004).

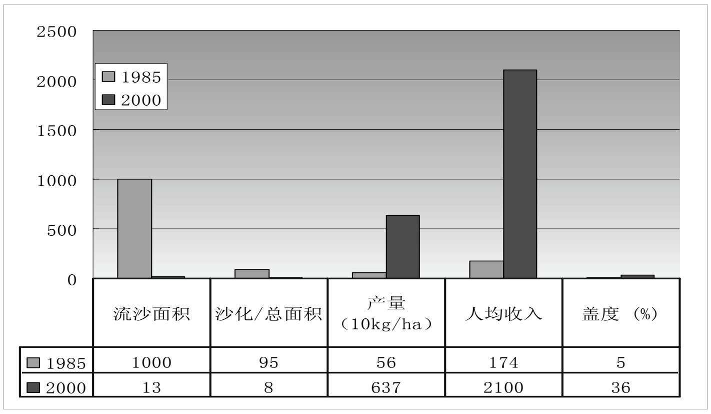

Fig. 33.3 Ecological and Economic gain in the demonstration Village

Increase in grassland is beneficial to restoration of degraded land on one hand, and provide materials for animal husbandry on the other hand. This model is valued as one of successful stories for saving the dryland by UNEP.

(5) Change of desertified land in the past 50 years

Based on former research findingds (Zhu Zhenda,1981)，analysis of satellite image found that since the middle of 1980s, desertification has been reversed from 61008km² in 1987 to 50198 km² in 2000, after the increase from 42300km² in 1959 to 51384km² in 1975（Wu Wei，2001, Ph.D. Dissertation(Table 33.1).

Table 33.1 Change of Decertified Land in the Past 50 Years in Horqin Sand Land (unit: km²)

Date	SD	HD	MD	LD	Area	Change
1959					42300	
1975	2829	7885	22495	18175	51384	+21.47
1987	5162	5422	21472	28950	61008	+18.72
2000	4674	5815	9009	30699	50198	-17.72

Note: SD: severely desertified land; HD: heavily desertified land; MD: moderately desertified land; LD: slightly desertified land;

This change was closely related to the participation of the locals and local governments, but it is more close to the research in desertification and demonstration of practical measures for desertification control and agro-pastoral development by the researchers of NDRS (Wu Wei，2001, Ph.D. Dissertation).

3. Conclusions

According to the analysis, above, it is concluded that loss of SOC and N is an essential process of desertification. Loss of SOC and N could be calculated with formula (1) and (2) below:

$$SOC\ (\text{gkg-1})=0.169 * \text{X(clay and silt loss rate\%)}+1.1484 \quad (1)$$

$$\text{TN (gkg-1)}=0.0215 * \text{X (clay and silt loss rate\%)}+0.149 \quad (2)$$

Desertification could lead to reduction of vegetation coverage from more than 50% to less than 10%, species number from 10-21 to 5-7, and the biomass from 520g/m²in 1937 to 350g/m²in 1982，210 g/m²in 1993 and 197 g/m²in 2002.

Water use by different communities in a growing season is in the order: *Pinus selvistris Var.* mongolica(452mm)>*Populus simonii*(419mm)>*Caragana microphylla*(412mm)> *Pinus selvistris Var. mongolica* + *Artemisia halodendron* (409mm)>*Hedysarum fruticosum* (396mm)> *Artemisia halodendron* (338mm) >control(shifting dune)(320mm). But annually, the order is changed into: *Pinus selvistris Var. mongolica* (389mm)> *Caragana microphylla* (368mm) > *Populus simonii* (349mm)> *Hedysarum fruticosum* (352mm)> *Pinus selvistris Var. mongolica* + *Artemisia halodendron* > natural grassland (301mm) > *Artemisia halodendron*(296mm) > control(shifting dune) (289mm). The irrigated maize, wheat and rainfed millet consumed 496mm, 409mm and 331.2mm of water in a growing season, respectively. This set of data provided a solid support to species choose and density decision in vegetation restoration in Horqin Sand Land and the areas alike.

According to the above data and demonstration, the proportion rate of cropland to woodland to grassland should be about 1:1:4. Of course, it is hard to say this is a best ration, but it has made a contribution to desertification control and proper land use strategy in the demonstration village. Since the middle of 1980s, desertification was reversed from 42300km² in 1959, 61008km² in 1987 to 50198 km² in 2000. Horqin Sand Land is the only land, as a whole, of complete desertification reversion in China. But it is still facing great challenge in front of climate change and population increase.

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34

Ecological Engineering Construction and Regional Ecological Restoration in Arid Desert Region

Scientific research progress of the Shapotou Desert Research and Experiment Station over the past 20 Years

Introduction of Shapotou Desert Research and Experiment Station

The Shapotou Desert Research Station was founded in 1955. It is one of the earliest established field long-term comprehensive observation of the Chinese Academy of Sciences. The station is located at the southeastern edge of the Tengger Desert in the Zhongwei city of Ningxia Hui Autonomous Region and lies at 104°57′E and 37°27′N, with an elevation of 1250m. Annual precipitation in the area is 186mm, mainly falls in June —August, annual evaporation 3000mm, mean annual temperature 9.6℃, and mean annual wind velocity 2.8m/s. As a composite district of calcic orthic aridsols and sandy entisols, the region is a steppified desert zone. Special geographical location determines its wide regional representativeness and regional boundary feature. As viewed from the climatic differentiation feature, it is located in a transition region between arid and semiarid zones, but as viewed from the natural landscape feature, the region to the east of the area is dominated by steppe and the region to the west of the area is dominated by desert. As viewed from the agricultural production ways, the region to the east of the area is irrigation agricultural zone, while the region to the west of the area is gradually replaced by rainfed agriculture. As the starting end if the Yellow River Irrigation District of the Ningxia Yingchuan Plain, irrigation agriculture in the region began in Han Dynasty. Viewed from the features of dust material transportation and aeolian sand movement, the region is located in an erosion-deposition transition zone; and viewed from the sand stabilization measures, it is a critical region of non-irrigation biological sand stabilization, to the west of the area irrigation is essential for the afforestation, while to the east of the area the mon-irrigation biological sand stabilization measures are feasible. Since the station is located at the tail end of the eastern monsoon, it has a special position in the physiographical and agricultural regionalization and the study of global changes, and also has important scientific significance in the multidisciplinary analysis and study, ecological process study, regional environment and resource investigations and applied basis studies for regional economic construction.

The Shapotou Station was officially approved as an open research station of the Chinese Academy of Sciences in September of 1990 and in 1992 it was listed as a station of China Ecological Research network (CERN) and in 2000 it was selected as a state key field scientific observation station by the national scientific and Technological ministry. In 2006 the station was officially listed as a national field scientific observation station and a national scientific popularization and education base. The station is a Research center of Drought and Destertification of the world laboratory (WL), a research point of UNESCO and MAB, a base of the International center for Research and Training on Desertification control and also a member of GTOS observation data and observation database of TWSNO.

With desert ecosystem, sandy land comprehensive rehabilitation and agricultural sustainable development as the research direction. The station mainly conducts the studies including arid desert region's ecological processes, restoration and reconstruction mechanism of damaged ecosystem, water balance of soil-vegetation-atmosphere system, eco-hydrological regulation mechanism of water cycle, desert environment and stressed physiological ecology, in the meantime, great attention is paid to the study and demonstration of desert rehabilitation and sandy land development techniques.

1. Key techniques for the establishment of vegetation in a desert with a precipitation of less than 200 mm

Based on the successful stabilization of mobile dunes, the Shapotou Station carried out long-term fixed site study on the theoretical pattern and technical system for the establishment of artificial vegetation under non-irrigation condition in the arid desert region. Long-term observation and study during last fifty years show that the establishment of vegetation restoration system dominated by xerophytic shrubs is the best model for the restoration of sand land ecosystem in the steppified desert and desertified steppe regions. The evolution of artificially established sand-binding vegetation verified a number of ecological principles for the restoration of vegetation and biodiversity in the arid region: In the earlier stage after establishing artificial vegetation, drought-resistant shrubs and sand fences can effectively reduce wind erosion of sand surface and ensure the stability of sand surface in the physical environment, in such a case the atmospheric dust and nutrients deposit on sand surface, thereby create a suitable condition for the invasion and spread of herbaceous plants, and the propagation of cryptogams makes the vegetation system more stable. The original vegetation with single community structure gradually evolves into the vegetation with complex multilayered structure and consisting of multifunction groups, such a change is the response of vegetation to the changes in the temporal-spatial pattern of the desert water environment. With the development of sand-binding vegetation, the distribution of precipitation is affected by surface structure and vegetation, the shallow soil layer becomes an active zone with largest water variations. This causes the shallow-rooted plants, including cryptogrammic algae to propagate extensively. These plants also evolve from pioneer colonized species to xero-mesophytic species, and some desert steppe species also gradually invade to become colonized species.

After 50 years of evolution the cryptogram in the sand-binding vegetation system increased to 40 species, other species included 16 herbaceous species, 28 bird species, 50 insect species and 23 macro-animal species. The restoration of biodiversity makes the relatively single sand-binding vegetation system evolving into a desert ecosystem with relatively complex structure and function. The continuous monitoring and study in the past half century have demonstrated that ecological engineering construction is a feasible measure to the restoration of regional ecosystem and biodiversity in arid regions of Chain and this also provides a scientific basis for the ecological construction in west China.

2. Ecological mechanism of maintaining vegetation stability and conceptional model for desert ecological restoration

Several hypotheses and conceptional models dealing with the grassland desertification or grassland degradation processes consider the shrubing of grassland vegetation in arid and semiarid regions as a striking feature of vegetation pattern changes due to grassland degradation or desertification. But the monitoring and study in Shapotou region in the past 50 years show that the shrub vegetation distributed in patches is also a basis for the restoration of grassland and the reversing of desertification. The establishment of artificial vegetation in the region began with the erection of sand fences and the planting of xerophytic shrubs. The presence of xerophytic shrubs caused the spatially heterogeneous changes of the original soil-relatively uniform shifting sand. The xerophytic shrub crown caused the redistribution of precipitation and atmospheric dustfall, this plus to litter accumulation and the formation of cryptogamic crusts accelerate the soil-forming processes under the canopy of shrubs and also create a condition for the invasion and establishment of herbaceous plants. But such processes reduce the precipitation infiltration into deep soil layer. With further desiccation of deep soil layer in the sand-binding vegetation area, the dominance and leading role of shrub species in the communities are gradually weakened or even tend to be withdrawn from the vegetation composition. Such a process correspondingly weakens the spatial heterogeneity of soil distribution due to the “fertile island effect” of shrubs. The massive propagation of cryptogams (algae, moss and lichen) on sand surface and the colonization of annual and perennial plants lead to the vegetation succession towards the herb-dominated species and the primary vegetation similar to those in the adjacent steppified desert and desertified steppe regions.

Therefore, the heterogeneity of the spatial distribution of soil resources plays an important role to the vegetation pattern and it is also a key factor affecting the degradation and restoration of vegetation in the arid regions. The research results in this respect have been published in 2004-2005 "Sciences in China".

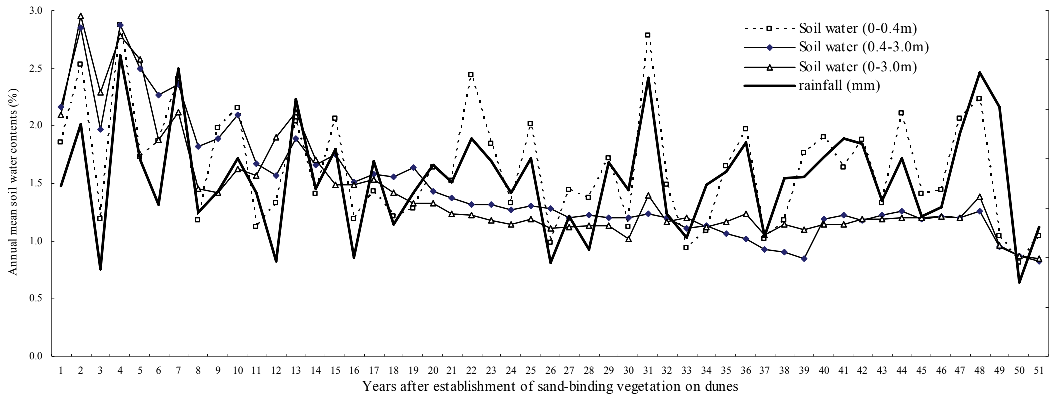

Fig. 34.1 Change of annual mean soil water content at different depyhs during 50 years after re-vegetation (site 1956)

3. Mutual controlling mechanism between vegetation and water cycle in arid desert region

Long-term fixed site observations at the Shapotou station have yielded a series of important research results in the water cycle in sandy land.

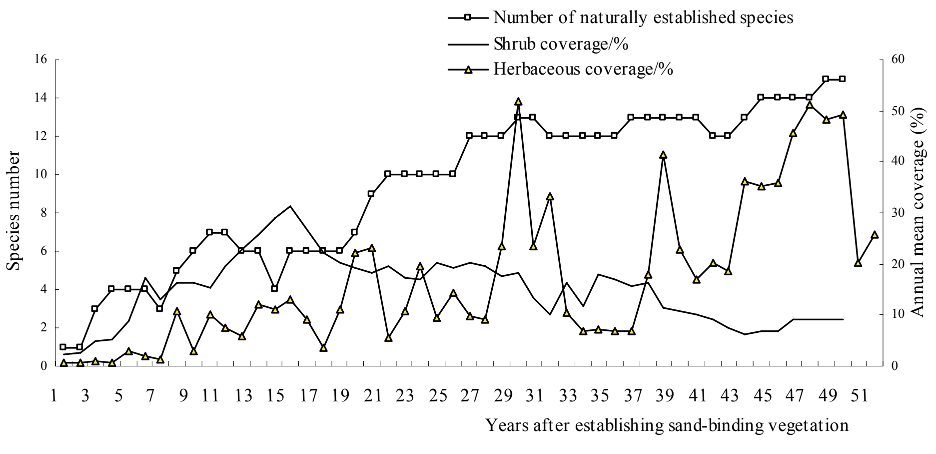

Fig. 34.2 Change in plant species richness and coverage during 50 years after sand stabilization and re-vegetation

(1) Driving role of water cycle to soil-vegetation system succession

Researches found that soil moisture content decreased rapidly in 9-10 years after the establishment of artificial vegetation and the deeper the soil layer, the larger the decrease in soil moisture content. 40 years later the soil moisture content always kept a low level (1.2% or so). The precipitation and moisture content in surface soil layer in the vegetated area exhibited an obvious positive correlation but it showed no significant correlation with the moisture content in deep soil layer. The water use characters of different plant species results in the difference in the spatial distribution pattern of soil moisture; the temporal-spatial variations of soil moisture in turn affected the composition, coverage and biomass of vegetation; the vegetation composition gradually changed from dominant shrubs to annual species and shallow-root subshrubs; the biomass of annual plants gradually increased with time, while the biomass of shrubs tended to decrease.

(2) Water re-distribution in soil-vegetation system determined quantitatively

The evapotranspiration in the growing season in the sand-binding vegetation area occupies over 90% of the precipitation of the same period and in the drought years water deficit may occurs in sand layer, but the surface evaporation in the unvegetated area is lower than 77% of the precipitation of the same period. The soil water changes in both vegetated area and unvegetated area are highly correlated to the precipitation processes. The total evapotranspiration in the areas with Artemisia ordosica and Caragana Korshinskii communities is roughly the same, their mean evapotranspiration rates are 1.31 mm d^{-1} and 1.22 mm d^{-1} respectively. The amount of water infiltrated into deep soil layer in the unvegetated area occupies about 30-40% of the precipitation with a mean infiltration rate of 0.63 mmd^{-1}. Artificially established vegetation can effectively use this part of precipitation and therefore no deep infiltration occurs in the vegetated area. The observations of condensed water show that the amount of surface condensation water tends to increase with the development of microbioltic crusts, the development of algal crusts is an important indicator showing the massive increase of condensation water amount. The increase in condensation water amount not only improves the surface micro-environment but also provides an important water source for the development of biotic crust species including algae and moss etc. In this sense, we say the condensation water takes part in the succession processes of desert ecosystem by affecting the development processes of microbiotic crusts.

(3) Plant transpiration and scale conversion

The studies by using porometer, heat balance technique and lysimetric pool covered with felt in growing season show that the daily variation trend of transpiration rate and stomatal conductivity is only related to the weather regime and exhibits a little interspecific difference. To obtain the total transpiration amount of plants, the transpiration rates determined by porometer in this study were successively conducted unit conversion, polynomial fitting of daily variation curve and scale conversion to obtain the daily transpiration. The fitted daily variation curves reached a significant level. The daily transpiration amounts of Artemisia Ordosica determined in 4 sample plots were significantly higher than those of Caragana Korshinskii, but the daily transpiration amounts in 2 sample plots with mixed Caragana Korshinskii and Artemisia Ordosica were smaller than those in the pure Caragana Korshinskii plot and pure Artemisia Ordosica plot. The variance analyses on the results determined by porometer and lysimetric pool show that the interspecific difference (Artemisia Ordosica and Caragana Korshinskii) reached a significant level but the difference between the determination methods of lysimetric pool and porometer was not significant. This shows that using felt-covered lysimetric pool to determine the transpiration amounts of plants in arid desert region is feasible and using leaf area index and effective coverage as a basis to make the scale conversion between leaf blade level and community level was successful.

4. Stress tolerance molecular biological mechanism and ecological adaptation strategies of plants in extreme environment

During the 2001-2005 period the biochemical and molecular biological experiment means (e.g. physiological, proteomical, function genomical and bioengineering methods) were used to mainly study the physiological and biochemical changes, signal conduction and the regulation mechanism at molecular biological level of the plant stress tolerance in extreme environment. For example, the photosynthetic characters of desert plants such as Pupulus Euphratica and Haloxylon Ammodendron etc. under adverse conditions (strong light and high temperature) and the responses of antioxidase system excited by active-oxygen free radical of Populus euphratica, Tamarix Chinensis, Artemisia Ordosica, Thellungiella Salsuginea, Phragmites communis and xerophytic wheat etc. were studied; the salt-resistant mechanism of desert plants were revealed using the Fourier infrared spectroscopy method; other studies include the protection of ascorbic acid to the plants stressed by salts and the new physiological and biological mechanism of plants to adapt to adverse environmental conditions. Through the studies of the main photosynthetic protein expression and metabolic mechanism of different leaf types of Populus euphratica and Ammopipthanthus Mogolicus stressed by drought, and the activity of microencapsulated enzyme ATPase of cytomenbrane and vacuolar membrane of salt-stressed Populus euphratica, Phragmites commuis and Thellungiella salsuginea, the expression and metabolic regulation features of resistant protein of desert plants under adverse conditions were preliminarily revealed.

