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土壤有机质对土壤水分保持及其有效性的控制作用

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摘 要 如何基于常规测定因子评估森林在土壤水分保持方面的生态效益, 并建立森林固碳效益与水文效益的联系等科学问题, 在综合评估森林生态效益方面有着重要意义。该文以南亚热带地区的3种不同演替阶段的森林生态系统(人工恢复的马尾松针叶林(*Pinus massoniana* coniferous forest, PF)、马尾松针阔叶混交林(mixed *Pinus massoniana*-broad-leaved forest, PBF)和季风常绿阔叶林(monsoon evergreen broad-leaved forest, MBF))为研究对象, 通过分析其土壤有机质及土壤水分状况在林内及林型间的分布格局差异, 探讨土壤有机质对土壤水分保持的控制作用。结果表明: 由PF至地带性顶级群落MBF的3种林分虽然相距很近且有关环境因子一致, 但0–30 cm土层的土壤含水量差异显著, MBF的最高, PBF其次; 3种林型林内土壤水分分布格局迥异, MBF的土壤水分随土层加深而递减的趋势明显, PBF土壤各层水分较为均一, PF则土壤表层水分含量较低, 与土壤有机质的状况一致。土壤水分特征曲线显示, 0–40 cm土层在相同基质吸力条件下的土壤水分含量: MBF > PBF > PF, MBF的保水性最好。进一步分析发现, 土壤孔隙度对土壤含水量的影响最大, 饱和含水量、土壤有机质次之, 同时, 考虑到土壤孔隙度和土壤饱和含水量对土壤有机质的高度依赖性, 我们认为土壤有机质控制着土壤含水量及其有效性(p = 0.014)。作为常规测定指标的土壤有机质, 不仅是森林固碳效益的关键指标, 而且可用来量度土壤水分保持及其有效性, 可以作为评价森林生态系统服务功能的一个综合指标。

关键词 鼎湖山自然保护区, 森林演替, 灰度关联分析, 土壤有机质, 土壤含水量

Controlling action of soil organic matter on soil moisture retention and its availability

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Abstract

Aims Assessment of the ecological benefits of forest in soil water retention based on conventionally monitored factors and exploration of the relation between forest carbon-sink function and hydrological benefits has special meaning in Millennium Ecosystem Assessment. Our objectives were to 1) characterize the spatial and temporal variations of soil moisture in three subtropical forests and 2) determine the controlling action of soil organic matter on soil moisture retention during vegetation succession.

Methods Standard plots were established in *Pinus massonniana* coniferous forest (PF), mixed *Pinus massonniana*-broad-leaved forest (PBF) and monsoon evergreen broad-leaved forest (MBF). We measured soil water content every 10 days from 2002 to 2008 using neutron probes and analyzed soil organic matter content in the laboratory by the potassium dichromate oxidation method.

Important findings With natural succession from planted PF to climax MBF, soil water content (0–30 cm soil layer) increased significantly; soil water content was highest in MBF and lowest in PBF. The distribution patterns of soil moisture in the three forests were different: the soil moisture of MBF decreased with soil depth, was more homogeneous in the soil profile in PBF and was lower at the surface than in deeper layers in PF. The soil water characteristic curves showed that under the same matrix suction the magnitude of soil water content (0–40 cm soil layer) was: MBF > PBF > PF; the soil of MBF was the most retentive. Further analysis indicated that soil porosity had the greatest impact on soil moisture, followed by saturated soil water content and soil organic matter content, while soil bulk density had a minimal impact. In the process of natural succession, soil moisture was significantly correlated with the soil organic matter content (p = 0.014), as the soil organic matter could affect soil moisture holding (p = 0.030). Accordingly, we recommend soil organic matter as an effective and integrated index for appraising forest ecosystem services.

