Soils, Section 1: Soil organic matter dynamics and nutrient cycling

Research Article

Soil Carbon and Nutrient Pools, Microbial Properties and Gross Nitrogen Transformations in Adjacent Natural Forest and Hoop Pine Plantations of Subtropical Australia

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Abstract

Background, Aims, and Scope. An improved understanding of important soil carbon (C) and nutrient pools as well as microbial activities in forest ecosystems is required for developing effective forest management regimes underpinning forest productivity and sustainability. Forest types and management practices can have significant impacts on soil C and nutrient pools as well as biological properties in forest ecosystems. Soil C and nutrient pools were assessed for adjacent natural forest (NF), first rotation (1R) (50-year-old), and second rotation (2R) (1-year-old) hoop pine (*Araucaria cunninghamii* Ait. ex D. Don) plantations in southeast Queensland of subtropical Australia.

Materials and Methods. Five transects spaced 3 m apart with 9 sampling points along each transect were selected (9.6 m x 12.0 m each site), with 45 soil cores (7.5 cm in diameter) collected and separated into 0–10 and 10–20 cm depths. These soils were analysed for total C, total nitrogen (N), C ($\delta^{13}C$) and N ($\delta^{15}N$) isotope composition. The 0–10 cm soils were analysed for pH, CEC, exchangeable cations, total P and total K, and assayed for microbial biomass C and N, respiration, metabolic quotient, potential mineralizable N (PMN), gross N mineralization (*M*) and immobilization (*I*).

Results. Total C and N in 0–10 cm soils were higher under NF and 1R plantation than under 2R plantation, while they were highest in 10–20 cm soils under NF, followed by the 1R and then 2R plantation. $\delta^{13}C$ was lower under NF than under the plantations, while $\delta^{15}N$ was higher under NF than under the plantations. Total P was the highest under NF, followed by the 1R and then 2R plantation, while total K was higher under the 2R plantation. No significant differences were detected for pH, CEC, exchangeable cations, microbial C and N, respiration and metabolic quotient among the 3 sites. PMN and *M* were higher under NF, while *I* was the highest under the 2R plantation, followed by the NF and then 1R plantation.

Discussion. Soil total C and N in 0–10 cm depth were significantly lower under 2R hoop pine plantation than those under NF and 1R hoop pine plantation. There were significant reductions in soil total C and N from NF to 1R and from 1R to 2R hoop pine plantations in 10–20 cm depth. This highlights potential N deficiency in the 2R hoop pine plantations, and application of N fertilizers may be required to improve the productivity of 2R hoop pine plantations.
There were no significant differences in other soil chemical and physical properties in 0–10 cm depth among the 3 sites under NF, 1R and 2R hoop pine plantations, except for soil total P and K.
Soil microbial biomass C, CO_2 respiration and metabolic quotient did not differ among the 3 sites assessed, perhaps mainly due to these biological variables being too sensitive to variations in soil chemical and physical properties and thereby being associated with a larger variability in the soil biological properties. However, soil potential mineralizable N, gross N mineralization and immobilization were rather sensitive to the conversion of NF to hoop pine plantation and forest management practices.

Conclusions. Total C and N in the top 20 cm soil were highest under NF, followed by 1R and then 2R hoop pine plantations, indicating that N deficiency may become a growth-limiting factor in the 2R hoop pine plantations and subsequent rotations of hoop pine plantation. The sample size for soil $\delta^{13}C$ seems to be much smaller than those for soil total C and N as well as $\delta^{15}N$. The significant reductions in soil total P from NF to 1R and then from 1R to 2R hoop pine plantations highlight that P deficiency might become another growth-limiting factor in the second and subsequent rotations of hoop pine plantations. Soil microbial properties may be associated with large spatial variations due to these biological properties being too sensitive to the variations in soil chemical and physical properties in these forest ecosystems.

Recommendations and Perspectives. Soil potential mineralizable N, gross N mineralization and immobilization were useful indices of soil N availability in response to forest types and management practices. The sampling size for soil $\delta^{13}C$ was much smaller than the other soil chemical and biological properties due to the different patterns of spatial variation in these soil properties.

Keywords: Forest management; hoop pine plantations; plantation productivity; soil microbial activity; soil nutrient availability; spatial variability