The callus culture of desert plants and the establishment of suspended cell system and the studies of the mechanism of ion migration and the conduction of important signal molecules (H_2O_2 and NO) of desert plants such as Populus euphratica, Phragmites communis and Tamarix Chinensis etc. have provided a theoretic basis for the research of signal conduction mechanism of desert plants under adverse environmental conditions.

Through the cloning of Na^+/H^+ retropress protein gene, K^+ channel protein KT1 and KT2 and out-directed K^+ channel protein gene of Populus euphratica, the protein expression and gene function analysis, the salt-resistant mechanism of Pupulus euphratica was determined at molecular level. Furthermore, the Na^+/H^+ retrogress protein gene was transferred in the plants such as Pupulus ningshanica and Arabidopsis to obtain the salt tolerance and therefore they can grow normally on salinized soil.

Ecological strategy and response of plants to arid environment stress

With the widespread desert annual species Eragrostis minor as the research object, the adaptive strategies of annual plants to the random environment were studies from seed germination, population dynamics, population spatial distribution pattern and competition and regulation. The survival rate of annual plant seedlings in growing season depends on the precipitation intensity and duration which activated the germination of seeds. The optimal germination strategy of annual plants appears as a continuous germination process under the optimal condition in growing season, such continuous process is an adaptive character to the random environment. From the continuous and multiyear statistical data it has been found that water condition in the habitat where Eragrostis minor population exists is a leading factor controlling the dynamics of Eragrostis minor, and the competition between individuals inevitably leads to the self-thinning phenomena. In the years with plentiful and uniform precipitation, the density of Eragrosticminor minor population depends on the death, i. e. the survival rate increases with decreasing population density. The main form to adjust the population number through intraspecific competition is to adjust the initial density with large variation amplitude to the final density with narrow variation range.

5. Role and position of microbiotic crusts in the desert ecological restoration and reconstruction

Systematically studied the propagation of cryptogams on stabilized sand surface and the formation and evolution processes of microbiotic soil crusts. This study fills in the gap in the research of biotic soil crusts in the temperate desert (Patrick, 2002; Büdel, 2003). The invasion and propagation of desert algae on the relatively stable sand surface mainly depends on the clay content in surface soil layer, and soil chemical properties (PH, EC, some macro-elements and micro-elements) also play an important role. It has been found that in the evolution processes of microbiotic soil crusts, some bacterial microorgnisms first occur in the relatively stable subsurface layer of sand dunes and the cyanobacteria with strong resistance to drought stress and disturbance start to propagate and form cyanobacterial crusts, thereby create a microhabitat for the formation of algal crusts. The formation of algal crusts improves soil water-holding capacity, alters the spatial distribution of infiltration precipitation and creates a condition for the formation of hydrophilic moss crusts. The widespread distribution of these crusts further stabilize the dune landscope and finally occur the lichen-participated microbiotic soil crusts. This research results has been presented in some international and domestic magazines and cited by SCI (Patrick, 2002; Ren et al. 2005; Hu et al., 2003a, b, 2004; Nash, 2003; Bullard, 2004; Li X Y et al., 2004; Zhang et al., 2005; Li S Z et al., 2006)

Fig. 34.3 Change in algal and cyanobacteria species diversity after stabilization by revegetation on shifting sandunes in the Tengger Desert

Using LISEM model to simulate the influence of microbiotic soil crust on the precipitation infiltration into stabilized dunes in the Tengger Desert. This study concluded that the influences of microbiotic soil crusts on the precipitation infiltration depend on the precipitation intensity, regional precipitation amount and physiochemical properties of soil substrate underlain by microbiotic crust; it also gives an explanation to the international debate (i. e. biotic crusts decrease the precipitation infiltration, or the increased infiltration has little effect, See Eldridge and Greene, 1994). The dry gypsum-bearing soil crusts or crusts on stabilized dune surface can decrease the precipitation infiltration, but the crusts in semiarid steppe region or open forest land can increase precipitation infiltration, and the algal crust in the severely disturbed area has little effect on the precipitation infiltration. In addition, it is also closely related to the crust type, precipitation amount, intensity and temporal-spatial distribution in different bioclimatic zones.

Through massive field fixed site observation and greenhouse experiments systematically studied the microbiotic soil crusts in relation to the seed bank, seed germination, and colonization of vacuolar plants, analysed and explained some international debates as to this scientific problem. The study concluded that the influences of microbiotic soil crusts on the seed bank, seed germination and colonization of vascular plants depend on the crust type, composition of cryptogamic species in microbiotic crusts, and regional climate conditions (e.g. wind erosion regime and precipitation distribution), and also depend on the biological characters of plant seeds themselves (e.g. seed size, shape, whether they have the structure to penetrate crusts or are easy to be dispersed, and dormant character of seeds). It has been proved that microbiotic crusts are soil N and C sources available for the desert system. This study provides a scientific basis for the protection of microbiotic soil crusts in arid region and dryland management.

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35

Adaptative Strategies of Plants Inhabiting Semi-arid Areas

Scientific research progress of Ordos Sandland Ecological Research Station

Introduction of Ordos Sandland Ecological Research Station

Ordos Sandland Ecological Research Station (OSERS) was set up in December, 1990, jointly by The Institute of Botany of the Chinese Academy of Sciences and the Yi-Ke-Zhao Meng League (currently, Ordos City), the Inner Mongolia Autonomous Region. It is one of the earliest Research Stations to be built on the ecotone areas where desertification is quite serious. The research activities in this area can be tracked as far back as in 1986. From that time, ecologists from the Institute of Botany, CAS, started to investigate the natural resources in this area, comprehensively studying plant physiological ecology as well as Soil-Plant-Atmosphere Continuum (SPAC). In order to better serve the mining exploitation, better control desertification, as well as expand the experimental area, the building of the Shi-Long Temple Research Base started in 1995 and was completed in 1996. The Shi-Long Temple Base was designed according to the pattern of the“3-circle” demonstration pattern, which was created by Chinese academician, Dr. ZHANG Xin-Shi.

OSERS is located on the northeastern edge of Mu-Us sandland of Ordos Plateau, Inner Mongolia. The geographic location is 39°29'37.6" N, 110°11'29.4" E, and the altitude is about 1300 mm a.s.l. The area where OSERS is located is complicated eco-geographic transition zone, the natural habitats are frail and sensitive, and it is one of areas where desertification is most active.

OSERS belongs to the temperate semi-arid grassland zone, the average annual temperature is 5.7°C, annual precipitation is 388 mm, but the annual potential evaporation is as high as 2500 mm, the frost-free period is 128 days, the time of annual sun irradiation is 2800-2900 h.

The vegetation types in this area include: (1) grass and brushwood on the szyrt; (2) brushwood on the moving, semi- and stabilized sand dunes; (3) meadow on the bottomland; (4) halomorphic and marshy vegetation. Soil types include: (1) chestnut soil on the szyrt; (2) Wind-induced sand on sand dunes; (3) meadow soil, saline alkali soil as well as marsh gley on the bottomland.

The Long-term objects includes: (1) Long-term monitoring the temperate semi-arid shrubs and grass ecosystem, to determine the dynamic trends and the reasons for the changes in the ecosystem and environmental factors in this area.(2）Research on the mechanisms and the related ecological processes of degeneration, restoration and regeneration of the desertified grassland; exploring the model for the continuing use of the desertified land in semi-arid areas.(3) Researching on the biodiversity conservation of shrubs inhabiting semi-arid areas; establishing a germplasm bank and living gene bank of the shrub, to serve for the germplasm conservation of shrub resources. (4) Using the life history as the clue, revealing the general ecological adaptation strategies of plants in semi-arid area.

On base of long-term site-specific and regional researches on plant ecophysiology, biodiversity of shrub, and sandy land ecosystem and landscape in Mu Us sandy land, we considered sustainable ecological principle, theory of human and nature harmonization, emphasized on unification of desertification combating and local soc-economy development, then optimized ecological pattern for desertification combating in Mu Us sandy land has been established. It set a successful sample for desertification combating in wide arid and semiarid area.

1. Vegetation characteristics and soil properties spatial pattern in the Mu Us Sandy Desert

The relationship between vegetation and soil is central to ecological research． In the Mu Us sandy desert，study of this relationship is required for understanding of landscape ecological processes and restoration of degraded lands．Spatial patterns of vegetation cover，(plant)species richness，soil organic carbon，total nitrogen and their interaction at different spatial scales and habitats in M u Us are analyzed in this paper．Significant positive correlations between vegetation cover and species richness，and between soil organic carbon and total nitrogen were revealed at al1 scales and habitats studied．Similar spatial patterns of vegetation cover and species richness and soil organic carbon and total nitrogen were found on scales from 50 to 5000 m In contrast．No significant correlations between the vegetation and soil characteristics were observed on these scales，implying that soil organic carbon and total nitrogen were not the principal factors．However．on scales less than 50 m the significant positive correlations between species richness and soil organic carbon and total nitrogen contents on fixed dunes，and the significant negative correlation between species richness and soil organic carbon were detected．These results indicate scale-dependence in the relationship between vegetation characteristics and soil properties in this environment.

2. Roles of clonal growth of the rhizomatous grass Psammochloa villosa in patch dynamics of Mu-Us Sandy land

Mu Us sandy landscape is a mosaic of many different patches. A number of ecological processes at landscape level control the dynamics of these patches. Clonal growth of the rhizomatous grass Psammachloa villosa is one of the ecological processes not well known up to now. In this paper, the role of clonal growth of P. villosa on the parch dynamics in M u Us sandy landscape was examined by means of field investigation in three l hm^2 wind—eroded plots and by methods of the acid fuchsun application Each plot was divided into 625 4m × 4m quadrats. The plant species occupied most of the quadrats in the mobile sandy patches of the three plots. Its rhizomes extended from the semi fixed sandy patches to the mobile sandy patches. Number of ramets, number of rhizome branches, length of rhizome and aboveground biomass of P. villosa extending from the semi—fixed sandy patches to the mobile sandy patches were measured. In both the mobile and semi-fixed sandy patches, P. villosa plants usually distributed most of their roots belowground from 30cm to 50em depth. The soil water content in 30-50 cm depths belowground was higher in the mobile sandy patches than to the semi fixed sandy patches. In Mu Us sandy land, the wind-erosion and the rainfall regime discouraged the plant seeds' generation and surviva1. However, the heterogeneous environments caused by the wind-erosion may benefit the clonal growth P. villosa extended its rhizomes towards the mobile sandy patches where the soil water contents were high. Clonal integration between the ramets in the different patches promoted the plant growth. This result suggests clonal growth of P. villosa played an important role in stabilizing wind eroded patches.

3. A Trade-off between guerrilla and phalanx growth forms in Leymus secalinus under different nutrient supplies

A phalanx growth form enables clonal plants to make better use of resource-rich patches, whereas a guerrilla growth form provides them with opportunities to escape from resource-poor sites. Leymus secalinus produces both spreading (guerrilla form) and clumping ramets (phalanx form). Here, the hypothesis that a trade-off between the two growth forms in L. secalinus exists under different resource levels is tested.

Ramets of L. secalinus were grown under three levels of nutrient supply. With increasing nutrient supply, the proportion of clumping ramets (in total number of ramets) increased, whereas that of spreading ramets decreased (Fig. 35.1). With increasing nutrient supply, the number of buds increased, whereas biomass per bud decreased (Fig. 35.2). A trade-off between bud number and size further supports the above hypothesis because larger buds were more likely to develop into spreading ramets, and smaller buds into clumping ramets. Mean spacer length between spreading ramets was significantly smaller under the high than under the medium nutrient supply.

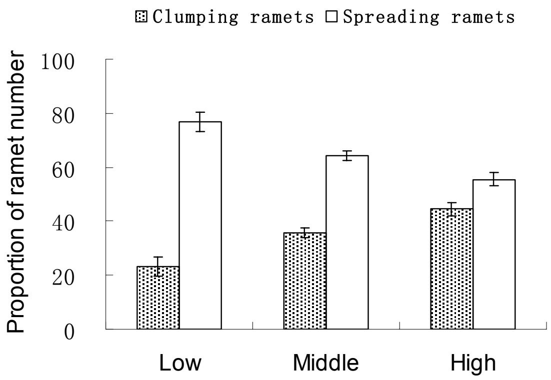

Fig.35.1. The proportion of two clonal growth forms in L. secalinus exists under different resource levels

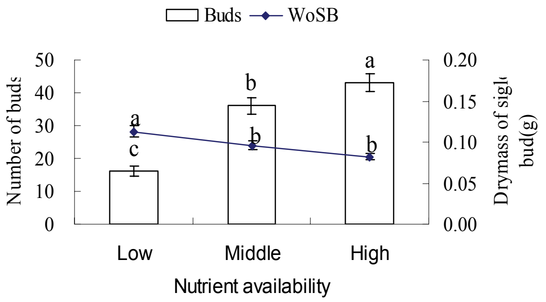

Fig. 35.2. The number of buds and drymass of single bud in L. secalinus exists under different resource levels

The results suggest that a trade-off between the two growth forms in L. secalinus exists under different nutrient supplies. Such a trade-off together with plasticity in spacer morphology may enable L. secalinus to make better use of small-scale heterogeneity in resource supply.

4. Clonal plants along the sandy hill- slope in Ordos Plateau and relation of their importance to plant species diversity

We investigated the distribution of clonal and non-clonal plants along the sandy hill- slope in Ordos Plateau, using the line intercept method and the point method. One-way ANOVA was used to compare the difference of species richness and importance of plants with different growth forms among communities along the sandy hill- slope. We used the regression analysis method to analyze the relation of species diversity to importance of clonal plants in the communities. Species richness of clonal plants was higher in the ridge summit and the mid-slope, while lower in the foot- slope. The same trends were found for non-clonal plants, their species richness in the ridge summit and mid- slope was higher than that in the foot slope. Variation of species richness of phalanx clonal plants was similar to that of non-clonal plants. Guerilla clonal plants were absent in the ridge summit and few in the mid-slope, while abundant in the foot- slope. The importance of clonal plants in the foot slope was higher than in the ridge summit and the mid- slope. The importance of non-clonal plants in the foot slope was lower than in the ridge summit and the mid- slope. The importance of clonal plants was higher than the non-clonal plants in the mid- slope and the foot slope, while there was no such a difference between them in the ridge summit. The importance of phalanx clonal plants in the ridge summit and the mid- slope was much higher than that in the foot slope. In contrast, the importance of guerilla clonal plants in foot slope was much higher than that in ridge summit and mid- slope. The importance of phalanx clonal plants was higher than that of guerilla clonal plants in both the ridge summit and the mid-slope, while in the foot slope, the importance of guerilla clonal plants was higher than that of phalanx clonal plants. In the ridge summit, the relations of community plant species diversity to importance of clonal plants, importance of non-clonal plants as well as importance of phalanx clonal plants were parabola. In the mid-slope, plant species diversity increased with increasing importance of non-clonal plants, while it decreased with increasing importance of clonal plants as well as importance of phalanx clonal plants. In the foot- slope, plant species diversity was positively correlated to the importance of non-clonal plants, and negatively correlated to the importance of clonal plants as well as importance of guerilla clonal plants. Our results confirmed that clonal growth in plants is adaptive in general under stressed conditions, and clonal plants are more important in stressful habitats. There are marked differences between phalanx and guerilla clonal plants in their optimal locations along the sandy hill- slope. Phalanx clonal plants are more abundant and more important in drier habitats. In contrast, guerilla clonal plants tend to be more abundant and more important in wetter habitat. This suggested that phalanx clonal plants seem to have strong ability to grow under stressed environments. In the community located in ridge summit, Shannon-Wiener index increase and then decrease with increasing importance of clonal plants. In mid- slope and foot- slope communities, Shannon-Wiener index decrease with increase importance of clonal plants owing to their strong spreading ability.

5. Possible role of pectin-containing mucilage and dew in repairing embryo DNA of seeds adapted to desert conditions

Repair of damage to DNA of seed embryos sustained during long periods of quiescence under dry desert conditions is important for subsequent germination. The possibility that repair of embryo DNA can be facilitated by small amounts of water derived from dew temporarily captured at night by pectinaceous surface pellicles was tested. These pellicles are secreted during early seed development and form mucilage when hydrated.

Seeds of Artemisia sphaerocephala and Artemisia ordosica were collected from a sandy desert. Their embryos were damaged by gamma radiation to induce a standard level of DNA damage. The treated seeds were then exposed to nocturnal dew deposition on the surface of soil in the Negev desert highlands. The pellicles were removed from some seeds and left intact on others to test the ability of mucilage to support repair of the damaged DNA when night-time humidity and temperature favoured dew formation. Repair was assessed from fragmentation patterns of extracted DNA on agarose gels.

For A. sphaerocephala, which has thick seed pellicles, DNA repair occurred in seeds with intact pellicles after 50 min of cumulative night dew formation, but not in seeds from which the pellicles had been removed. For A. ordosica, which has thin seed pellicles, DNA repair took at least 510 min of cumulative night dewing to achieve partial recovery of DNA integrity. The mucilage has the ability to rehydrate after daytime dehydration. The ability of seeds to develop a mucilaginous layer when wetted by night-time dew, and to repair their DNA under these conditions, appear to be mechanisms that help maintain seed viability under harsh desert conditions.

6. Diversity and resistance of rhizobia isolated from Caragana intermedia in Maowusu Sandland

Fifteen rhizobia strains were isolated from wild shrubby legume Caragana intermedia in Maowusu Sandland. A dendrogram was constructed based on esterase profiles, showing a rich diversity of these rhizobia. Many biochemical characteristics were detected, including acid or alkali production, catalase activity, utilization of sole carbon sources, and resistance to salt, acid-alkali and temperature variation. The results indicated that all the rhizobia strains isolated from Caragana intermedia could excrete H^+ on YMA agar and produce catalase. 73.3% strains could tolerate NaCl stress at 3% concentration, and 80% strains could grow at 50°C. Except the difference in lactose and starch utilization, rhizobia strains had no bias on the rest carbon sources. However, the difference in resistance to stress existed among strains, which might be related to the adaptation of rhizobia to diverse landscapes in Maowusu Sandland. It was revealed that rhizobia nodulating Caragana intermedia could be used as a new germplasm to fix nitrogen under severe environment.