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在千年生态系统评估(Millennium Ecosystem Assessment)的推动下, 以生态系统服务为核心的生态系统评估已成为当代生态学的前沿领域(李文华, 2006)。森林作为陆地生态系统的主体, 其服务功能价值的评估是研究的一个热点(余新晓等, 2005)。在此背景下, 建立森林固碳效益与水文效益的联系等科学问题, 对综合评估森林生态效益及其服务功能具有重要的意义。

从土壤发生学原理看, 土壤有机质是形成土壤理化性状的基础, 是联系成土过程中生物要素与土壤发生、演化的纽带(黄昌勇, 2000), 调节着土壤固、液、气三相的量和结构, 影响着土壤生态功能的各个过程(Oades, 1984; Haynes *et al*., 1991; Chertov *et al*., 2002; 张勇等, 2005)。土壤理化性状的差异决定着土壤持水、保水和土壤水分的有效性(黄承标和梁宏温, 1999; 景国臣等, 2008)。土壤有机质含量的多少受制于地上植被及其根系有机质的输入及分解的动态平衡(Bargali *et al*., 1993; 梁宏温等, 1993; 陈立新等, 1998; Guo & Sims, 1999; 陈龙池等, 2002)。在土壤剖面完整、未受干扰的森林生态系统中, 土壤有机质含量的高低在一定程度上反映了地上植被的发育状况。大量的研究(Jia *et al*., 2005; Nadporozhskaya *et al*., 2006; 张红等, 2006; He & Tang, 2008; 杨世琦和杨正礼, 2008)表明: 随着森林演替、土壤有机质含量逐渐增加, 成熟森林土壤仍在积累有机碳(Zhou *et al*., 2006)。因此, 土壤有机质在森林生态系统的环境指标中处于核心地位。

土壤水分是森林生态系统物质循环的载体, 对土壤中养分和能量的分配格局起着重要的调节作用, 对森林生态系统径流产生、蒸散过程、水分循环和水量平衡的研究具有重要意义。土壤水分的变化特征受土壤理化性质和区域气候特征、植被类型等外界条件的密切影响(龚元石等, 1998; 邱扬等, 2000)。随着群落演替的进行, 群落的结构和功能发生相应的改变, 土壤水分特征也发生相应的变化, 并呈现出不同的时空分布特征(王国勤, 2008)。土壤水分特征曲线反映的是土壤水分的数量与能量之间的关系(李开元和李玉山, 1991), 是研究土壤水分滞留和运移等土壤水分运动机制的基础。土壤有机质除影响土壤的比表面积(钟国辉等, 2005)外, 其自身结构疏松多孔(王国梁等, 2003), 是形成土壤最基本的结构单元——团聚体的重要物质(彭新华等, 2003)。它们通过改善土壤结构、降低土壤容重和增加土壤毛管孔隙度等土壤物理特性对土壤的蓄水和持水性产生作用(赵世伟等, 2002)。因此, 土壤有机质深刻影响着森林生态系统土壤层水分持留(Gupta & Larson, 1979)及其土壤水分特征曲线(Ouattara *et al*., 2006)。

本文从鼎湖山自然保护区人工恢复的马尾松针叶林(*Pinus massoniana* coniferous forest, PF)—马尾松针阔叶混交林(mixed *Pinus massoniana*-broad-leaved, PBF)—季风常绿阔叶林(monsoon evergreen broad-leaved forest, MBF)这一自然演替序列上的3种林型土壤(0–80 cm土层)有机质含量及其林内土壤(0–90 cm土层)含水量分布格局及过程出发, 探讨土壤有机质对土壤水分持留的影响及其有效性的控制作用, 试图阐明森林的自然演替实质是以土壤有机质的积累为表征的森林生态系统, 包括蓄水、保水等生态效能优化在内的逐步更新成熟过程, 土壤有机质可以作为评价森林生态系统服务功能的一个综合指标。

1 研究地概况

鼎湖山国家级自然保护区(112°30′39″–112°33′41″ E, 23°09′21″–23°11′30″ N)地处我国南亚热带, 位于欧亚大陆东南缘, 属南亚热带湿润季风型气候, 水热资源丰富。平均年降水量为1 678 mm, 其中80%的降水分布在湿季4–9月(Zhou *et al*., 2011)。年平均气温为21.4 ℃, 最冷月(1月)和最热月(7月)的平均气温分别为12.6和28.0 ℃。年平均相对湿度为80%, 年平均蒸发量为1 115 mm。该保护区由两个相对独立的集水区组成: 东沟(613.2 hm^2)和西沟集水区(542.8 hm^2)。这里分布着包括演替初期的PF、演替中期的PBF和演替后期的MBF(彭少麟和王伯荪, 1993)在内的多种植被类型(表1)。土壤类型主要为赤红壤和黄壤, 平均土层厚度50–80 cm。PF和PBF下为赤红壤, 土层浅薄; MBF下为水化赤红壤, 局部地区土层厚度在100 cm以上。

表1 试验样地概况
Table 1 General information of the experimental sites

森林类型 Forest type	坡度 Slope gradient	坡向 Slope aspect	海拔 Altitude (m)	林龄 Forest age (a)
马尾松针叶林 *Pinus massoniana* coniferous forest (PF)	25°–30°	西南 Southwest	200–300	50–60
马尾松针阔叶混交林 Mixed *Pinus massoniana*-broad-leaved forest (PBF)	28°–35°	西南 Southwest	220–300	70–80
季风常绿阔叶林 Monsoon evergreen broad-leaved forest (MBF)	25°–33°	东北 Northeast	220–300	400

2 研究方法

2.1 土壤体积含水量

在3种林型内设置标准样地, 于2002年至2008年, 每隔10天(即每月的5日、15日和25日)用中子水分仪(CNC503B, 北京超能科技公司, 北京)分别测定0–15 cm、15–30 cm、30–45 cm、45–60 cm、60–75 cm、75–90 cm这6个土壤深度的土壤体积含水量。

2.2 土壤有机质

鼎湖山自然保护区的3种林型分别设置了固定破坏性样地, 随机选取6个样点, 在0–10 cm、10–20 cm、20–40 cm、40–60 cm、60–80 cm土层分别采取土样, 带回实验室用重铬酸钾-硫酸氧化滴定法(刘光崧, 1996)分析土壤有机质含量。

2.3 土壤水分特征曲线的测定

土壤水分特征曲线采用离心机法测定(邵明安和黄明斌, 2000)。

2.4 灰关联系数与灰关联度的计算

灰关联系数的计算式为:

$$\xi_i(k)=\frac{\min\limits_i\min\limits_k \varDelta_i(k)+\rho\max\limits_i\max\limits_k \varDelta_i(k)}{\varDelta_i(k)+\rho\max\limits_i\max\limits_k \varDelta_i(k)}$$

式中: $\xi_i(k)$为关联系数; $\varDelta_i(k)$为比较数列与参考数列各对应点的绝对差值; ρ为分辨系数, ρ越小, 分辨率越大, 一般取$\rho = 0.5$。

灰关联度λ_i由平权法求得, 计算式为:

$$\lambda_i=\frac{1}{n}\sum_{k=i}^{n}\xi_i(k)\quad(傅立, 1992)。$$

3 结果和分析

3.1 不同演替阶段的土壤水分状况

演替序列上的3种林型, 以MBF土壤水分随土层加深(0–90 cm深处)而递减的趋势最为明显, 演替中期PBF土壤水分垂直分布相对均匀(24.8 ± 1.9)%, 初期PF由于林分结构简单, 郁闭度低, 表层土壤(0–15 cm深处)水分亏缺严重, 低于其下15–30 cm、30–45 cm、45–60 cm土层的土壤含水量。在0–15 cm和15–30 cm土层, MBF土壤水分含量显著高于其他两种林型($p < 0.001$), PBF也显著高于PF ($p < 0.05$)。其余土层间, MBF和PBF土壤含水量之间的差异均不显著($p > 0.05$), 但MBF显著高于PF ($p < 0.05$)。从单个林型来看, MBF和PBF 0–30 cm土层的土壤含水量显著高于其下部土层($p < 0.05$), 30 cm土层以下的土壤各层含水量差异不大($p > 0.05$)。这说明: 随着森林的演替, 土壤水分逐渐向根系比较密集的土层集中分布, 这同时也是细根生物量增加、细根垂直分布表层化的过程(彭少麟和郝艳茹, 2005)。在45–60 cm、60–75 cm和75–90 cm土层, 水分主要受土壤结构和地下水的影响, 故在45 cm以下的土层中水分变化的幅度不大(图1)。