7. Experimental measurement of the water relations parameters of nine shrubs and some ecological interpretations

Determination of some water relations parameters of 9 shrubs with the Pressure-volume technique has shown that there were considerable variations in the water relations parameters of different shrubs and that some parameters were indicative for their adaptations to the ecological conditions. It has been found that two desert shrubs, Tetraena mongolica Maxim. and Zygophyllum xanthoxylon (Bge.) Maxim., exhibited strong ability of drought tolerance, whereas the typical sandy shrubs were quite diverse in adaptation strategy. Salix psammophila C. Wang et Ch. Y. Yang, Artemisia ordosica Krasch., Caragana intermedia Kuang et H. C. Fu and Ammopiptanthus mongolicus (Maxim.) were more or less close to each other in water relations parameters. Their $\psi_{\pi,p}$ ranged from - 1. 4 MPa to - 2. 4MPa, and Vp/ Vo lay between 62 % and 76 %. However, some special features of adaptation were found in the other three species, e.g., Sabina vulgaris Ant., Hedysarum mongolicum Turcz. and Artemisia sphaerocephala Krasch.

8. Species- and habitat-variability of photosynthesis, transpiration and water use efficiency of different plant species in Maowusu Sand Area

Photosynthesis (Pn), transpiration (E) and water use efficiency (WUE) of more than 66 arid sand species from different environmental habitats, shifting sand dune, fixed sand dune , lowland and wetland in the Maowusu Sand Area were analyzed and the relation among these characteristics and the resource utiliza2tion efficiency, taxonomic categories and growth forms of the species were assessed. The results showed that species from Chenopodiaceae, Gramineae, Leguminosae which possessed the C_4 photosynthesis pathway, or C_3 pathway and also with nitrogen-fixation capacities had higher or the highest Pn values, i.e., 20～30 μ mol $CO_2 \cdot m^{-2} \cdot s^{-1}$, while that of evergreen shrub of Pinaceae had the lowest Pn values, i.e., 0～5 μ mol $CO_2 \cdot m^{-2} \cdot s^{-1}$. Those species from Compositae, Scrophulariaceae, and Gramineae with C_3 pathway but no N-fixation capacity had the highest E rates, i.e., 20～30 mmol $H_2O \cdot m^{-2} \cdot s^{-1}$ and again the evergreen shrub together with some species from Salicaceae and Compositae had the lowest E rates, i.e., 0～5 mmol $H_2O \cdot m^{-2} \cdot s^{-1}$. Species from Leguminosae, Gramineae and Chenopodiaceae with C_4 pathway or C_3 pathway with N-fixation capacity, both shrubs and grasses, generally had higher WUE. However, even the physiological traits of the same species were habitat- and season- specific. The values of both Pn and E in late summer were much higher than those in early summer, with average increases of 26%, 40% respectively in the four habitats. WUE in late summer was, however, 12% lower. Generally, when the environments became drier as a result of habitats changed, i.e., in the order of wetland, lowland, fixed sand dune and shifting sand dune, Pn and E decreased but WUE increased.

9. Response of seedlings of three dominant shrubs to global warming in Ordos Plateau

Ordos plateau is a classical semi-dry sandland in China. The dry ecosystem responds sensitively to water-heat pattern of global change there. The distribution pattern and productivity of terrestrial ecosystem are greatly affected by global warming. Ecological adaptation strategies of seedlings of Caragana intermedia Kuang et H. C. Fu, Hedysarum mongolicum Turcz. and Artemisia ordosica Krasch., three dominant shrubs in Ordos plateau, were investigated in terms of morphological plasticities, biomass effects and photosynthetic and physiological characters, to the global warming by artificially controlling two temperature levels. The results show that the effects of temperature enhancement on growth and photosynthetic and physiological characters were obviously different among these three plant species. Temperature enhancement significantly increased tree height, leaf number, leaf area, biomass, photosynthetic rate, transpiration rate and stomatal conductance of C. intermedia and H. mongolicum seedlings, indicating that elevated temperature significantly affected the growth of these seedlings positively. Elevated temperature had almost no significant effect on the growth of A. ordosica seedlings. Their leaf number, leaf size, leaf area, biomass , transpiration rate and stomatal conductance did not increase obviously, but tree height and photosynthetic rate obviously increased with increasing temperature. Interspecific growth was significantly different among C. intermedia, H. mongolicum and A. ordosica seedlings. Except leaf size, values of the other seven characters of C. intermedia seedlings were greater than those of H. mongolicum and A. ordosica seedlings.

10. Establishment of optimized eco-productive paradigm in the farming-pastoral zone of northern China

The farming-pastoral zone of northern China plays a dual role in ecological conditions and production and occupies an important position in the national economy. In this paper, the methodology of system engineering is introduced to construct and optimize an eco-productive paradigm system for the typical areas of the farming-pastoral zone. The system was constructed in the following steps: (1) design the framework of the paradigm system based on the data of physical site characteristics, bio-communities, production and economy, social culture and historical changes; (2) analyze the vegetation patterns, the interactions between vegetation and environmental factors (natural, social, economic, etc.) and the contributions of vegetation to the area, including the synthesis of the existing researches; and (3) provide the spatial arrangements of ecosystems and planning of each area, raise a comprehensive indicators of evaluation, evaluate the feasibility and soundness, and determine the optimum eco-productive paradigms for policymakers which were land-use patterns within the threshold of ecological conservation.

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36

Water Use Strategy, Hydrological Process and Vegetation Restoration for the Desert Plants along the Southern Fringe of Junggar Basin

Scientific research progresses of Fukang Desert Ecological Research Station

Introduction of Fukang Desert Ecological Research Station

In arid regions, water is the most important determinant for landscape differentiation and the most limited factor in ecosystem production. Vegetation is the most significant characteristic of landscape differentiation and the essential element of the ecosystem. Since Fukang Desert Station was founded in 1987, the research on hydrological processes in temperate arid region and vegetation/plant-water relation at different scales has been carried out systematically in Sangong River Basin and original shrubby desert land on the southern periphery of Gurbantonggut Desert, Central Asia. Based on the control experiments and long-term observation, some significant progresses have been achieved in the following aspects.

1. Plant-water relations and response and adaptation characteristics of desert plants towards water condition variation

(1) When water condition changes dramatically in their habitats, the physiological activities of desert plants remain relatively stable, while their morphologic characters on individual scale, especially root system, adjust efficiently.

The research was carried out on dominant species in the typical desert shrub community, i.e. *Tamarix spp*., *Haloxylon ammodendron* and *Reaumuria soongonica*. Significant interspecific variation exists in the root morphology and water use strategies of these desert shrubs (Fig. 36.1). Despite these differences, physiological activities of these studied species remain stable under precipitation change. For instance, net photosynthesis rate on leaf scale measured after one-month drought was consistent with that measured after rain (Fig. 36.2).

Further research shows that their responses and adaptation to changes in water conditions are significant and effective on individual scale. The balance between water supply and demand in a plant can be maintained by *morphological* adjustment of the plant root (Fig. 36.3) and shoot systems (Fig. 36.4). On the one hand, the absorbing roots in the upper soil may continue to adjust efficiently during progressive drought or after rain; on the other hand, shoot size may shrink by partial defoliation or increase by leaf emergence/expansion in response to change in soil water within the root zone. The decrease in area and water supply capacity of the feeder roots is usually accompanied by a decrease in leaf area through defoliation. Such morphological adjustment maintains the balance between the water supply to the root system and the water demand of the shoot system, and ensures stable water supply to the surviving leaves (Fig. 36.5) and thus their consistent photosynthetic capacity. It shows that due to long-term adaptation to water stress, responses of desert shrubs towards changes in water conditions are significantly different from those of other plants. The strong morphologic plasticity ensures their normal photosynthesis on leaf scale. For some strong drought-resistant desert shrubs, defoliation and a higher quota for root system are two sides of the morphological trade-off that ensures normal photosynthesis and subsistence of the limited assimilative organs under severe water stress. When water shortage is alleviated, abundant new assimilative organs germinate in order to maximize the photosynthesis and biomass accumulation. Such morphological adjustment is one of the main strategies of these desert shrubs for their survival in water-limited environment. The integrated study of detailed ecophysiological and morphological responses will play an important role in predicting the survival of desert shrubs under human or natural disturbance in the future.

The relevant research articles *were* published on *Plant and Soil* 285, 5-17 with a cover image and a commentary, and on *Plant*, *Cell and Environment* (*Online Early* doi: 10.1111/j.1365-3040.2006.001626.x).

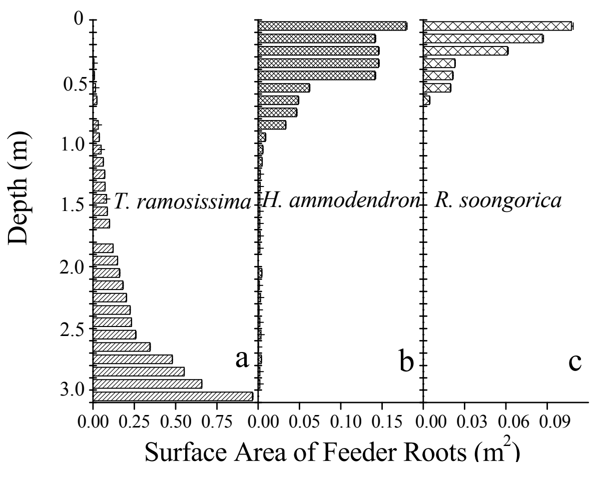

Fig. 36.1 Vertical distribution of feeder roots and water use strategy of three dominant species - *Tamarix ramosissima* (relying on groundwater), *Haloxylon ammodendron* and *Reaumuria soongonica* (utilizing precipitation)

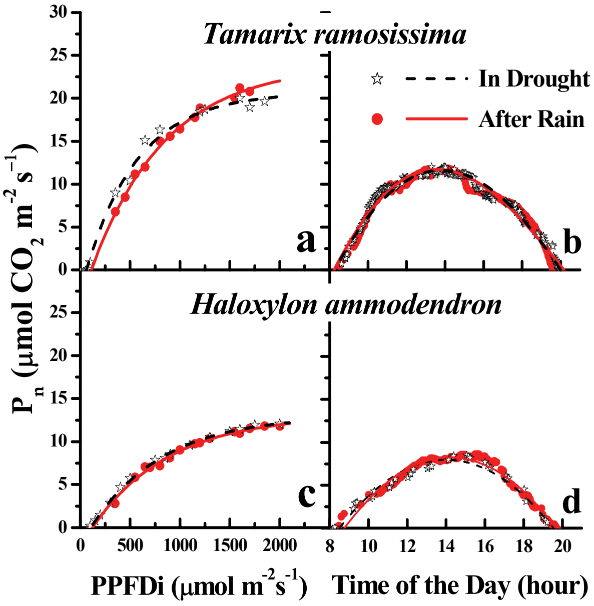

Fig. 36.2 Photosynthesis of *Tamarix ramosissima* and *Haloxylon ammodendron* under contrasting water conditions

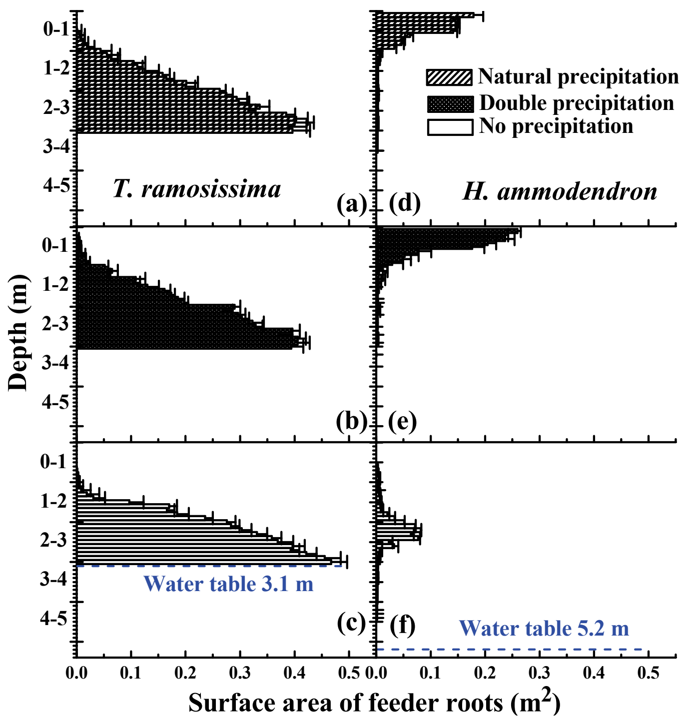

Fig. 36.3 Changes in root distribution of Tamarix ramosissima and Haloxylon ammodendron after precipitation treatments

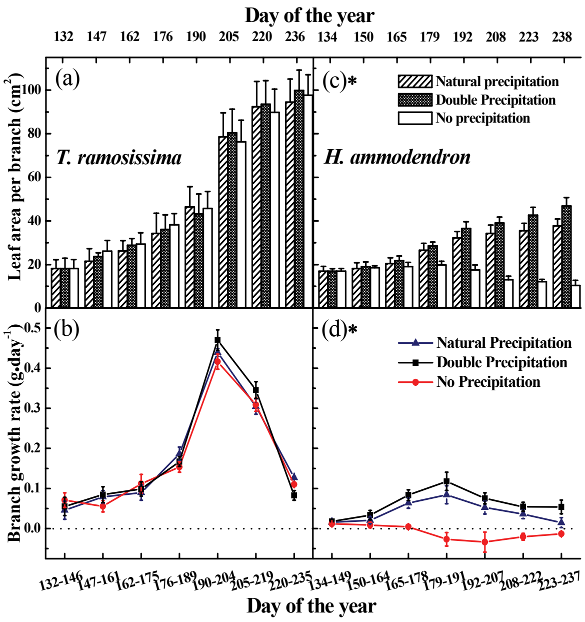

Fig. 36.4 Seasonal changes in branch and leaf growth of *Tamarix ramosissima* (a,b) and *Haloxylon ammodendron* (c, d) under three precipitation treatments

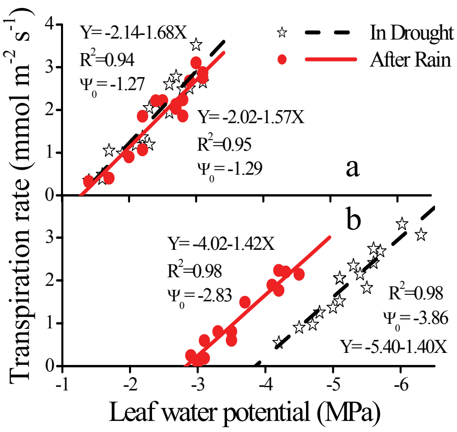

Fig. 36.5 Hydraulic conductance of *Tamarix ramosissima* and *Haloxylon ammodendron* under contrasting water conditions

(2) Morphological adaptation of water-transport system in plants, when soil water status and evaporation demand varies for the whole life history of plants, is the main mechanism for plants to maintain favorite water status and normal physiological activities.

Transpiring plants need to extract water from the soil in order to compensate for water loss from leaves, and to maintain a favourable plant water status and normal growth. While the potential rate of water loss from a plant depends on its shoot dimension and the atmospheric condition it is subjected to, the capacity for water extraction from soil is determined by the root system and the physical conditions in the surrounding soil. When soil texture or atmospheric evaporative demand varies, plants co-ordinate their capacities for liquid phase and vapour phase water transport through long-term acclimation of the hydraulic system, or plastic morphological adaptation of the root/leaf ratio.

When soil or atmospheric conditions change, water transport through root-soil or leaf-atmosphere surfaces will be influenced, and the existing balance will hence be broken. The function of immediate adjustment is so limited that plants can approach new balance between water supply and demand only by adjustment or adaptation at larger scale. However, most experiments have focused on short-term adjustment at physiological scale, and the research on long-term adjustment (for example, during the whole life history) of the individual plant has been ignored.

Our experiments were carried out on an annual crop *Gossypium herbaceum L.*.Three levels of soil texture and three levels of atmospheric evaporative demand were set during the growing season. A series of measurements were carried out in the harvest season. b. Hydraulic conductance per leaf area (K_l) under different atmospheric evaporative demands in the same soil texture.

In different soil textures under the same atmospheric evaporative demand, plants develop the same hydraulic conductance per leaf area which stands for the intensity of water demand per leaf area, but significantly different hydraulic conductance per root length which indicates capacity in water supply per root length: the value in clay soil is about twice over that in sandy soil (Figure36.6a). Under different atmospheric evaporative demands in the same soil texture, plants develop the same hydraulic conductance per root length, but significantly different hydraulic conductance per leaf area: the value outdoor is about twice over that indoor (Figure36.6b). It is concluded that when soil texture or atmospheric evaporative demand varies, plants co-ordinate their capacities for liquid phase and vapor phase water transport through long-term acclimation of the hydraulic system, or plastic morphological adaptation of the root/leaf ratio.

The relevant article was published on *Plant*, *Cell and Environment* 28, 492-499, and then embodied in a Virtual Special Issue about hydraulic conductance system in plant (www.blackwellpublishing.com/journals/pce).

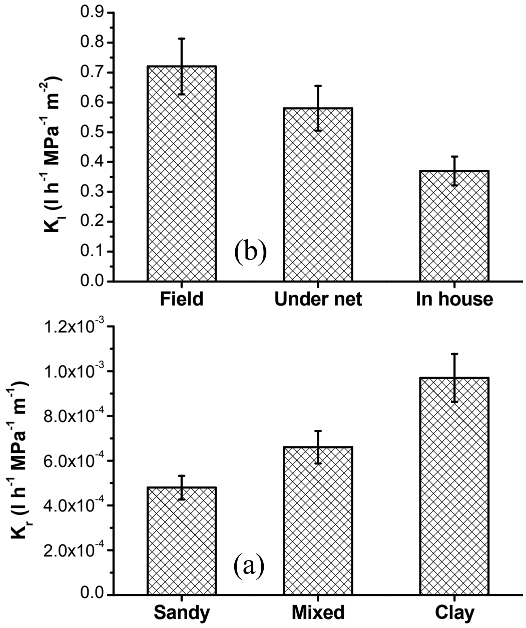

Fig. 36.6 Hydraulic conductance per root length (K_r) in different soil textures under the same atmospheric evaporative demand.

(3) The plants grown in heavy-textured soil have a lower apparent hydraulic conductance, which proved good evidence for the Root Contact hypothesis.

Under general condition, the measured water potential gradient between soil and leaf is much larger than the sum of the respective gradients in plant and in soil. Namely, a part of water transport resistance occurs in neither soil nor plant. It could be deduced that this resistance occurred on the root-soil surface. Root Contact hypothesis was hence presented by Hekelrath *et al*. in 1977. It supposes that root does not contact soil in heavy-textured soil; the root surface exposed in soil holes does not contact wet soil grains and is not available for absorbing water, which results in an apparent surface resistance and water potential gradient. This hypothesis has been applied widely in modeling and theoretical computation successfully. And some relevant experiments have been carried out to validate this hypothesis, among which the most direct evidence came from the microscopical structure of root-soil surface in particularly loose or dry soil (Kooistra et al., 1992; North & Nobel, 1997). However, this research was limited in partial root, and could not be generalized at the whole root system due to the spatial heterogeneity of soil water content and root density.

To validate the universality of Root Contact Hypothesis, the research focusing on root surface was designed. The resistance on the root-soil surface in heavy-textured soil will definitely result in the decrease in apparent hydraulic conductance, vice versa. Furthermore, the measurement and calculation of apparent hydraulic conductance was based on average value of the whole root system.

A part of the above-mentioned results was published on *Plant, Cell and Environment* in 2005: under general condition, apparent hydraulic conductance per root length in sandy soil was only half of that in clay soil (Fig. 36.6a). Our research plays an important role in the theorization of Root Contact Hypothesis and the perfection of Soil Plant Atmosphere Continuum theory.

(4) Water potential of root-soil surface plays a key role in determining the temporal variation and spatial distribution of water absorption of plant root system.

Under most conditions in natural habitats, plant root system grows in the soil with uneven moisture, which makes it difficult to quantify the plant response to soil moisture. Our experiments show that the soil moisture plants actually sense can not be reflected by averaging soil moisture spatially in any form (Fig. 36.7). When root system grows in thoroughly wet soil, the spatial distribution of water absorption in the entire root zone is represented by spatial variance of root length density in modeling. However, such simulation seldom agrees with the actual status: the intensity of root water-absorption in upper soil is much stronger than that in deeper soil in thoroughly wet soil; roots in deeper soil remain "dormant" until water deficit occurred in upper soil. This phenomenon is called as "moving sink" (Gardner, 1991).

Our research indicates that plant root system senses the water potential of root-soil surface which may be very different from the measured soil water potential. So soil water content or soil water potential can not be utilized to estimate when plants are under water stress. Instead, the value of water deficit derived from water balance theory shows significant relation with canopy conductance (Fig. 36.8).

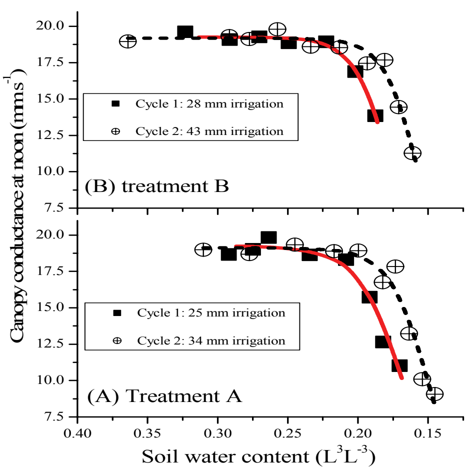

Fig. 36.7 Plant canopy conductance declines in different soil moisture under different treatment or in different irrigation period of a treatment.

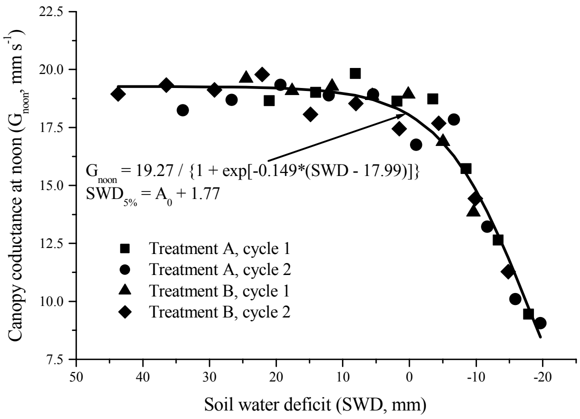

Fig. 36.8 The decline of canopy conductance occurs at the same value of water deficit which is calculated according to water balance theory.

Furthermore, our research shows that the calculated water potential of root-soil surface changes along with depth in soil, which is caused by axial resistance of root system. It explains the “moving sink” in the process of root water-absorption, and proves that axial resistance of water absorption in root system is not neglectable. The relevant articles were published on *Agricultural Water Management* (2004, 65, 21-38), *Plant, Cell and Environment* (2002, 25, 491-500) and *Plant and Soil* (2002, 243, 131-142) respectively.

The above-mentioned research results could be concluded as the following three aspects. (1) The response and adaptation of desert plants to water condition: when water condition changes, desert plants rely on efficient morphological adjustment to achieve stable physiological activities. The plasticity of root system plays a particularly essential role in their survival. This indicates that the existing individuals of these desert shrubs can maintain themselves for a long term even under drastic climate change and human disturbance. Hence, the plant community succession in this region will be a long-time process. (2) Water transport in soil-plant system: morphological adjustment at individual scale is the main mechanism by which water transport between the two surfaces (root-soil and leaf- atmosphere) remains consistent in a long period; and root contact hypothesis is validated by our research. (3). Water potential on root-soil surface: this water potential determines the temporal and spatial variances in the process of root water-absorption.

These results will facilitate the relevant research on plant-water relation in the future.

2. Special eco-hydraulic processes in Gurbantonggut Desert

The hydraulic processes of winter snow melting, and the stem flow of *H. ammodendron*, were studied in their original habitats at the southern periphery of Gurbantonggut Desert. The main research results could be concluded as following.

(1) Generally, there are "wet island" around the stems of *H. ammodendron*, and .soil water condition in its root zone is much favorable than in other zones. The average of stem flow funnelling ratio around its root zone is 46.6, the highest among the known desert vegetation. Such a precipitation effect magnified in root zone can be regarded as the main reason for the formation of "wet island" around the root system of *H. ammodendron*.

(2) The shape of canopy and stem of *H. ammodendron* is very propitious to intercept precipitation and converge it. The average percentage of precipitation interception is 0.62mm, with the lowest value of 0.27mm. The ratio of stem flow is 11% averagely with the highest value of 41.3%. The low interception ratio and high stem flow ratio enable precipitation to be stored rapidly in sandy soil around root system. In addition, owing to the high infiltration of sandy soil, water in deeper soil can be supplied in time.

(3) In the sandy soil of Gurbantonggut Desert, the storage and transformation of winter precipitation is very efficient: about 78.8% of water from melting transforms into soil water. The low temperature in winter may reduce the evaporation; the thin snow layer (20-30cm), and the sandy soil with low water moisture and high infiltration, are beneficial for melting and infiltrating in spring.

The efficient storage and utilization of rainfall and snow are the main reasons for the high diversity and coverage of plant species in Gurbantonggut Desert. Our research will play an important role in understanding eco-hydraulic processes in desert ecosystem.

3. Alternative Furrow Irrigation in agricultural ecosystem in oasis

Under alternative furrow irrigation, crop roots grow in different water conditions. The roots in dry soil zone are under certain water stress and abscisic acid (ABA) is thus derived and transported to leaves. ABA may adjust the closure of stomata. At the same time, the roots in wet soil supply enough water to maintain photosynthesis. Hence, the water loss due to evaporation is decreased with little effect on crop assimilation. Our research shows that alternative furrow irrigation can save much water at the sacrifice of a little decline in yield. Furthermore, the improvement of cotton quality and the decrease in expense of field management may offset the loss caused by the decline in total yield. Obviously, alternative furrow irrigation will be beneficial economically in cotton production in Xinjiang.

4. Breeding of salt-tolerant crops in arid region

The first salt tolerant wheat variety in Xinjiang, called Xindong 26, had been bred by the scientists in Fukang station. This variety can be grown in the land with salinity of more than 2% in weight, and its percentage of seedling survival may approach over 75%. Under regular irrigation, its yield is about 3000-4500 Kg/hectare. In the saline alkali field with salinity of 0.6~1.0%, its yield is more than 4350 Kg/hectare.

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37

Study on the Theoretical Basis and Technological Methods for Sustainable Management of Desert-Oasis Ecosystem

Scientific research progresses of Cele Desert Research Station

Introduction of Cele Desert Research Station

Cele Station is located at the north of Kunlun Mountain and the south edge of Takelimagan Desert(80°43'45"E、37°00'57"N，1318.6m a.s.l). It belongs to the extreme arid area of temperate zone from the climate type, and it is one of the three extreme arid areas in the world. It belongs to oasis-desert ecological zone of Tarim-Tuha Basin from the ecological type, and it is one of the most frangible regions. The environment characteristics of climate is extreme arid and the desert plants are the absolute dominance in this region. There is representative in this region among the world arid lands. Seen from the ecotype, Cele Station is located at oasis-desert transition zone in the southern fringe of Takelimagan Desert, and this area is natural laboratory to develop the study on the stability mechanism of ecosystem and the transition zone. Because the oasis-desert transition zone converge desert ecosystem and oasis ecosystem, and the two ecological process of desertification and oasisification happened together here. Its main characteristics is: the ecosystem structure is simpler; the process of soil formation is weaker; water environment is worse; the plant species is sparse and the net primary production of plants is lower; the plant species is surrounded by many stresses. Therefore the land desertification is a very important ecological problem here.

Since set up in 1983, Cele Station has done many research projects in fundamental theory and plants restoration techniques about the ecosystem course, according to the hot scientific problems in preventing from desertification and vegetation restoration. By implementing these research projects successfully, Cele Station has acquired lots of achievements: 1) 11 prizes of different grades in these years had been obtained, include 2 international prizes, 3 national prizes and 6 departmental prizes; 2) there are more than 100 papers had been published on the international or national scientific journals by students of Cele Station, some of them were published in the famous journals or academia communication in international meeting; 3) these research projects have enhanced and developed some related subjects of Cele Station. Some research contents and technological methods have been improved and developed in Ecophysiology, Restoration Ecology, Protection Ecology and Desert Environment. Meanwhile, some new and important progresses have been made in certain research fields.

1. Better adaptability to adversity of desert plants

By the systematic research about adaptability to adversity of desert plants which grow in the south of Takelimagan Desert, for example: Alhagi sparsifolia (Fabaceae), Calligonum caput-medusae (Polygonaceae), Populus euphratica (Salicaceae) and Tamarix ramosissima (Tamaricaceae), some new ideas about these desert plants had been acquired, it helped to enrich and develop the research contents of ecophysiology and vegetation ecology. At the same time, these works have provided some important theoretical basis for plant restoration in south of Takelimagan and other similar environment areas. The results including:

(1)The primary desert plants do not experience obvious water stress during their growth season. By analyzing the measurements results including physiological parameters (water potential, photosynthesis rate, transpiration rate and water use efficiency), biochemical index and growth index of these plants, it shows that these desert plants have relative food water supply status during several continuous growth periods (Fig. 37.1); in spite of the extreme drought condition, the transpiration rate of plants don't been limited by water deficiency obviously (Fig. 37.2); the normal flood irrigation don't have marked effect on the plants water status; the roots of plants can connect with groundwater, the very important precondition for the normal survival and growth of plants is to maintain the stable level of groundwater and prevent the roots from being destroyed.

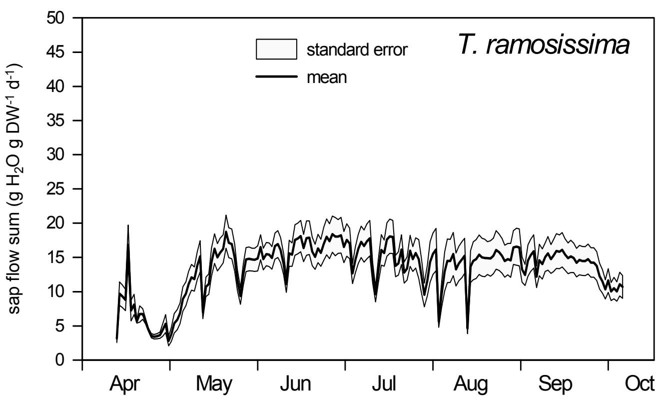

Fig. 37.1 The seasonal variation of sap flow of *T. ramosissima* in foreland of Cele Oasis

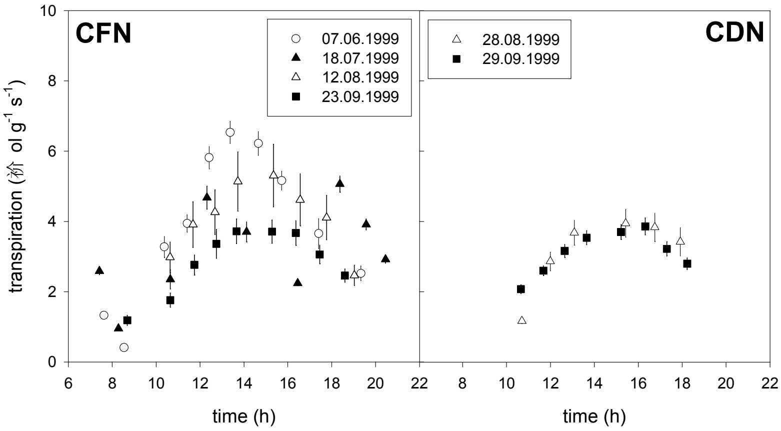

Fig. 37.2 Diurnal courses of transpiration and stomatal conductance of *Calligonum caput-medusae* in 1999. Plots of the irrigation treatment are compared.

(2) The different ecophysiological adaptive types of these plants have been compartmentalized. The five ecophysiological adaptive types of these plants have been compartmentalized based on the adaptability of plants to extreme habit and the measurements of photosynthesis rate (Pn) and transpiration rate (Tr). A---The ecophysiological type including: the low photosynthesis rate and low transpiration rate(Alhagi sparsifolia); high photosynthesis rate and high transpiration rate(Populus euphratica and Tamarix ramosissima); high photosynthesis rate and low transpiration rate(Calligonum caput-medusae). B---The adaptive type including: high water potential and delayed dehydration type(Alhagi sparsifolia and Calligonum caput-medusae), low water potential endurable dehydration type(Populus euphratica and Tamarix ramosissima). It shows that these ecophysiological and adaptive types are the primary adaptive strategies of desert plants in this area.

2. Higher water consumption and productivity of desert plants

(1) The water consumption of desert plant community is higher,(up to 183～528 kgH2O /m2 yr), which approach to the water consumption of deciduous forests community with 1000mm annual precipitation in the temperate zone. Among these investigated plant species, the water utilization of Alhagi sparsifolia (Fabaceae) and Populus euphratica (Salicaceae) is especially higher than the other desert plants. This results also demonstrate that the good water supply condition of these desert plants from another aspect (Fig. 37.3).

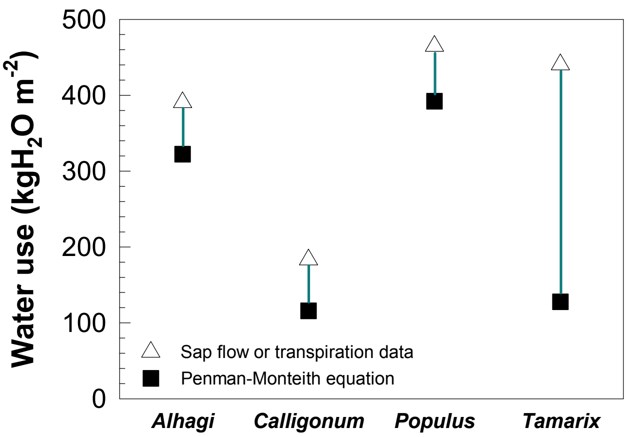

Fig. 37.3 Water use per unit soil area on the investigation sites in the vegetation period of 1999

(2) The potential productivity of desert plants are very higher, which is almost same to the quantitative levels of plant types in the humid zone. The effect of irrigation on the productivity can be neglected. The correlative relationship that had been confirmed between the biomass and productivity of plants had provided the basis for the establishment of the endurable use intensity of desert plants (Fig. 37.4).

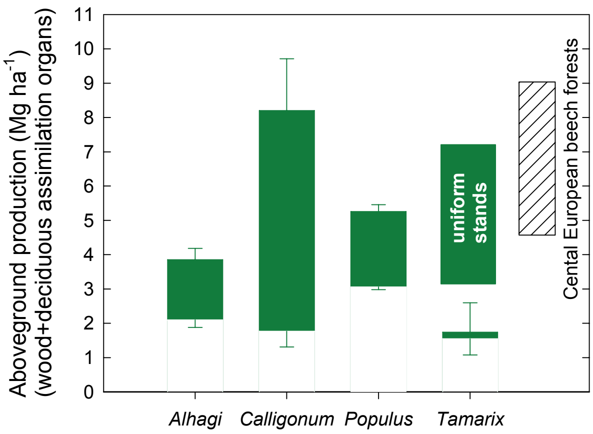

Fig. 37.4 Range of aboveground production of typical stands in the foreland of Qira oasis in summer 1999. Range of production in a temperate climate forest is shown for comparison.

3. Vegetation distribution pattern and temporal and spatial variety regularity in the desert-oasis transition zone

(1) To elucidate the space distribution regularity of plants in the desert-oasis transition zone. The communities composed by Tamarix ramosissima (Tamaricaceae)、Alhagi sparsifolia (Fabaceae) 、Karelinia caspica and Phragmites communis Trin in the periphery of Cele Oasis

occupy the absolute dominance. Populus euphratica (Salicaceae) 、Alhagi sparsifolia (Fabaceae) and Calligonum caput-medusae (Polygonaceae) also occupy certain distribution areas, but it is not large. This research offers a foundation for the effective protection and proper utilization of desert plants in the foreland of oasis.

(2) To clarify the temporal and spatial variety regularity of desert plants in the desert-oasis transition zone. Because of the double influence of nature and artificial on the foreland plant species, there were a significant change in the distribution area of plants in the desert-oasis transition zone from 1956 to 2000, i.e., the boundary of oasis extending out 0.5～1.0km, and the outside of transition zone shrinking 1.5km (Fig. 37.5). This result enriches the research contents of vegetation ecology.