土壤表层(0–30 cm深处)水分主要受林内微气象和植被覆盖状况的影响。MBF与其他两种林型相比, 近地面层气温较低、风速较小、湿度较大、土壤蒸发量较小, 因此土壤含水量较高。PBF各土层(0–30 cm土层除外)的土壤含水量都非常接近于MBF, 这与土壤有机质含量的变化格局具有一致性, PBF可能已经达到了后期演替阶段(尹光彩等, 2003), 且系统演替的内部格局趋向为地下部分特征的更新先于地上部分。

3.2 土壤水分特征曲线

3.2.1 曲线拟合

土壤水分特征曲线能反映土壤的蓄水性能。为了便于换算和分析, 常将土壤水分特征曲线概括为经验公式。其中, Gardner和Visser提出的幂函数方程(宋吉红, 2008)具有待定参数较少的优点, 在实际应

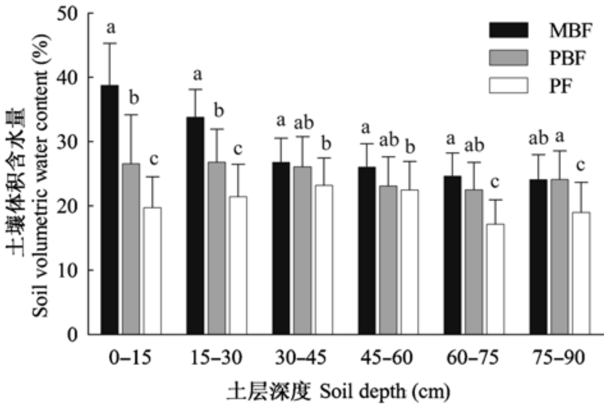

图1　3种林型不同土层土壤体积含水量(平均值±标准偏差)。同一土层具有不同字母的差异显著($p < 0.05$)。MBF, 季风常绿阔叶林; PBF, 马尾松针阔叶混交林; PF, 马尾松针叶林。

Fig. 1　Soil volumetric water contents of different soil layers in the three forest types (mean ± *SD*). Different letters indicate significant differences at $p < 0.05$ level in the same soil layer. MBF, monsoon evergreen broad-leaved forest; PBF, mixed *Pinus massoniana*-broad-leaved forest; PF, *Pinus massoniana* coniferous forest.

用中比较方便: $\theta = as^{-b}$。式中: s为土壤吸力; θ为土壤质量含水率; a和b为参数。

从表2可以看出, 土壤水分特征曲线的数学模型较好地描述了鼎湖山不同类型森林土壤的水分特征。参数a随着植被类型的不同, 呈现出有规律的变化: MBF > PBF > PF。参数a和b的大小主要受土壤质地(主要是小于0.1 mm的物理性黏粒)和土壤有机质含量的影响(何金海等, 1982)。

3.2.2　3种林型土壤水分特征曲线的比较

土壤持水性能主要受土壤总孔隙度、毛管孔隙度、土壤容重、土壤有机质、土壤颗粒组成的影响(周择福和李昌折, 1994)。就单个林型来看, 土壤水分特征曲线显示为: MBF随着土层的加深(0–80 cm深处), 相同土壤吸力条件下的土壤含水量逐渐降低, 保水性递减, 这与对应于各层的土壤有机质含量较一致; PBF土壤0–80 cm土层的土壤水分特征曲线差异并不明显; PF由于土层间异质性较大无明显规律。在演替序列上, 以3种林型0–10 cm土层为例, 在相同基质吸力情况下, 土壤水分含量为: MBF > PBF > PF, 深层土壤水分特征曲线趋同(图2)。MBF的土壤保水能力最好, 水分不容易损失, PBF次之, PF最差。

3.3　土壤理化性质对土壤含水量的影响——基于灰色关联方法的分析

以该地区3种林型为研究对象, 采用灰色关联

表2　不同土壤深度的土壤水分特征曲线的数学模型

Table 2　Mathematical models of soil water characteristic curves at different soil depths