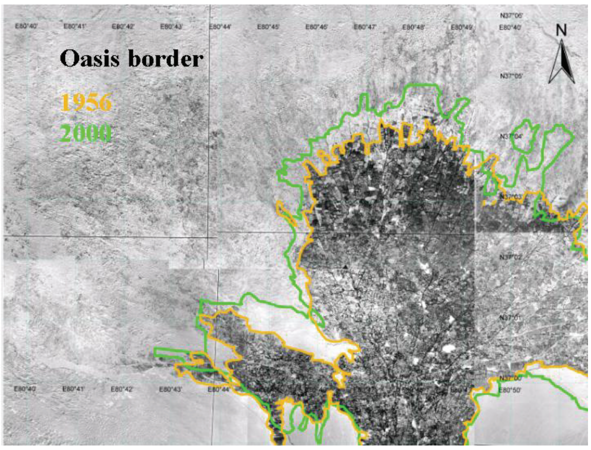

Fig. 37.5 Aerial photographs from 1956 with the oasis border in 1956 in orange and in 2000 in green

4. Basic extending pattern of desert plant groups

The study on the propagation of key plant species show that the expansion of plants is mainly completed by root systems and belowground buds at Cele oasis-desert transition zone. Because of the limit of soil water content and the pressure of overgrazing, it is hard to restore naturally the vegetation by seeds under the present time. So it is rare to see the natural seedlings in this region. But some key plant species can expand their groups effectively by root systems and belowground buds. It is shown that the clone growth is very important during the development process of desert plant community. Therefore, it is one of the most important methods to prevent the root systems of these clone plants from being destroyed in order to ensure the normal restoration and group extension of desert plants (Fig. 37.6).

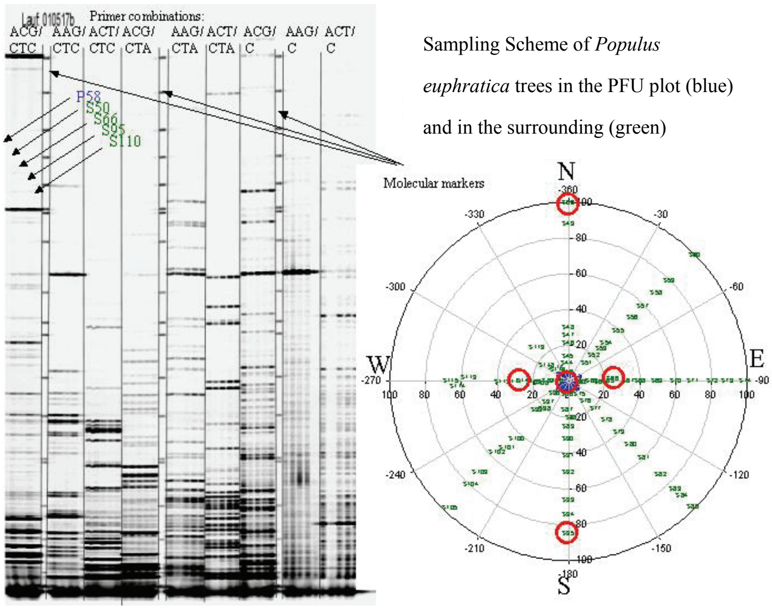

Fig. 37.6 Sampling design and AFLP fingerprinting results using 9 different primer combinations. On the right: Position of all sampled *Populus euphratica* trees. Green colours indicate trees that were sampled on transects in 8 directions over a distance of 100 m each. The red circles indicate the 5 individual trees analysed.

5. Optimal model of oasis defense systems

(1) To bring forward the basic model of establishment of oasis sand-defending systems in the south fringe of Takelimagan desert. Based on the analysis of the environmental characteristics (extreme drought, intense evaporation, frequent wind and smaller diameter sand particles, wind and drought occur in the same time and the different water resources distribution among seasons) in this area, a basic model of oasis sand-defending systems and its function had been brought forward, i.e., sand-block river to hold up parts of sands, natural perennial herbage plants to block sands, artificial shrubs to reduce the speed of wind, narrow but many rows defending systems around farmland to protect agriculture production.

(2) To establish the optimal structure model of shelterbelt around oasis in the south fringe of Takelimagan desert. A conclusion had been drawn that the model of the main direction of shelterbelt should be vertical to main wind direction is the best based on the basic layout of shelterbelt structure and the orthogonal experimental design in the establishment of oasis shelterbelt systems in the south edge of Takelimagan desert. If the actual topography condition can not meet this design, the angle of main shelterbelt and main wind direction could not less than 60 degree. Meanwhile, sub-shelterbelt should keep 300 to 500 meters away from the main shelterbelt. The results can provide scientific support for the management of oasis ecosystems.

6. Coupling model of water-fertilizer-heat in high-yield cotton ecosystem

(1) To bring forward the planting model of high yield of “two layers-two cotton individuals” based on the combination condition of light-heat and water-fertilizer in the southern rim of Takelimagan Desert. That is to say that there are two cotton individuals in each planting point during the cotton seedlings period, and the “two layers” are formed gradually during the cotton growth period by means of the different management methods. This model enable crop to utilize properly the light-heat-water resource and establish the basis of high yield of the crop.

(2) To confirm the coupling effectiveness of water-fertilizer-heat, the impact factors, the key factors and their combination in ecosystem of high yield of cotton field under the different conditions. The model that based on the coupling of water-fertilizer-heat in cotton field ecosystem will provide the systematic and scientific data for the proper planting and effective management of local main crop.

7. Research progress of desert environment in Cele Desert Field Station

The occurrence progress and transport mechanism of the sand storm had been studied in the south fringe of Tarim Basin. Some conclusions had been drawn based on the long-term research and monitor as following:

(1)To explain the occurrence condition of sand storm under the different ground surface in Tarim basin. The wind speed (9.5m/s-3m) of sand-blown in wetness condition is 1.27 times to which in drought condition; there is a great difference in the wind speed of sand-blown under different ground surface condition (Gobi and quicksand environment).

(2) To discover the characteristics of the composition and the grain distribution of the dust in the south fringe of Tarim basin. The diameter of aerosol in Takelimagan desert is between 4.7-7.0μm and 3.3-4.7μm. Otherwise, NH4+ is discovered in the sample of the aerosol (Fig. 37.7).

(3) To open out the regularity of spatial and temporal distribution of sand storm and its transport routes in the southern fringe of Tarim basin. This study had an important theoretical implication and applied value. It will make a huge contribution to the development of society and economy and the construction of ecological environment in the area.

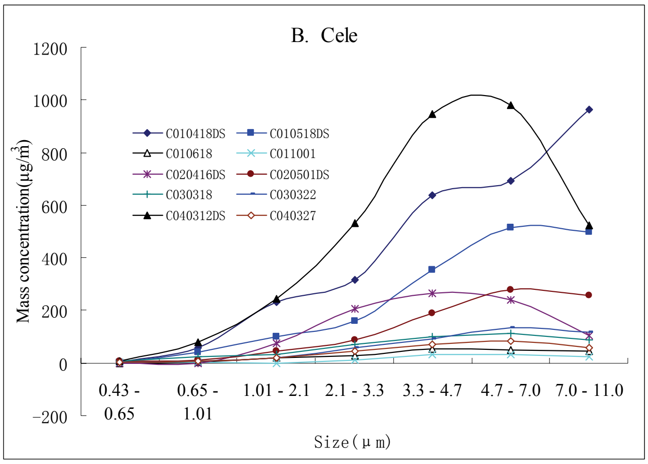

Fig. 37.7 The distribution of aerodynamic diameter(μm) in the southern of Taklimakan Desert

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38

Structure and Function of Shallow Lake

Scientific research progress of Donghu Experimental Station for Lake Ecosystem

Introduction of Donghu Experimental Station for Lake Ecosystem

Donghu Experimental Station of Lake Ecosystem is situated in the middle reach of the Yangtze River (30°33′N, 114°23′E) and is about 18 m height above sea level. The Yangtze River is the longest river in Asia and its water capacity is only lower than Amazon, Congo and Ganges Rivers in the world. Its the total runoff is about 100 billion m3, accounting for 42% water volumn of total river outlet into the sea in China. Complex river-lake ecosystems are formed in this area due to connecting between tributaries and lakes, exhibiting a flooding-plain scene, which provide abundant resource by hydrobiology and fishery base. The fish yield from this area comporises 2/3 of total fish production in China. Three Gorge Project is also builded in this area.

Donghu Experimental Station of Lake Ecosystem (DESLE) is located in Wuhan City, Hubei Province. The station belongs to the Chinese Academy of Sciences (CAS) and built up in 1980. In Wuhan, which is called water city, there are over 100 lakes with the surface area larger than 1 km2. Lake Donghu, as the mainly focused lake by the station, has a total surface area of 27.8 km2 with water depth ranging from 2m to 4m. This lake is a typical shallow lake in the midlle reach of the Yangtze River.

In the 1960s of last century, Lake Donghu was divided into several sections by artificial dikes, including Guozhenguhu, Tanglinjhu, Houhu, and Niuchaohu. Due to the difference of trophic states in these sections, ecological factors, including plankton and fish, varied widely, which provide us a suitable area to study function, sucession and sustainable development of lake ecosystem.

In recent decades, our station devotes all our effort to the studies on effects of human activities on lake ecosystem and process in Lake Donghu and to elucidation of theories for environmental renovation in Lake Donghu and other similar lakes in China. Based on studies on processing of trophic dynamics, eutrophication, environmental degradation, down-up effects of fishes (including effects on algal bloom by stocked fishes) and optimized patterns of fisheries, the theories in freshwater ecology and restoration of aquatic plant have been developed and biological accumulation mechanism and effective management methods for local government on lake eutrophication have been illustrated and provided.

1. Historic change characteristics of the Lake Donghu ecosystem

In the 1950s, the people from the Institute of Hydrobiology, the Chinese Academy of Sciences began to study the limnology of Lake Donghu. After the foundation of Donghu experimental station of lake ecosystems, water quality, communities of aquatic organisms were investigated at three stations, named I, II and III station respectively, set in the main area of the lake (Fig. 38.1). These works have great potential to explore the long-term dynamics of nutrients, zooplankton and fish, as well as to illuminate the disappearance of cyanobacterial blooms. Meanwhile, the achievements got in Lake Donghu could be expanded to other similar lakes.

The studies on phosphorus lasted for about 50 years (1957-2005). In 1957, the averaged concentration of total phosphorus at station I and II was 0.094mg/L and 0.065 mg/L, respectively. Total phosphorus maintained at a low level during 1957-1974, but it increased sharply in 1975 and peaked during 1983-1985. At station I, the maximum concentration of total phosphorus (i.e. 1.349mg/L) occurred in August of 1984, and 0.757mg/L at station II in August of 1983. Afterwards, the total phosphorus concentration at the two stations began to decline. The SRP was also low during 1950s and 1970s, and peaked in the 1980s and began to decline at the end of 1990s. The maximum concentration of SRP at station I (i.e. 1.032mg/L) occurred in March of 1984, and 0.223mg/L at station II in September of 1983. The dynamics of total phosphorus and SRP was similar at the two stations; for example, they began to increase in the 1950s, and peaked in 1984, and began to decline afterwards. Total phosphorus and SRP at station 1 are higher than those at station II. The possible reason can be attributed to the high population density around and two major sewage inlet in the Shuiguo bay.

(1) Pelagic plankton

During 1982-1983, the clear water phase could be found in spring. However, high biomass of cyanobacteria was followed in summer. From 1999 to 2005, the biomass of phytoplankton maintained at a relatively low level and the lake water at a turbid state. The increasing biomass of silver and bighead carp not only inhibited the bloom of cyanobacteria but also depressed the development of macrozooplankton, and indirectly favored the development of small algae. Because of the increasing biomass of planktivorous fish, the density of cladocerans and copepods declined since 1980s and kept at a low level after 2000. However, the density of rotifers and ciliates maintained at a relatively high level. The predation of planktivorous fish on crustaceans may favor the development of small zooplankton indirectly.

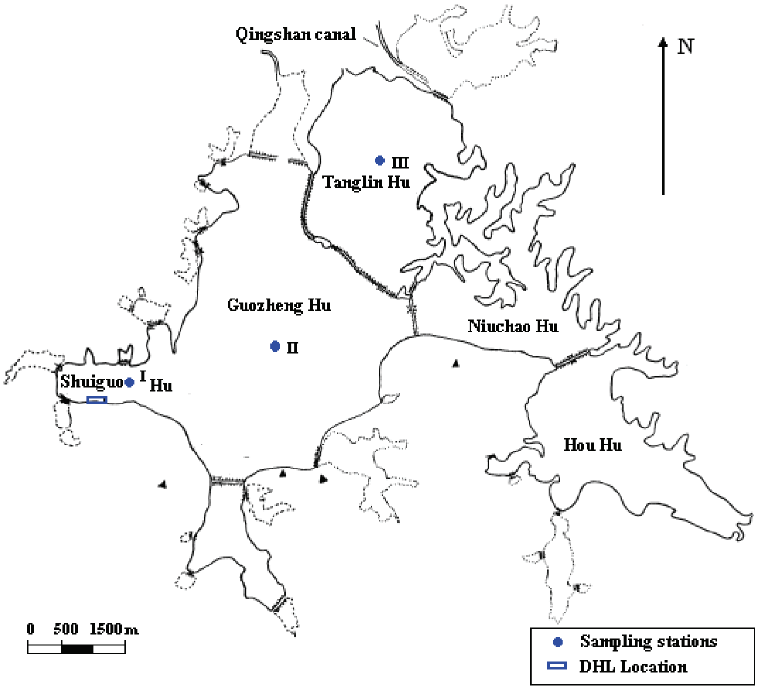

Fig. 38.1 The sketch of Lake Donghu and sampling stations

(2) Zoobenthos

Drastic changes in the community structure of macrozoobenthos had occurred during the 1960s-1990s, among which the most significant phenomenon was the loss of species biodiversity. During the 1960s, a total of 133 taxa of macrozoobenthos were found in Lake Donghu, while were only 67 taxa during 1990s. The reduction of species of macrozoobenthos was closely related to the changes in environmental conditions such as the isolation of the lake from the eutrophication, and disappearance of macrophytes. Perhaps, the latter two changes were more important.

(3) Fishes

The fish community has changed greatly in Lake Donghu since 1950s. Species number of fish declined from 67 in the 1970s to 39 in the 1990s, and now it was dominated by silver and bighead carp. The cultured larvae (13 cm) increased from 130×10^4 in 1973 to 461×10^4 individuals in 2004, and the fish yield increased from 235kg/ha in 1973 to 1110kg/ha. 95% of the fish yield are composed of silver and bighead carp. The disappearance of cyanobacterial blooms has great relation to the high biomass of filter-feeding fish.

2. Proposal and application of non traditional biomanipulation theory

Recently, the functions of aquatic ecological system are seriously destroyed by intensive large-scale cyanobacteria blooms, which regularly occurred in most of important lakes of China. Many cyanobacteria species can produce microcystins, which are risky to both the ecosystem and human health. Moreover, cyanobacteria blooms can destroy the structure and function of aquatic ecological system as well as the water landscape. Microcystins can accumulate in aquatic animals, and then transferred to human through food-web. So, it is a hot focus by international society that how to effectively control and eliminate the toxic cyanobacteria blooms. Base on the successful practice that the cyanobacteria blooms had been eliminated for 16 years by controlling the abundance of piscivorous fish and stocking filter-feeding fish in Lake Donghu, and a series of in situ enclosure experiments that focusing on the control of cyanobacteria blooms using silver and bighead carp, Liu and Xie (1999, 2001) put forward the theory of non-traditional biomanipulation that controlling the abundance of piscivorous fish and stocking the filter-feeding silver and bighead carp to directly forage the cyanobacteria bloom. It is an ecological method that suppressing the cyanobacteria blooms by food chains. The main principles of this method are extracting the nitrogen and phosphorus from the lake water using algae, and controlling the cyanobacteria development using the feeding of silver and bighead carp, then eliminating the nutrient in the water through the fish yield. By using this method, the cyanobacteria blooms disappear in Lake Donghu, which always occurred regularly in this lake before the middle of 1980s. And in the eutrophic Lake Tai that with a heavy cyanobacteria blooms, we also obtained a good effect in the in situ experiment.

To achieve economic, effective and ecological water purification, we set up a large fish pen of 1.032km^2 to stock silver and bighead carp for controlling the cyanobacteria blooms in Meiliang Bay, which is located in the north of Lake Tai, Jiangsu Province, China. Our results indicated that the pen-cultured silver and bighead carp can reduce the biomass of Microcystis by 38% during the outbreak of cyanobacteria blooms. Moreover, the feeding of silver and bighead carp not only induced the decline of total biomass of cyanobacteria, but also significantly decreased the relative proportion of cyanobacteria in the phytoplankton community. The feeding of silver and bighead carp also greatly reduced the microcystins concentration in the lake water (reduced by 77% in July, and 38% in September, respectively). In conclusion, non-traditional biomanipulation, controlling cyanobacteria blooms by stocking silver and bighead carp, provide an effective approach for management of many similar lakes in China. We suggest we can stock filter-feeding fish in eutrophic lakes which suffer from the nuisance blooms of cyanobacteria. Controlling algae blooms using silver and bighead carp can obtain a high profit but a low cost. It can yield a significant economic profit, and eliminate quite a large quantity of cyanobacteria in the water at the same time. More important, it can bring up a significant society profit (reducing the pollution load in the water and improving the aquatic environment). So, the bio-control of algae (such as non-traditional biomanipulation) can translate the waste into useful things, which is a sustaining economic model.

3. Biological mechanism driving seasonal changes of internal phosphorus loading in shallow lakes

Phosphorus is the most important macronutrient in lake waters. Excessive P loading is a chief causative agent of algal outburst and freshwater eutrophication. Phosphorus exchange of the water-sediment interface has been brought to our attention. The exchange of phosphorus at sediment-water is one of important part of phosphorus circulation in freshwater waterbodies. This process is mediated with various physical, chemical and biological factors. Consequently, contents of phosphorus including released from sediment is hotly discussed. Fe, oxygen and some related factors (such as disturbing and degradation) have attracted attentions when mechanism of phosphorus releasing is considered. However, most of results of variety of P concentrations are still unclear.