林型 Forest type	土壤深度 Soil depth (cm)	数学模型$^{1)}$ Mathematical model$^{1)}$	决定系数 Determination coefficient (R^2)
季风常绿阔叶林 Monsoon evergreen broad-leaved forest	0–10	$\theta = 25.081s^{-0.172}$	0.992**
	10–20	$\theta = 23.283s^{-0.161}$	0.986**
	20–40	$\theta = 22.807s^{-0.142}$	0.987**
	40–60	$\theta = 20.608s^{-0.143}$	0.987**
	60–80	$\theta = 19.080s^{-0.153}$	0.990**
马尾松针阔叶混交林 Mixed *Pinus massoniana* broad-leaved forest	0–10	$\theta = 22.918s^{-0.204}$	0.993**
	10–20	$\theta = 21.353s^{-0.186}$	0.985**
	20–40	$\theta = 22.003s^{-0.158}$	0.983**
	40–60	$\theta = 22.113s^{-0.149}$	0.986**
	60–80	$\theta = 21.363s^{-0.146}$	0.987**
马尾松针叶林 *Pinus massoniana* coniferous forest	0–10	$\theta = 17.947s^{-0.163}$	0.995**
	10–20	$\theta = 13.126s^{-0.198}$	0.988**
	20–40	$\theta = 15.576s^{-0.166}$	0.989**
	40–60	$\theta = 18.355s^{-0.132}$	0.987**
	60–80	$\theta = 18.196s^{-0.140}$	0.990**