Experimental and field studies on the mechanisms of P release from the lake sediment in the middle and lower reaches of the Yangtze River in China were carried out, and our station reported firstly international that the phenomenon and mechanism, of which cyanobacteral blooming leading to phosphorus releasing from sediment (internal P loading increased). This consequence challenged the popular TN:TP theory which was used to explain outburst of cyanobacterial blooms (Xie, 2006). Long-term study of Lake Donghu (Wuhan) algal, especially cyanobacterial blooms can promoted P releasing from sediment (Xie et al. 2002); Experimental researches conducted in Lake Donghu indicated that phosphorus selectively pumped from sediment was resulted from cyanobacterial blooming in midsummer and this process was influenced by contents of P in sediment, that was, pumping effected more intensely followed with higher concentrations of sediment P. Selectively pumping challenged the N:P theory (Smith, 1983) which was popular applied to explain outburst of cyanobacterial blooms. The present results indicate that a low TN:TP ratio is not the cause of algal blooms, but a result of the blooms. Selectively pumping triggered by cyanobacterial blooms explained the disappear of algal blooms induced by decreased of TP and SRP in water column after stocking of planktivorous silver and bighead carp (non traditional biomanipulation) in shallow hypereutrophic Lake Donghu in 1980s. Furthermore, it explained why P concentrations decreased when biomass of phytoplankton was low and which was considered as clear-water state during seasonal succession of algal community in some Europe lakes. On the other hand, it explained phytoplankton biomass decreasing caused by P reduction after application of traditional biomanipulation. Comparative limnology of shallow lakes of the middle and lower reaches of Yangtze River showed that TN:TP ratio was relative lower in algal growth seasons. Based on selectively pumping P from sediments induced by cyanobacterial blooms, our state firstly carried out the latest viewpoint that the close relationship between variety of seasonal of internal P loading and lake trophic state was drived by algal photosynthesis.

4. Degradation mechanism of aquatic plants in shallow lakes in the

Yangtze Basin

Long-term ecological research in Lake Donghu found that the decline of aquatic macrophytes vegetation is the result of the anthropogenic impacts e.g. Lake Eutrophication, fishery enhancement, waterbody fragmentation. These factors mainly resulted in low light, low oxygen, nutrient enrichment in hydrophytes, increase of periphytons and the stress on hydrophytes from increase of related DOC, decrease of soluble CO_2 and enhancement of allelopathic effect from algae. At present, most attempts are focused on the effects of shading, allelopathy, disease, and anoxia and toxicity of sediment in eutrophic waters on decline and disappearance of submerged plants. However, research on the direct consequence of eutrophication such as N, P increase is scarcer. Ammomium (NH_4^+) is the important nitrogen source in the growth of plants. Due to increasing input of outer nitrogen runoff and drop of dissolved oxygen, NH_4^+ concentration markedly increased in eutrophication. High external ammonium could cause a severe stress syndrome in many higher plants, and inhibit both of respiration and photophosphorylation in them. Our study indicated that submersed plants were rather sensitive to this toxicity, furthermore induced the elevation of free amino acid (FAA) content in plant tissues. Detoxification in plants mainly worked through synthesis of amino acid with high nitrogen percentage. A high ammonium level in the water column has been suggested as an important stress factor for the hydrophytes from eutrophic lakes. To discuss the functions and related mechanisms in decline of aquatic higher macrophytes for the elevation of ammonium concentration in eutrophic waters has a very important significance in the recovery of aquatic plant and lake ecosystem restoration. Studies indicated that the growth of hydrophytes in eutrophic waters was inhibited by the low ratio of free amino acid (FAA) to soluble carbohydrates (SC) (FAA/SC), because detoxification of ammonium in plants caused the excessive FAA accumulation and SC consumption. Vallisneria natans, as studied in our researches, was wildly distributed around China, and now sharply reduced in severe eutrophication of lakes in reaches of Yangtze River. Our studies found a phenomenon that the reduction of FAA/SC ratio in the hydrophyte tissues induced the drop of biomass in the eutrophic waterbodies, and expatiated on the stress and the effect mechanism from ammonium upon aquatic higher plants.

Field study evidences and laboratory experiments on ammonium enrichment for the decline of submersed plants were first acquired. Through applying FAA/SC ratio as an indicator to judge the C/N balance of submersed plants, we discussed ammonium enrichment on the inhibition of the growth of a submersed macrophyte, Vallisneria natans, in shallow lakes around reaches of Yangtze River. Additionally, through the methods of experimental ecology, we also discussed the mechanism about the effect of this indicator’s change on the growth of submersed macrophytes. Our results indicated that ammonium enrichment had more significant impacts on the reduction of hydrophytes biomass than nitrate (NO_3^-) enrichment. Acute experiments also showed that as the increase of NH_4^+concentration, FAA in Vallisneria natans was rapidly accumulated while SC contents in shoots & leaves tissues were fast reduced. However, increase of NO3- concentration didn't induce these changes above. It also indicated that Vallisneria natans was susceptible to the stress from high external NH4+. Besides, NH4+ was also used for the synthesis of FAA, which promoted the FAA accumulation.

5. Food web structure and dynamics in shallow eutrophic lakes

The structure and trophic relationship of food webs are fundamental research topics in modern ecology. Food webs are important for the understanding of patterns and processes of an ecosystem. Stable isotopes of carbon and nitrogen, as a powerful approach to study the structure and dynamics of food webs and trophic relationships, have been increasingly used in the studies on a wide variety of ecosystems. By using the carbon and nitrogen stable isotope analysis, we found that in the hypereutrophic subtropical Lake Donghu, high external nutrient loading and the presence of abundant detritus from submersed macrophytes were responsible for the high sediment ^{15}N and ^{13}C，respectively. ^{13}C was significantly higher in submersed macrophytes than in other macrophytes. The similar ^{13}C values in phytoplankton, zooplankton, zoobenthos, and planktivorous fish indicate that phytoplankton was the major food source for the consumers. By using a ^{15}N mass blance model, we estimate that the contributions of zooplankton to the diet of silver carp and bighead carp were 54% and 74%, respectively, which is in agreement with previous microscopic observation on intestinal contents of these fishes.

Stable carbon and nitrogen isotopes were used to investigate food web and to determine the importance of external and internal carbon sources in Lake Chaohu. Temporal and spatial variations, and overlap in the carbon and nitrogen signatures of primary producers made it difficult to determine unambiguously the feeding habits of many consumers. However, stable carbon isotopic signatures suggested that autochthonous carbon sources were the main carbon inputs was seemed to be neglectable to the local food chains. Both invertebrates and fish appeared to eat a variety food (often more than one trophic level), indicating that a continuous rather than discrete measure of trophic position would be useful in describing trophic relationships in this lake. Temporal and spatial changes in $\delta^{13}C$ and $\delta^{15}N$ of seston (mainly phytoplankton) and isotopic relationship between seston and the lake anchovy (Coilia ectenes) were studied in the large eutrophic freshwater Lake Chaohu in China. Much of the spatial and temporal variation in $\delta^{13}C$ of lake anchovies was explained by variation in seston, indicating a strong link between pelagic primary production and higher order consumers. Because the lake is shallow, there were no significant differences in $\delta^{13}C$ and $\delta^{15}N$ of seston between surface and overlying waters. Spatially, the relatively high $\delta^{13}C$ and $\delta^{15}N$ of seston in the western part of the lake might be due to high levels of anthropogenically derived N and C introduced from the surrounding cities through sewage drainage systems. The trophic position of the lake anchovy in the food web of Lake Chaohu was estimated to be 2.9-4.1 (3.5 ± 0.4), which agrees well with the previous stomach content analysis suggesting that the lake anchovy fed both on zooplankton and small planktivorous fishes.There were large variations of stable carbon and nitrogen isotope ratios of lake anchovy from Lake Chaohu. Significantly distinct stable carbon and nitrogen isotopic compositions between small (<=130mm) and large (>130mm) lake anchovy imply that they feed on food sources that are overall different in isotopic composition for some considerable time. $\delta^{13}C$ and $\delta^{15}N$ signatures of lake anchovy provided evidence for food-web differences between small and large lake anchovy, indicating that small lake anchovy were feeding on a predominantly plankton-based diet while large lake anchovy were living on a more benthic and picivorous feeding mode.

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39

Eco-environment research and Eutrophication Control in Shallow Lake

Scientific research progress of Taihu Laboratory for Lake Ecosystem Research

Introduction of Taihu Laboratory for Lake Ecosystem Research

Aimed at physical process and environmental effect, nutrient release from inner source and eco-dredging technology, characteristic of ecosystem structure and it's application, ecological model on hydrodynamic and eutrophication, and ecological remediation technology, extensive regular monitoring, in situ observations and experiments, indoor simulations, and numerical model simulations for Lake Taihu were conducted at Taihu Laboratory for Lake Ecosystem Research (TLLER). TLLER is an integrative laboratory for lake ecosystem research, and can provide long-term continuous data of Lake Taihu. This lab serves mealy for foundational and applied research regarding limnology. Wuxi headquarter of TLLER is situated in the east shore of Meiliang Lake (31^{o}24'N, 120^{o}13'E), the fifth largest freshwater lake in china. Dongtaihu station of TLLER is located in west shore of Dongtaihu Bay, Suzhou. The climate is an SE–NW monsoon climate. The mean annual air temperature is between 14.9°C and 16.2°C. The mean annual precipitation and evaporation are 1000–1400 mm and 941mm, respectively. Lake Taihu is the third largest freshwater lake in China, with a water surface area of about 2338 km^2, a mean water depth of 1.89m, and a mean annual runoff of 4.1*10^{11} m^3. The area of Lake Taihu Basin is about 3.65*10^4 km^2, which reaches Jiangsu, Zheiiang, Anhui, and Shanghai the regions with the highest population density. Within the basin, there are Shanghai Podong Hi-tech Zone, Suzhou Industrial Park, and Xukou & Mashan national tourism vacation zones.

1. Physical process and its environmental effect in lakes

Based on the numerical simulation and the in situ observation of wave and multilayer current, Hu et al. (2005) found the relationship of wave and current to wind speed, wind direct, water depth, and wind fetch length in shallow lake. The results elucidated vertical structure of wind-driven current of shallow lake (Hu, 2004) and obtained resuspension flux of sediment under different wind-wave conditions in Lake Taihu (Hu et al., 2005).

Long-term observation on ecosystem and lake physical process in Lake Taihu, and related to simulating experiments indoor indicate that there is a closely correlation between the release of inner source and sediment resuspension in shallow lake and strong disturbance of sediment induced by wind and wave (Qin (2004, 2005), Fan (2004) and Zhu (2005). The driven factors of sediment resuspension in Lake Tahu was further identified by Luo et al., 2003 and Qin et al., 2005 by the of comparing the wave stress and the current stress. The indoor flume experiment of nutrient release from lake sediments was conducted, critical wave stress of sediment and the thickness range of surface sediment moving into suspension (Qin et al., 2004) was ascertained, as well as the effects of hydrodynamic disturbance on nutrient release from sediments in Lake Taihu (Fan et al., 2001, 2004; Zhu et al., 2005).

Light field observation and indoor experiment of light transmission under different wind and wave conditions conducted byYang et al (2003) and Zhang et al. (2004a) have shown there is a green or red shift of spectrum with the increase of water depth in shallow lake, and the attenuation of available radiation (PAR) for photosynthesis was enslaved to suspended matter concentration and primary productivity of phytoplankton concentrates in surface water (the water depth is beyond 0.8m) in overwhelming majority area in Lake Taihu. The dominant factors controlling ultraviolet radiation attenuation is yellow matter in Lake Taihu (Zhang, 2006), and the quantitative relationship between the resuspended sediment duo to wind and wave and the water optical characteristic and the primary productivity of phytoplankton was setup. Further the character of attenuation of PAR was discovered: it increase as wave and current of lake become stronger. The small flow velocity will increase the primary productivity of phytoplankton, on the contrary, the strong flow will make it descend (Zhang et al., 2004b). These researches deepened the understanding of the primary productivity, the ecosystem structure, and the environment control mechanism of Lake Taihu.

2. Inner release of nutrient and the eco-dredging technology in Lake Taihu

Based on intensive investigation for the sediment in different region in Lake Taihu, Zhang et al. (2004) and Zhu et al. (2004) found the characteristic of the regional and seasonal distribution of the sediments and the nutrients in Lake Taihu. They also determined the activated phosphorus species of the sediment in the lake. Fan et al. (2004) investigated the release characteristic of nutrient elements in sediment under undisturbed and disturbed condition using self-designed propeller-driven sediment resuspension equipment (Fan, 2004).

Due to the unclear distribution of Lake Taihu sediment, unknown pollution loading from inner source, and the ineffective effect of sediment dredging, based on the main objectives of polluted sediment, inner source loading, and sediment dredging, the multidiscipline integrated research and simulation were conducted regarding the distribution characteristic of pollutant nitrogen, phosphorus, organic carbon in both sediment and interstitial water and the bio-geochemical behaviors of nutrients on sediment-water interface. Further combine with the in situ tracing and comparison of the dredging engineering at the heavily polluted region in Lake Taihu, we strengthened the knowledge of the nutrient release characteristic from the inner source in shallow lake, and put forward the corresponding principle of ecological dredging.

The research took the lead of the world in developing interface process research of the new surface layer after the dredging. The result indicated that the new surface layer may be re-polluted after dredging and its bio-geochemical process was the important factor that controls the dredging effect. The research preliminarily clarified that sediment dredging which aimed to improve water quality can cause the risk of environmental pollution. It provides the base and method to lake sediment dredging evaluation.

This research leads the world in the field of the interface process of the new surface layer and the activated mechanism. It is regarded as a scientific warranty that directed ecological dredging in Lake Taihu and Dongjianhu Lake in Zhejiang. The research has guided the overall treatment and management in Wulihu in Lake Taihu, and plays an important instructional role to the control of inner source pollution in the other shallow lake (Fan et al., 2004). Applying the achievement, Wuxi municipal institute of hydrmdic engineering design and research obtained huge economic and environmental benefit. The institute gave this result a high evaluation that by using the ecosystem risk index evaluation method provided by Nanjing Institute of Geography and Limnology Chinese Academy of Sciences they determined the ecological dredging depth of 0.2m-0.7m, thereby the dredging area was reduced from 4.76 million m^3 to 2.07 million m^3, and approximately 48.4 million Yuan of investment was reduced. After more than two years since the sediment dredging, the majority parameters of water quality have been improved obviously in Wuli Bay and the degree of eutrophication decreased significantly. These suggested that implement of sediment dredging in Wuli Bay and local ecosystem treatment in west Wuli Bay have already obtained good environmental effect. This project was awarded the accessit of the science and technology progress by Jiangsu province in 2006.

3. Study on ecosystem structure of Taihu and its application

By the integrated survey for Lake Taihu in the 1960s, comprehensive pollution investigation for Lake Taihu in 1980-1981, agricultural practices of water body in east Lake Taihu in 1982-1985, overall survey for Lake Taihu in 1987-1988, and comprehensive integration and analysis of the long-term monitoring data of ecosystem structure evolution for the period of

1991-2002 from TLLER, we found that as the increase of the eutrophication the biology diversity in Lake Taihu has decreased to different degrees. The miniaturization of zooplankton individual was obvious and its density increased significantly in the northern and northwest lake regions (Chen et al., 2005). The population of the macro-fish continuously declined while the micro-fish yield clearly increased in Lake Taihu (Liu et al., 2005).

With the support of the research foundation which focused on the long-term continuous, systematical, automated monitoring of cyanobacteria bloom-forming and it's environmental characteristic, the major controlling factors of cyanobacteria bloom in Meiliang bay, Lake Taihu, were established, the maintenance mechanism of low concentration nutrient during cyanobacteria bloom and the influence mode of nutrient on algae growth in Lake Taihu were presented (Chen et al., 2004; Qin et al., 2004). We concluded the four-phase development hypothesis on the process of the cyanobacteria bloom-forming: dormancy in winter, recruitment in spring, growth and float to the water surface in summer and sink to the sediment in autumn. There are different factors that may influence the status of algae in different phases. For example, in winter the dormancy phases is likely to be controlled by low temperature and illumination； in spring the main factors that affect the recruitment may be the temperature and dissolve oxygen on the sediment surface. In addition, the algal growth rate was controlled by the nutrient and energy needed for photosynthesis and cell division. The hydrological and meteorological condition would cause the algae to float up to water surface and then form the water bloom. The further pertinence survey is necessary to control the cyanobacteria bloom before it starts to recruit, develop and bloom.

According to long-term observation data from TLLER, the reasons for fishery resource deterioration and aquatic macrophytes degradation were clarified, the measure were put forward to solve the flaw of over-fishing, large-scale expansion of the enclosure culture and unreasonable layout and structure, namely, set up the fishery function and resource protection region in Lake Taihu based on its water environment and regional distribution characteristic of the creature. While developing economical, high effective, sustainable and pollution-free fishery mode to prevent grass type lakes from swamping, we should keep the same level of the yield of aquatic macrophytes and promote the sustainable utilizations of the biology resources in Lake Taihu (Gu et al., 2002, 2005).

4. Large shallow lake hydrodynamic-eutrophication ecological model

On the basis of systematical integration of the investigation and experiment data of lake current, water level, water quality, and ecosystem variety, especially the monitoring data of TLLER since 2001, foundational database of Taihu ecological environment changes was constructed, 3D models (Qin et al., 2001; Hu et al., 2002; Luo et al., 2004) was developed. hydrodynamic processes, nutrient transformation, creature growth, metabolism and population competition et al have been integrated into EcoTaihu Model. It includes 27 parameters such as lake hydrodynamic factors (water level and lake current), water quality parameters (NH_4-N, NO_3-N, NO_2-N, PO_4-P,DO), sediment exchangeable-N, sediment exchangeable-P, dissolved-P and dissolved oxygen of interstitial water in sediment, biologiacl factors (phytoplankton biomass, zooplankton biomass, fish biomass, hydrophyte biomass, detritus, phytoplankton nitrogen, zooplankton nitrogen, hydrophyte nitrogen, fish nitrogen, detritus nitrogen, hydrophyte phosphorus, zooplankton phosphorus, phytoplankton phosphorus, fish phosphorus, detritus phosphorus). The experimental methods of the in situ experiment, long-term observation in fixed point, and numerical simulation were adopted to determine the model parameters (Hu, 2006), which laid a foundation for forewarning system of the water environment in Lake Taihu. By far, EcoTaihu Model is one of the more perfect lake ecological models in our country, and plays an important role in explaining forming mechanism of water quality in Lake Taihu, exchange of the nutrients and alga in water body between Meiliang Bay and Main part of Lake Taihu, budget balance of the nutrients and alga and origin of the alga bloom in Meiliang Bay. It is also applied to evaluate lake currents of Lake Dishuihu and Lake Zhuhu in Shanghai and the effect of the water transfer from Yangtze River to Lake Taihu project on improving water quality in Lake Taihu, and to analyze feasibility of building the Meiyuan pumping station to improve water quatity in Meiliang Bay and Wulihu Bay. It plays very important roles on displaying the impact of the sediment in Lake Taihu on water quality and influence mechanism of wind stress on alga transfer and alga bloom forming, etc.