1) θ, 土壤质量含水率; s, 土壤吸力。

**, $p < 0.000\ 1$. 1) θ, Mass water content of soil (%); s, soil suction.

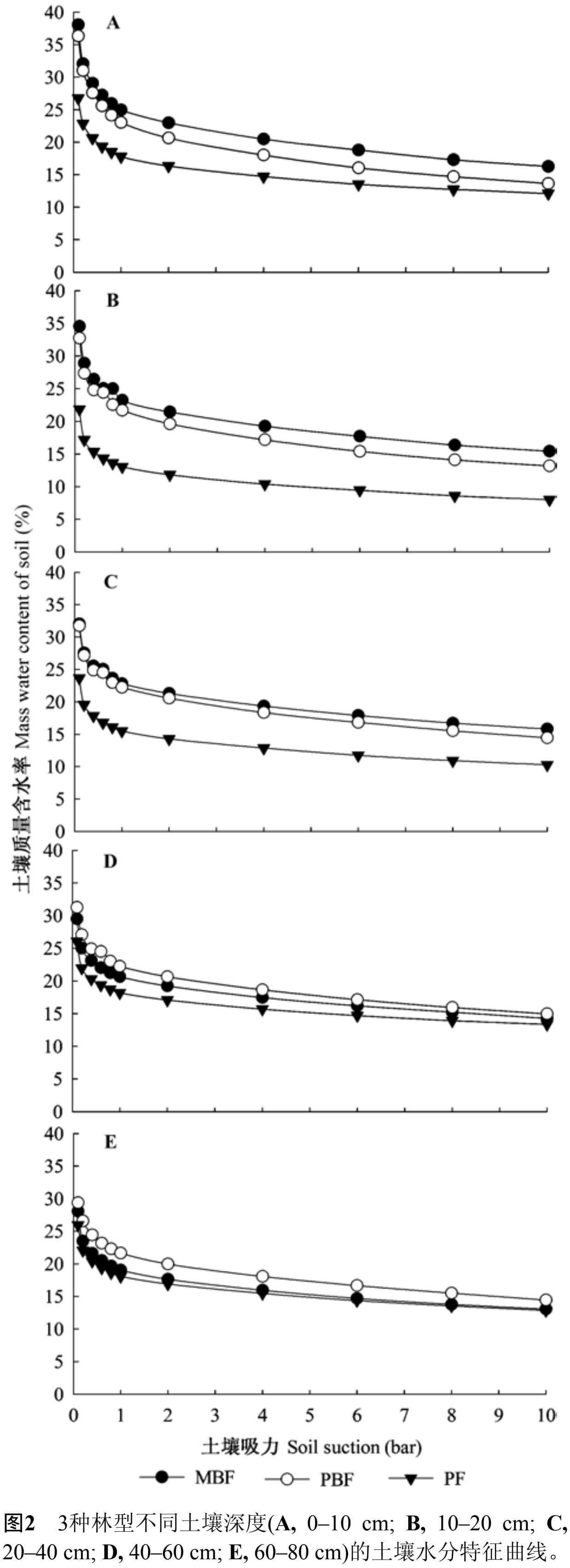

图2 3种林型不同土壤深度(**A,** 0–10 cm; **B,** 10–20 cm; **C,** 20–40 cm; **D,** 40–60 cm; **E,** 60–80 cm)的土壤水分特征曲线。MBF、PBF和PF见图1。

Fig. 2 Soil water characteristic curves at different soil depths (**A,** 0–10 cm; **B,** 10–20 cm; **C,** 20–40 cm; **D,** 40–60 cm; **E,** 60–80 cm) in the three forest types. MBF, PBF and PF see Fig. 1.

分析法探讨了土壤理化性质对土壤保水功能的影响。选用的土壤参数为饱和持水量、土壤孔隙度、土壤容重和有机质含量。3种林型的土壤体积含水量及土壤理化性质见表3。

先对各参数数列进行生成处理, 采用最大值化的处理方法, 在各组参数中选取其中的最大值作为标准, 然后把每组参数与其对应的最大值相除, 所得比值生成新的数列(表4)。

以土壤体积含水量为参考数列, 土壤理化参数为比较数列, 求比较数列与参考数列各对应点的绝对差值, 根据灰关联系数的计算公式, 求得各参数对应点与土壤体积含水量间的灰关联系数(表5)。

根据灰联度的计算公式, 分别求出土壤理化参数与土壤体积含水量之间的灰关联度: 土壤饱和持水量的灰关联度为0.729, 土壤孔隙度的灰关联度为0.856, 土壤容重的灰关联度为0.446, 土壤有机质的灰关联度为0.688。由此可见, 土壤参数与土壤体积含水量的灰相关度大小依次为: 土壤孔隙度>饱和持水量>土壤有机质>土壤容重。土壤孔隙度与土壤体积含水量的关系最为密切, 影响也最大, 土壤饱和含水量和土壤有机质含量次之, 土壤容重最小。每个因子的灰色关联度值均大于或接近0.5, 说明这些因子对土壤体积含水量的影响都很大。

4 讨论

土壤有机质是土壤的重要组成部分, 也是全球碳平衡过程中非常重要的碳库(黄昌勇, 2000)。国内外针对不同恢复演替阶段、不同植被类型下土壤有机质含量的分布及变异格局的研究众多(田应兵等, 2004; 吴建国等, 2004; Jia *et al*., 2005; Nadporozhskaya *et al*., 2006; He & Tang, 2008; 刘旭辉等, 2009), 普遍认为: 随着森林演替的进行, 土壤各层逐渐积累有机质, 以土壤表层的积累最为显著, 且随着演替时间的延长, 有机质积累的层次逐渐加深。Zhou等(2006)通过对鼎湖山自然保护区成熟森林(> 400 a)长达25年的监测研究发现, 其0–20 cm土层的有机碳贮量仍在以0.54–0.68 Mg C·hm^{-2}·a^{-1}的速度显著增加(p < 0.000 1)。如图3所示, 进行土壤有机质与各对应土层自然状态下土壤含水量、土壤水分特征曲线参数a的回归分析, 可以看出二者均达到了显著水平, p值分别为0.014和0.030。土壤水分特征参数a决定了曲线的高低, 即持水能力

表3 鼎湖山3种林型的土壤含水量和土壤理化性质
Table 3 Soil water content and soil physic-chemical properties of three forests at Dinghushan

林型 Forest type	土壤体积含水量 Soil volumetric water content (%)	饱和持水量 Saturated water content (%)	土壤孔隙度 Soil porosity (%)	土壤容重 Soil bulk density ($g\cdot cm^{-3}$)	有机质含量 Organic matter content ($g\cdot kg^{-1}$)
季风常绿阔叶林 MBF	29.02	51.00	55.05	1.01	25.29
马尾松针阔叶混交林 PBF	24.85	48.88	40.75	1.23	23.75
马尾松针叶林 PF	20.46	40.68	39.05	1.31	13.30

MBF, monsoon evergreen broad-leaved forest; PBF, mixed *Pinus massoniana*-broad-leaved forest; PF, *Pinus massoniana* coniferous forest.

表4 土壤体积含水量和土壤理化性质生成数列
Table 4 Generation series of soil volumetric water content and soil physic-chemical properties

林型 Forest type	土壤体积含水量 Soil volumetric water content	饱和持水量 Saturated water content	土壤孔隙度 Soil porosity	土壤容重 Soil bulk density	有机质含量 Organic matter content
季风常绿阔叶林 MBF	1.00	1.00	1.00	0.77	1.00
马尾松针阔叶混交林 PBF	0.85	0.96	0.74	0.94	0.94
马尾松针叶林 PF	0.71	0.80	0.71	1.00	0.53

MBF, monsoon evergreen broad-leaved forest; PBF, mixed *Pinus massoniana*-broad-leaved forest; PF, *Pinus massoniana* coniferous forest.

表5 土壤理化性质参数与土壤体积含水量的灰关联系数和灰关联度
Table 5 Grey correlation coefficient and degree between soil volumetric water content and soil physic-chemical properties

林型 Forest type	饱和持水量 Saturated water content	土壤孔隙度 Soil porosity	土壤容重 Soil bulk density	有机质含量 Organic matter content
季风常绿阔叶林 MBF	1.00	1.00	0.39	1.00
马尾松针阔叶混交林 PBF	0.57	0.57	0.62	0.62
马尾松针叶林 PF	0.62	1.00	0.33	0.45
关联度 Correlation degree	0.729	0.856	0.446	0.688

MBF, monsoon evergreen broad-leaved forest; PBF, mixed *Pinus massoniana*-broad-leaved forest; PF, *Pinus massoniana* coniferous forest.

大小, 并随着植被类型的不同呈现出演替序列上有规律的变化。土壤有机质含量的增加, 一方面改善了土壤结构, 使孔隙度增加; 另一方面 改变了土壤的胶体状况, 使土壤吸附作用增强。这两方面的作用都有利于土壤水分的保持, 从而使土壤含水量增加(单秀枝等, 1998)。由初始PF至地带性顶级群落MBF的演替过程中, 土壤有机质含量逐渐积累, 土壤各相应土层含水量也在显著增加, 土壤有机质对土壤含水量有着显著的控制作用。

土壤作为气候、生物等因素综合作用下形成的一种特殊的自然体, 土壤孔隙度、土壤饱和含水量、土壤容重是其水分状况量度的客观指标。然而, 从土壤发生学的原理来看, 上述3个指标均在不同程度上受到土壤有机质的影响, 尤其是发育良好的土壤, 其孔隙度及饱和含水量显著受控于土壤有机质(单秀枝等, 1998; 赵世伟等, 2002)。这主要是由于土壤有机质自身结构疏松多孔, 同时又能有效地促进土壤团聚体结构的形成而影响土壤空隙及其吸水、持水能力, 改善土壤通气和透水性(Adams, 1973; 彭新华等, 2003; Rawls *et al.*, 2004)。此外, 也有研究表明, 土壤有机质含量越高, 土壤有效水含量也越高(文启凯等, 1992; Hudson, 1994)。

在自然状态下, 土壤有机质的输入主要源于森林凋落物。演替序列上3种不同的林型, MBF凋落物分解率最大, 系统的养分循环强烈(闫俊华等, 2001), 与其他两种林型相比, 土壤层蓄水、保水能力更强。土壤有机质的量作为土壤肥力水平的一项重要指标, 对土壤的物理、化学和生物性质都有着深刻的影响。未受外界扰动条件下, 有机质对土壤水分的显著改善作用无疑是该地区森林持续更新演替的保障。