5. Shallow eutrophic lake ecological remediation technology

Based on the relationship of the cyanobacteria bloom and aquatic macrophyte to environmental condition and the inner nutrient release mechanism in large shallow lake, sponsored by Jiangsu Science and Technology Department, Environmental Protection Department of Jiangsu province, EU international cooperation project, and special project from The Ministry of Science and Technology of the People’s Republic of China and Chinese Academy of Sciences, a plenty of experiments and demonstrative studies related to the treatment and ecological remediation of the eutrophic lakes were curried out. Theories and methods to improve water quality of local water body using physical and ecological engineering were put forward (Pu et al., 2001, 2002; Wang et al., 2001, 2002). At the same time, the related technologies, such as bio-manipulation, incrustation of bio-community, and immobilized nitrogen cycle bacteria were explored. With the demonstration experiment of ecological restoration going thoroughly on, thinking of improving the basic environment was firstly brought on to guide the ecosystem developing toward healthy lake ecosystem. Moreover, many technological ways to purify the lake water have been put in use, such as Flow Guide, algal controlling enclosures, wave absorption, and aquatic macrophyte planting, etc. By the integrations of various techniques, super-large-scale demonstration engineering, in the intake area of Xiaowanli water plant in Meiliang Bay, Lake Taihu, obtained better effect in purifying water. This made a new progress on the theories and the practices to restore ecosystem of eutrophic lake (Qin, 2005). This technology was applied to the treatments of other lake, such as Lake Mochouhu, Lake Taihu, Lake Tianmuhu, Lake Guchenghu, and Lake Xuanwuhu, etc.

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40

Impact of climate Change and Human Activities on Eco-safety and Sustainability of the Bay Ecosystem

Scientific research progress of Jiaozhou Bay Research Station of Marine Ecosystem

Introduction of Jiaozhou Bay Research Station of Marine Ecosystem

The Jiaozhou Bay lies between 35°38′ - 36°18′ N and 120°04′ - 120°23′ E, covering an area of 390 km2. As a semi-closed fan-shaped sea bay, it is surrounded by the Qingdao city, and connects the Yellow Sea with a narrow channel in the south. Its average depth is 6-7 m, with most part of the bay is no deeper than 5 m. Population density around the Jiaozhou Bay is high. Farms, factories, highways, ports, tourism etc. can all affect the environments of the bay.

The Jiaozhou Bay lies in warm temperate monsoon climate area, with annual average air temperature of 12.3°C, average total solar radiation of 480-518 KJ/cm2/a, and rainfall of 725-1100 mm per year. It shares similar environmental and biota characters with coastal areas of the Yellow and Bohai Seas. Biological productivity and diversity was high in this area: about 175 phytoplankton species have been identified and annual primary production is 503 mgC/m2/d; 110 zooplankton species have been identified and average biomass is 100mg/m2.

The Jiaozhou Bay Station was founded in 1981 in the name of ‘The Huangdao Island Mariculture Proving Ground’, which was changed into ‘The Huang Island Mariculture & Biotechnology Experimental Station’ in 1986. In 1991, it was accepted as one of the 29 field observation stations of China Ecosystem Research Network (CERN), in which it was called ‘The Jiaozhou Bay Marine Ecosystem Research Station (JBMERS)’. It is the only observation and research station in temperate China Seas. In 2005, it was authorized membership of State Ecosystem Observation and Research Network, in the name of ‘State Observation & Research Station of Jiaozhou Bay Marine Ecosystem, Shandong’.

At the beginning, the Jiaozhou Bay Station mainly engaged in mariculture. All the three pivotal events in the Chinese mariculture history, aquaculture of seaweed, shrimp and shellfish, have originated from the Jiaozhou Bay. From 1990s, when environmental problems in the Jiaozhou Bay were getting serious, the Jiaozhou Bay Station turned to long-term observation of environments and ecosystem, especially eutrophication. Since 21st century, the Jiaozhou Bay Station and the scientists were trying to find out how the marine ecosystem was affected by global change and human activities and how it feedback, and to establish methods and techniques for sustainable developments.

1. Ecological forcing from climate change and human activities

According to high resolution records, annual average air temperature in the Jiaozhou Bay region was increasing in the past 30 years. Before 1980s, annual average temperature was lower than long-term average, while that since 1990s was higher than average of the past 30 years. Average temperature in February, May, August and November was found also increasing during this period. Temperature increased most rapidly in winter, i.e. February, and lest in summer, i.e. August. Long-term change of air temperature in this region is similar to that of Pacific Decadal Oscillation (PDO).

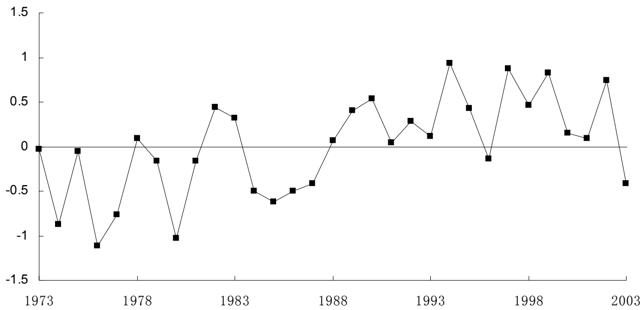

Fig. 40.1 Long-term variation of annual average air temperature (Anomaly, 1973－2003)

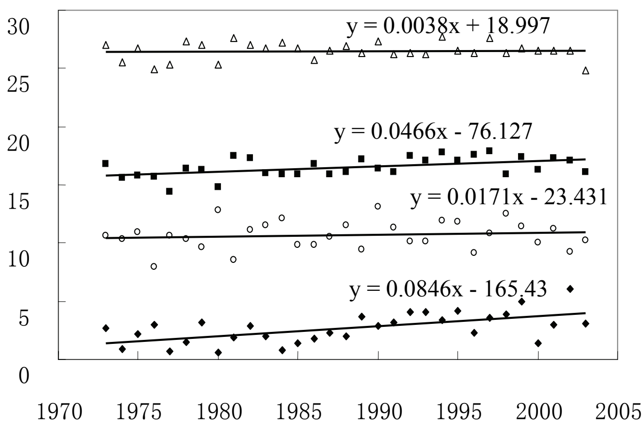

Fig. 40.2 Variation of average air temperature in February, May, August and November in the past 30 years

Based on the observing data from 1962 to 2004, nutrient concentrations in the Jiaozhou Bay have increased 3.1 times for PO4-P, and 8.1 times for DIN (Shen，2001). The mole ratio of DIN/PO4-P increased significantly from 15.9±6.3 in 1960s, to 36.5±11.6 in 2000s which was much more than Redfield value (16). SiO3-Si concentration remained at a very low level before 1990s and the ratios of SiO3-Si / PO4-P（7.6±8.9）and SiO3-Si/ DIN (0.19±0.15) were far lower than Redfield value (16 and 1). The increasing in the concentrations of N and P are the direct result of humen influences, such as the discharges of industrial waste and residential sewage and rapid development of sea farming. Low concentration of SiO3-Si was relative to building irrigation in rivers. High concentrations of N and P and low SiO3-Si, and high DIN/PO4-P ratio and vary low SiO3-Si / PO4-P and SiO3-Si/ DIN ratios show that SiO3-Si was main limiting factor of phytoplankton growth. The changes in nutrient structure have led to decrease of large diatoms and a shift of phytoplankton species composition. It was obviously relative to SiO3-Si limiting. Of late years, due to rapid development of city construction, SiO3-Si concentration in the seawater increased notably in Jiaozhou Bay and the ratios of SiO3-Si / PO4-P and SiO3-Si/ DIN also increased. The increasing of SiO3-Si concentration and its molar ratios broken the quondam balance between nutrients and accelerated eutrophication in Jiaozhou Bay waters, and red tide occurred frequently. In February, 2004, winter red tide was first found in Jiaozhou Bay. After autumn, nutrients concentrations increased rapidly, especially SiO3-Si and DIN, led to red tide of Lauderia annulata Cleve in winter. When the peak of red tide, nutrients were heavy consumed, and SiO3-Si was almost exhausted (0.49 μmol/L) and SiO3-Si/DIN and SiO3-Si/PO4-P ratios rapidly dropped down to 0.01and 1.04 respectively. SiO3-Si became limiting factor of phytoplankton growth and the red tide was finally controlled. Primary study shows that the variation in SiO3-Si concentration is one of major factor controlling waters eutrophication in Jiaozhou Bay (Shen et al.，2006).

2. Feedbacks of phytoplankton communities on environment changes

Phytoplankton abundance in the Jiaozhou Bay tends to increase in the past 50 years, and number of species was found fluctuated. These are regarded as signs of marine ecosystem alternation. Since middle 1990s, frequency of red tides keeps increasing. Besides the original red tide species Mesodinium rubrum, six diatom and one flagellate species were found causative species of HAB in the Jiaozhou Bay.

The distribution of phytoplankton characterized by dense area appeared mainly in the northeastern and northwestern parts nearshore area, and the lower were found in the middle and southern parts. The phytoplankton abundance was higher inside the bay than outside the bay. An obvious seasonal variation of phytoplankton was found. The peak of phytoplankton abundance frequently occurred in winter and summer. The lowest mainly occurred in autumn. Due to human activities, the environment of Jiaozhou Bay receives significant impact. The great quantity of industrial and residential waste water with high contents N, P and organic matters discharged into the bay every year. Significant long-term environmental changes had an obvious effect on the succession of phytoplankton community structure. The phytoplankton species composition, abundance and dominant species have occurred evident variation since 1954. Dominant species showed an obvious succession, some species such as Chaetoceros affinis, Thalassionema nitzschioides, Rhizosolenia setigera, Coscinodiscus radiacus replaced by Asterionella kariana, Thalassiosira nordenskioldi, Nitzschia paradoxa and so on. Some favored nutrient species on trophic physiology such as Skeletonema costatum and a warm water species Lithodesmium undulatum showed a significant increase. The phytoplankton diversity index (Shannon's H') has been shown to be a slight decrease over the past 50 years. From 1977 to now, red tide event have obviously increase tendency in number, frequency and intensity in Jiaozhou Bay (Wu et al., 2005). The eutrophication of marine area is considered the important factor that caused occurrence of red tide.

3. Bioremediation in coastal aquaculture and eutrophic systems

Mariculture has become one of the most important industries in China. The rapid development of mariculture has aroused increasing concern over its impacts on water environment of coastal waters. Reducing negative environmental impacts from mariculture activities is a key issue to ensure healthy and sustainable development of this industry. Suspension aquaculture of bivalves has been developing rapidly in the Jiaozhou Bay. Bivalves can remove a large amount of phytoplankton standing stock by filter-feeding, but these species in dense populations can also produce a large amount of faeces and pseudofaeces (biodeposits) that may lead to negative impacts on the benthic environment. Our recent results suggest that co-culturing of bivalve molluscs with sea cucumbers may provide an additional valuable crop with no additional inputs. It may be useful for both ecological aquaculture and bioremediation of eutrophic systems (Zhou et al., 2006a). In another case, the seaweed, red alga Gracilaria lemaneiformis, is found suitable as a good candidate for seaweed/fish integrated mariculture, which is suggestive to bioremediation in other eutrophic systems such as fed fish farms (Zhou et al., 2006b).

4. Anthropogenic impacts on environment changes in the last 100 years

Geochemical analyses are used to assess how the sediment records reflect the environmental changes of the Jiaozhou Bay. In the Last one hundred years, especially the last two decades, the Jiaozhou Bay has been greatly impacted by the increase of industrial activities and human interventions. A dated core sediment by 210Pb chronology was analyzed for concentrations of trace metals such as Li, Cd, Cr, Pb, Cu, Ni, Co, Zn together with C, N, P and BSi. Moreover, the burial fluxes of biogenic elements combined with the sedimentation rates were also calculated. The results showed that the development of the Jiaozhou Bay environment in the last one hundred years can be divided into three stages：（1） before the 1980s characterized by the relatively low sedimentation rate, weak heavy metal pollution and scarce eutrophication; （2） from the 1980s to 2000 or so, accelerating in the 1990s, during which high sedimentation rates, heavily polluted by heavy metals and biogenic elements as well as the frequent occurrence of red tide; （3） after 2000, the period that the improvement of environment, the whole system has been meliorated including the heavy metal pollution and hypernutriention.

5. Distribution and enrichment of heavy metals in surface sediments

Marine sediments, the sinks for pollutants, are widely recognized as a potential source of pollution, not only because they are always toxic above a certain level, but also they linger at sea bottom for long period. The contents of organic matter in samples in Jiaozhou Bay varied considerably, ranging between 27.72 % and 0.89%. As a good binding substrate for these metals, organic matter can cause change of these metals in the sediments. Cd, Cr, Cu, Pb, and Hg had a similar distribution pattern with the one in 1989; however, all the mean values were higher in this study. Compared to other bays in China, the contents of Cd, Cr, Cu, Pb, Zn, and Hg were higher than those in Bohai Bay; the mean value of Pb（35.17 mg/kg）was very close to the mean value of Pb （38.9 mg/kg） in Honghai Bay （near Shanwei of Guangdong）, but the Zn content doubled for nearly 100 times in Jiaozhou Bay. As a whole, these metals distributed mainly in the eastern part of Jiaozhou Bay near river outfalls and the Qingdao Harbor. Moreover, a clear gradually declining in the concentration was shown from river mouths to outer sea. Using the classification of Hhkanson （1980）, the metals in this bay can be divided into three groups: 1） negligible to low contamination, including Zn, Pb, Cr, Mn, and Fe; 2） moderate contamination including Cu and Cd; 3） severe contamination, including As and Hg.

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41

Structures, Functions and Dynamics of Marine Ecosystems

Scientific research progress of Marine Biology Research Station at Daya Bay

Introduction of Marine Biological Research Station at Daya Bay

The Marine Biology Research Station at Dayawan (MBRS), founded in 1984, situated at the west side of the Daya Bay (22° 31′ 17″ N, 114° 31′ 12″ E), affiliated to the South China Sea Institute of Oceanology, Chinese Academy of Sciences (CAS).

MBRS has become an open field station of the Chinese Academy of Sciences since 1990, become a data source plot of Chinese Biodiversity Research & Information Management since 1991, and become one of the leading station of the Chinese Ecosystem Research Network (CERN), CAS. MBRS becomes one of National Field Station of Marine Ecosystem Research and Observation in 2005. Long-term ecological and environmental monitoring of Daya Bay is the basic policy of the station. The station also aims to study the sustainable management of the ecosystem..

The station occupies a terrestrial area of 38,000 square meters, a water area of 60,000 square meters, and a total construction area of 4, 670 square meters.The main facilities standing in the station campus comprise: the Ecology Building, Ichthyology Building, Malacology Building, tens of indoor and outdoor aquariums, Experts House, Guest House, Residence, Dining Hall, and the auto-recording Weather Station.

MBRS has been monitoring the dynamics of the Daya Bay ecosystem and the biodiversity. She has undertaken many key projects from variety of sources, such as the State Basic Research Program 973, the State High-Tech Plan 863, National Science Foundation, CAS and Guandong Province etc. She has also been studying the structures and functions of the marine ecosystem, the impacts of human activities, the experimental biology of the important marine species. She was awarded many research prizes from CAS and Guandong Province. MBRS has become a key field station and research base marine sciences.

The station is well equipped with modern analyzing instrument and computer systems, which are financially supported by the World Bank loan. The major indoor and outdoor facilities are listed in the tables below. There are more than 20 faculty members in MBRS, including 8 research professors and 9 associate professors.

In recent five years, more than 240 research papers have been published both in and outside of China, including over 80 papers (SCI and EI) and other 160 papers. 8 monographs and version were published. 21 patents have been applied and accredited. 10 research projects have been won the national, ministerial and provincial awards. Marine Biology Research Station at Daya Bay provided the open field for more than 40 projects funded by nation and ministry, the total funds were about 40 millions RMB.

1. Dynamic variation model of ecosystem at Daya Bay

Wang youshao, Wang zhaoding and Huang liangmin summed up the dynamic variation model of ecosystem at Daya Bay based on the past two decades research results: The nutrition status has changed from poor to middle and even eutrophicated level in some parts of the bay. The average N/P ratio has increased from 1/1.5 in 1980s to over 50 at present, and the limiting nutrient factor has changed from N to P. The biological communities have been miniaturized, their biodiversities simplified and the biological resources declined. The phenomenon of stone coral bleaching has appeared, and the dominant species of coral communities have changed. Red tide events have occurred many times in the waters near the Aotou habor. All of these indicate that the ecosystem of Daya Bay is undergoing a rapidly deterioration. Daya Bay's sea area is the multi-ecosystem influenced by the human activities.