普遍认为: 土壤储存了陆地生态系统大约2/3

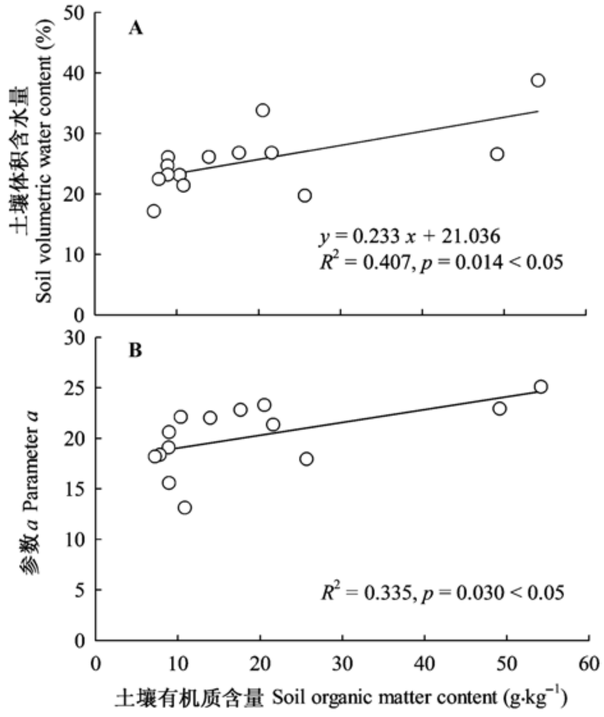

图3 土壤有机质含量与其各对应土层土壤体积含水量(**A**)及土壤水分特征曲线参数*a* (**B**)的回归。
Fig. 3 Regression between soil organic matter content and its corresponding soil layer's soil volumetric water content (**A**), parameter *a* of soil water characteristic curve (**B**).

的碳，以土壤有机质为代表的土壤碳的积累是所有自然区域土壤形成的主导性宏观过程(Chertov *et al*., 2002)。单秀枝等(1998)基于10个不同有机质含量的粉砂质黏壤土的实验性样本分析了土壤有机质对土壤水分常数的影响，指出随着有机质含量的增大，土壤的饱和含水量、田间持水量、毛管水含量增加，且均呈线性关系。这为本文有关森林自然演替过程中土壤有机质对土壤水分的控制性作用的讨论提供了很好的例证。Li和Shao (2006)通过对黄土高原半干旱区从弃耕地到以辽东栎(*Quercus liaotungensis*)为主的顶级森林群落长达150年的自然演替过程中土壤理化性质的分析也表明：随着时间进程，表层土壤容重显著降低，同时土壤孔隙度、土壤含水量、团聚体稳定性以及饱和水力传导度均显著增加，尤其在弃耕初期的14年间，由于土壤表层有机质含量的显著增加，上述变化相对较快。刘旭辉等(2009)以空间代替时间，研究了广西石漠化地区光板地→草地→藤刺灌丛→灌木林地→乔灌混交林→森林不同恢复阶段土壤有机质含量的差异，指出植被类型与土壤有机质含量的相关性极显著；此外，分析其土壤有机质含量与土壤(风干土)含水量数据发现，二者相关性亦极为显著($p = 0.003 < 0.01$)。总的来看，伴随着森林的演替、土壤有机质的积累，土壤层水分状况也在不断改善，蓄水、保水性能逐渐增强，从而更好地适应了演替后期森林生态系统对于水分的需求。

5 结论

鼎湖山自然保护区森林由PF到PBF再到顶级群落MBF的演替过程中，土壤有机质由表层至深层逐渐积累，同时土壤含水量亦呈现出同样的变化，二者具有明显的一致性。3种林型的土壤水分分布格局迥异，MBF的土壤水分随土层加深而递减的趋势明显，PBF的土壤各层水分较为均一，而PF的土壤表层水分亏缺。灰色关联分析表明：土壤孔隙度对土壤含水量的影响最大，土壤饱和含水量和土壤有机质含量的影响次之，土壤容重的影响最小。土壤有机质对自然及风干状态下的土壤含水量、土壤水分特征曲线均有显著影响。因此我们说，森林的自然演替实质是以土壤有机质的积累为表征的森林生态系统，包括蓄水、保水等生态效能优化在内的逐步更新成熟过程，作为常规测定指标的土壤有机质，可以作为评价森林生态系统服务功能的一个综合指标。

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