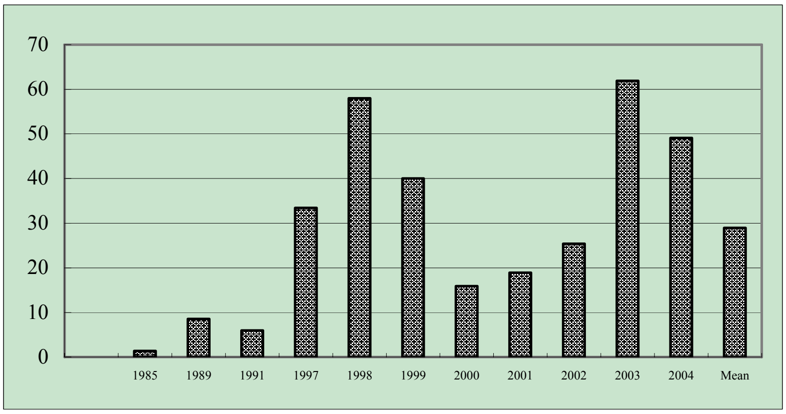


Fig. 41.1 Long-term changes of TIN/PO_4-P

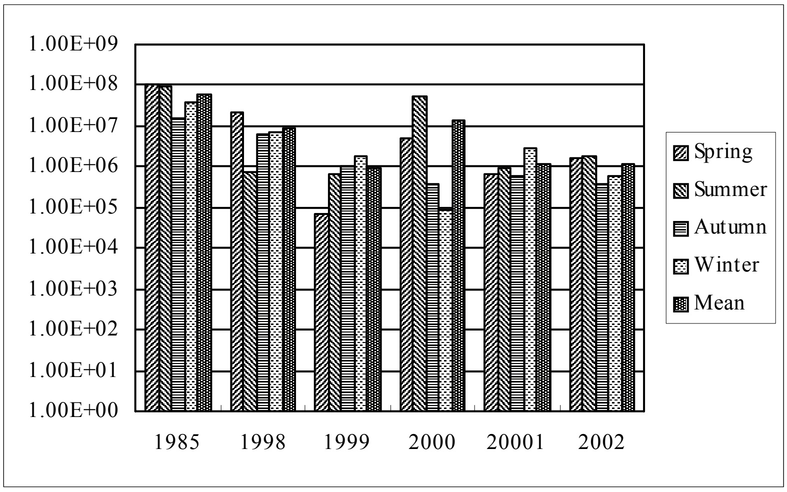
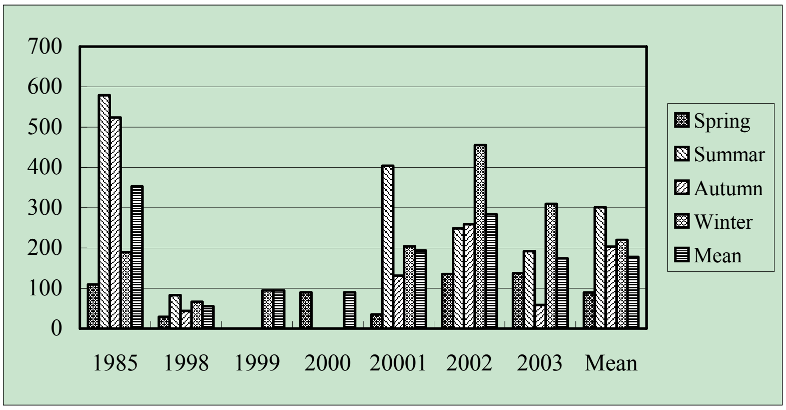


Fig. 41.2 Long-term changes of



phytoplankton

Fig. 41.3 Long-term changes of zooplankton

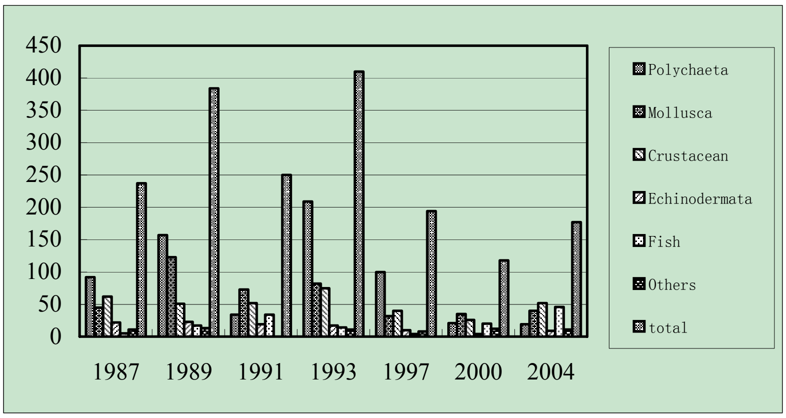


Fig. 41.4 Long-term changes of benthos

2. Lower nutrients-higher productivity relation and fast exchange mechanism of sea surface microlayer

Xu gongzhao, Wang zhaoding et al stated the relation between lower nutrients-higher productivity and the mechanism of the fast exchange of sea surface microlayer. There were sea surface microlayer enrichment effect s on N, P and Si. The NH_4-N was the main existing form of the inorganic nitrogen of sea surface microlayer at Daya Bay; Most of the nitrogen could be degraded into inorganic nitrogen under the condition of oxygen rich, which may be a principal cause result in lower nutrients-higher productivity. The phenomenon of lower nutrients-higher productivity at Daya Bay could be resulted in the fast exchange of sea surface microlayer.

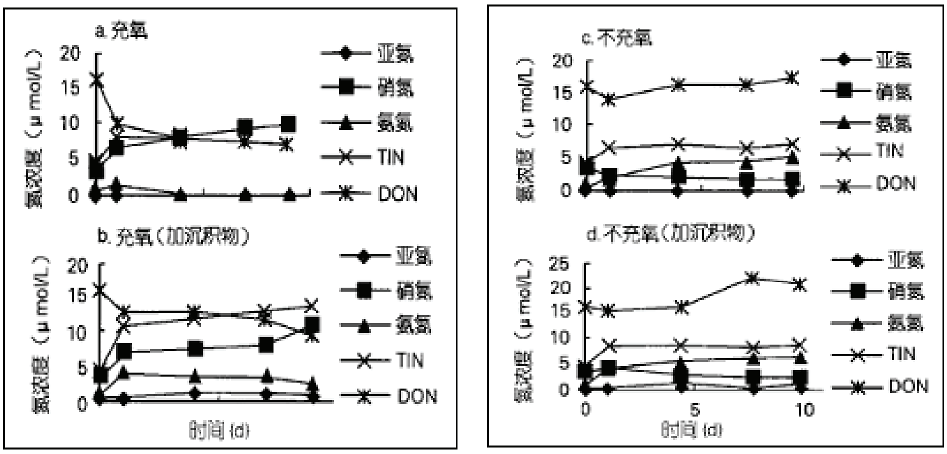


Fig. 41.5 Transformation of nitrogen species

3. Microorganism biodegradation mechanism in mangrove soil

The collection of microorganism degrading the phenyl methyl has been constructed. The collection include *Aeromonas caviae* W III, *Aeromonas punctata* T II, *Pseudomonas aeruginosa* Gs, *Rhodococcus ruber* Sa, *Klebsiella* sp. Sc, *Methylobacterium* sp. Sr and *Rhodococcus ruber* Sy and so on. According to the study on the kinetic degradation, the mechanism of many kinds of phenyl methyl (e.g.naphthalene, anthracene, phenanthrene and pyrene) degraded by microorganism in mangrove soil was revealed. This research will provide benefits for establishing the mechanism of the biodegradation in mangrove soil and provide new approach for environmental administration and degradation.

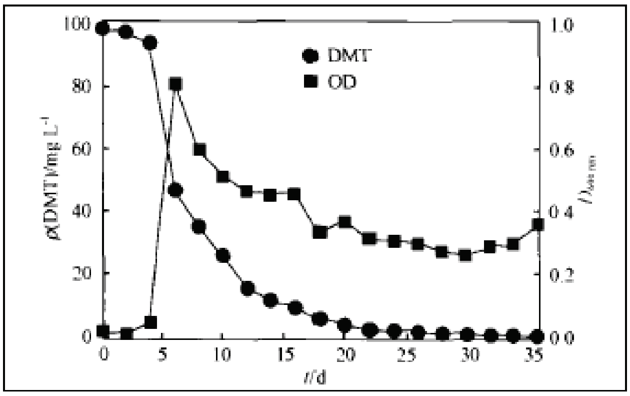


Fig. 41.6 Biodegradation of dimethyl terephthalate (DMT) by a mixed culture of mangrove microorganisms

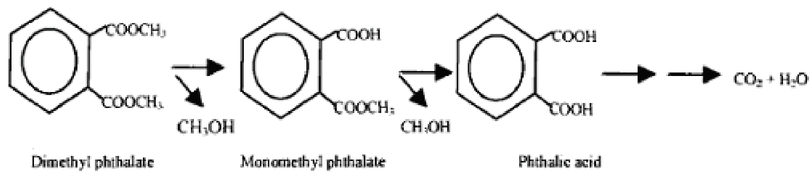


Fig. 41.7 Microbial degradation and biochemical pathway of phthalic acid (PA) and ortho-dimethyl phthalate ester (DMPE) using enrichment consortia of bacteria isolated from sewage sludge

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42

Environmental Changing Process and Biodiversity Conservation in South China Sea

Scientific research progress of Hainan Tropical Marine Biology Research Station

Introduction of Sanya Tropical Marine Biological Research Station

Hainan Tropical Marine Biology Research Station, CAS, was founded in 1981, locating at Luhuitou peninsula, Sanya, Hainan province. It covers 14 hectares, and has 7000-square meter seawater farming ponds and comprehensive experimental area. It is certified as a Chinese Ecosystem Research Network station in 2002. In 2005, it became a national open key experimental station. During the past two decades, we make progress in cultivation of seawater pearl, seawater aquaculture of Spirulina, as well as the study and utilization of tropical marine bioactive substance. Since the station turned to be a member of CERN, we carried out a series of research and achieved preliminary results on biological nitrogen-fixation in mangrove wetland, nutrient cycling in coral reef ecosystem and the characters of Sanya Bay upwelling.

1. Study on biological nitrogen fixation in tropical mangrove wetlands

Two years-scale in situ nitrogen fixation assay was conducted in tropical costal wetland. Diverse nitrogen-fixing bacteria were observed and isolated in laboratory. High nitrogen-fixing rates were detected in symbiotic nitrogen-fixing bacteria in mangroves. For the first time we considered that nitrogen fixation was the major source of combined nitrogen input in mangrove forest habitats in China.

Cultivation-based analysis and culture-independent PCR- Denaturing Gradient Gel Electrophoresis were employed to assess the composition of diazotroph species in mangrove habits of Sanya Bay. Analysis of DGGE Gel resulted in a total of 145 detectable bands in 64 different positions, which indicated a diverse nitrogen-fixing bacterial assemblage in mangrove habits. The predominant DGGE bands were sequenced, yielding 31 different nifH sequences. All the sequences obtained have been assigned to the GenBank nucleic acid sequence database with accession numbers EF178501-EF178502, EF185784-EF185791, EF191077, EF196648-EF196656, EF199926 and EF494084-EF494093. Most sequences were from Proteobacteria, e.g. α, γ, β, δ-subdivisions, and characterized by sequences of members of genera Azotobacter, Desulfuromonas, Sphingomonas, Geobacter, Pseudomonas, Bradyrhizobium and Derxia. This is the first time a direct molecular approach was used to investigate the nitrogen-fixing bacterial composition in mangrove ecosystem. All nifH sequences were reported for the fist time in mangrove system.

High nitrogen fixation rate were detected in six cultivable nitrogen-fixing bacteria isolated from mangrove wetland. Their NifH sequences were amplified and sequenced. The accession numbers in GenBank database are EF107640, EF191079, EF199928, EF422072, EF422074 and EF422075. We assessed a group of Azotobacter, which can be used as biofertilizers. We carried out a series of nitrogen fixation tests. The results revealed that nitrogen-fixing community has stable highly efficient nitogenase activity. We have submitted two related applications for invention patents.

2. Research on coral reefs

Early in 1960s, the researchers of South China Sea Institute of Oceanology, Chinese Academy of Sciences began to study coral reefs. Coral reefs are concentrated the vicinity of Luhuitou in Sanya Bay. Zou et al. (1975) reported that hermatypic corals of Luhuitou coastline consisted of 12 families, 24 genera and 81 species, which formed approximately 70.4 percent of all species on Hainan Island. Qi et al (1984) recorded about 700 species of Mollusks found in Hainan Island, more than 300 species of which found in the vicinity of Huihuitou.

Coral reef ecosystems are usually highly productive ecosystems. After a long period of study the researchers of the station summarized the nutrient regeneration mode of different nutritional structure of Sanya Bay, which clarified the theoretical mechanism of nutrient regenerated during the ecology progress contributed to the highly productivity in the ecosystem. Combining the nutrient supply of terrestrial input, upwelling and biological nitrogen fixation, explored the resource of available nitrogen and its cycle way, which laid the foundation for raised nitrogen cycle theory of coral reef ecosystem.

3. Reconstruction on the environmental changing process at different time-scales in the South China Sea

With coral reefs and deep-sea sediments as paleo-environmental proxies, we have reconstructed past environmental changing progress and events at different time-scales, and identified some new phenomena and new evidences occurred over past environmental history. Our work in these fields has contributed to the further understanding of paleoceanography and monsoon climatic history, and developed the theoretic knowledge on coral reef and micropaleontology. Our work can be summarized as the following aspects:

(1) High-resolution (monthly, seasonally, and annually) Holocene climate reconstruction with coral skeletal ^{18}O and Sr/Ca of mid-late Holocene corals developed in the South China Sea.

(2) Reconstruction of historical coral reef bleaching, including low-temperature induced cold-bleaching and high-temperature resulted present warm-bleaching.

(3) Providing evidences of multiple Holocene sea-level highstands from coral reefs in the South China Sea, and exploring the relationships between the sea level fluctuations and climate changes.

(4) Identifying storm cycles over the last millennium recorded in coral reefs, southern South China Sea.

(5) Establishing the high-resolution age patterns of the deep-sea sediments respectively from the southern South China Sea and the warm pool area of the Western Pacific over last 40 ka, and the paleo-environmental evolutionary process.

(6) Identifying the 200 ka cycles of the radiocalare funa over last 1 Ma, and an abrupt event of the ecological changing around 0.47 Ma BP.

(7) Establishing the sedimentary sequence over last 10 Ma and the East Asian summer monsoon activity history.

4. Upwelling and phytoplankton ecosystem in Sanya Bay

Long-term systemic investigation revealed that Sanya Bay is affected by an exotic cold-water upwelling and thermocline occurring during June–August and disappeared from September to the following March due to the mixing of the seawater. In Sanya Bay the dissolved inorganic nitrogen were significantly affected by upwelling, especially NO_3-N. The studies on spatial and seasonal variation of nitrogen compounds are important for the further study of regional new productivity and sustainable development of coral reefs and other ecosystem. It can supply research foundation for the further study of global environmental change and regional response.

(1) Our investigation results showed that pelagic cyanobacteria provide great lot inputs of ‘new nitrogen’into the bay through nitrogen fixation. We also conducted preliminary studies on how the new nitrogen input into the bay, its input intensities and seasonal variation. These research is important for the reasonable calculation of new productivity, carbon and nitrogen balance budget, as well as the sustainable development of productivity.

(2) The investigation of marine cyanobacteria carried out in various ecosystems including

coral reefs, mangrove communities, macroalgae ecosystem, seagrass beds and microbial mats in Sanya Bay and the regional areas. The results revealed that Sanya bay support a diverse marine cyanobacteria resource and the nitrogen-fixing cyanobacterium contribute a major fraction of new nitrogen input to the oligotropic tropical Sanya Bay.

Further study is doing on how the new nitrogen input response to the South China Sea monsoon and its feedback mechanisms. The results will be significant for the sustainable development of tropical marine productivity.

5. Research and utilization technology on tropical marine bioactive substances

The research on marine bioactive substances and resource utilization technology were carried out. During the 10th Five-Year Plan period, one national drug-manufacturing of new drug, 3 health food certification and nearly 10 functional foods certification were approved. Twenty two patent applications were submitted, and 18 were approved. More than 80 research papers (more than 30 SCI indexed) and two monographs (cooperation) were published.700 marine biological compounds have been isolated and identified. Among these about 90 were new compounds, about 21 were lead activity compounds (anti-tumor, anti-Alzheimer's, etc.).

A top award of progress in science and technology was awarded by Hainan province.

6. Monitoring research and data management in Sanya Bay

Hainan Station serves as a filed platform for experiment and research. It became to be a national open key experimental station (pilot station) in 1999. It is certified as a Chinese Ecosystem Research Network station in 2002. The station undertook the ecological monitoring research from 1998. It has sent monitoring data to CERN since 2003.

According to the standard of CERN, CAS, the station completed the construction of data management information system.

Now Hainan station has accessed 260 MB (database) of the research data in marine environmental factors, marine biological community, marine ecosystems structure function and primary productivity (Table 42.1).

The station focused on data management on water environmental monitoring, biological monitoring and its own research data. With the management of dedicated staff, data transmission and sharing is implemented.

Table 42.1 data accumulation and storage in Hainan station

	Aquatic environment monitoring	**Biological monitoring**	**Meteorological monitoring**	**Research projects**	**Others**
Starting and ending years	1986-2005	1986-2005	2004-2005	1979-2005	1979-2005
Data	3 Mb	2.5 Mb	10 Mb	200Mb	600Mb, 19books
Storage mode	database	database	database	database	CD, text

In accordance with the requirements of CERN, Hainan station submitted the monitoring data to the CERN center. Meanwhile there is a backup in station. Various paper historical data and file information, as well as important samples and specimens are stored in file room and Tropical Marine species Hall of South China Sea Institute of Oceanology respectively. According to the requirements of CERN, a part of paper data was kept as backup in station.According to the state regulations and requirement of CERN, CAS, Hainan station provides standardized service of data observation for all.

Beside above our station have done some research for national natural protection zone for coral reef. For example (1) Sanya coral reef national grade natural protection zone project of coral reef ecological system protection to provide a policy foundation to reasonable exploitation of Yalong Bay. (2) Sanya management department project coral reef national grade natural protection zone of the research on the layout of the zone to provide a policy foundation to the layout of natural protection zone.

2） Published papers

Hainan station provides a good technological platform. Many domestic and foreign experts and scholars went to the station for research work. Hong Kong University of Science and Technology together with Hainan station established a joint lab, which made an important contribution for research work. In recent years, Hainan station as a technological platform has published 160 papers, among these 149 (74 SCI indexed) are published in core publications. It has completed a monograph.

Thirty three national patent applications were submitted, and 20 were approved

3） Main Awards

(1) Successfully completed the research on the tropical marine bioactive compounds the project of Hainan province government and developed the national semi-standard medicine sea water pearl juice and having got economic benefit more than one billion Chinese Yuan that

was awarded the science and technology progress top grade prize by Hainan province government in 2004.

(2)The project, development of series products of pearl, have got economic benefit more than 400 million that was awarded the first grade prize of science and technology product utilization by Hainan province government in 2004.

(3) The laboratory of the station was honored as a excellent laboratory of Hainan province by Hainan province government.

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Distribution Map of Ecological Station of CERN

Monitoring, Research & Demonstration

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