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Introduction

An improved understanding of important soil carbon (C) and nutrient pools as well as microbial activities in forest ecosystems is required for developing effective forest management regimes underpinning forest productivity and sustainability (Bubb et al. 1998, Carlyle et al. 1998, Chen et al. 2002, 2004, Mao et al. 2002, Mather & Xu 2003, Chen & Xu 2006, Xu & Chen 2006). Forest types (Riha et al. 1986, Saetre & Bååth 2000, Verchot et al. 2001, Mao et al. 2002, Chen et al. 2004, He et al. 2005, Burton et al. 2007a, b) and management practices (Carlyle 1994, Pu et al. 2001, Chen et al. 2002, 2003, Blumfield & Xu 2003, Mathers et al. 2003, He et al. 2006, Bastias et al. 2006a, b, 2007) can have significant impacts on soil C and nutrient pools as well as biological properties in forest ecosystems. Hoop pine (*Araucaria cunninghamii* Ait. ex D. Don) is a native rainforest species of south-east Queensland. Most of the current hoop pine plantations (ca. 50,000 ha) in south-east Queensland of subtropical Australia were established on the previous natural forest land. Little information is available about the impacts of conversion from natural forest to hoop pine plantations and about the effects of plantation management on soil chemical, physical and biological properties. Better information on spatial variability in soil chemical, physical and biological properties in forest ecosystems can assist in the development and application of effective soil sampling strategies for quantifying the impacts of forest types and management practices on soil C and nutrient pools and dynamics in relation to soil quality and forest productivity (Hirobe et al. 1998, Morris and Boerner 1999, Laverman et al. 2000, Prasolova et al. 2000b, Rayment & Jarvis 2000, Blumfield et al. 2006, 2007). Recent advances in development and application of ^{15}N labelling methods have highlighted the potential for studying gross nitrogen (N) transformations such as gross N mineralization, immobilization and nitrification rates in forest soils (Murphy et al. 1999, Neill et al. 1999, Wang et al. 2001, Chen et al. 2002, Bengtsson et al. 2003, Burton et al. 2007a, b). The objectives of this study were to: (1) quantify the impacts of forest types (natural forest dominated by eucalypt species *vs* hoop pine plantations) and management practices (harvesting and conversion from the first rotation to second rotation hoop plantation) on soil C and nutrient pools in adjacent natural forest (NF), 50-year-old first rotation (1R) and 1-year-old second rotation (2R) hoop pine plantations; (2) examine the spatial variation in soil C and N parameters and number of soil samples to be taken for assessing the forest type and management impacts on these soil properties in the 3 adjacent forest ecosystems; and (3) assess microbial properties and gross N transformations in the top 10 cm soil under the adjacent NF, 1R and 2R hoop pine plantations in south-east Queensland of subtropical Australia.

1 Materials and Methods

1.1 Site description

The NF, 1R and 2R plantation sites are located in the Yarraman State Forest of south-east Queensland, Australia (26°52' S, 151°51' E), lying in the upper catchment of the Brisbane River. The soil is a Snuffy Mesotrophic Red Ferrosol (Soil Survey Staff, 1999). Altitude at the sites is about 428 m above sea level. Annual rainfall varies from 433 to 1,110 mm, with an average of 791 mm. Winter temperatures range from 4 to 20°C, and summer temperatures from 17 to 29°C. The NF, 1R and 2R plantation sites are adjacent to each other with similar slopes of approximately 2–3°. The NF site is classified as a rainforest/bastard scrub and dominated by bunya pine (*Araucaria bidwilli*), yellowwood (*Terminalia oblongata*), crows ash (*Pentaceras australis*) and lignum-vitae (*Premna lignum-vitae*), with emergent hoop pine (*Araucaria cunninghamii*). Before establishment of 1R hoop pine plantation, larger trees of natural forests were logged using bullock teams and small dozer, and the under story scrub and the residues were brushed off to a height no greater than 15 cm in order to be scattered evenly across the site, and were burnt when dry. The 1R hoop pine plantation was established in 1949 at approximately 1,540 stems ha^{-1} by hand planting and then thinned to a final stocking of 430 stems ha^{-1}. The 2R hoop pine site was planted in November 2000 after clearcut harvest of part of the 1R hoop pine plantation using Timbco harvester in September 1999. For site preparation, a D5M dozer was used to form windrows of 1R harvest residues spaced at about 6 m apart. The stocking density at the 2R hoop pine site was approximately 620 stems ha^{-1} when the soil was sampled in October 2001.

1.2 Soil sampling

All three sites were sampled on the same grid pattern in August 2000, when the 1R plantation harvest residues were windrowed for about 4 months and the 2R hoop pine seedlings were planted about 3 months later. Five transects spaced 3 m apart with 9 sampling points along each transect (1.2 m between 2 adjacent sampling points) were selected for each of the 3 sites (9.6 m x 12.0 m), with 45 20-cm soil cores (ca. using an auger with 7.5 cm in diameter) taken from the relevant sampling points and separated into 0–10 and 10–20 cm depths. There were 90 soil samples from each forest site for determining soil total C, total N, stable C isotope composition (δ^{13}C) and N isotope composition (δ^{15}N), which were also used to estimate appropriate sample size or number required for detecting differences in these soil variables between the forest sites.

Following the preliminary study on the spatial variation in soil total C and N, δ^{13}C and δ^{15}N in the top 20 cm soil, significant differences were detected in these soil parameters between the 3 sites. A second soil sampling (0–10 cm depth) was undertaken in October 2001 for assessing soil biological properties and gross N transformations in laboratory assays. The 1R hoop pine plantation was approximately 51 years old and the 2R hoop pine 2 years old when the second soil sampling was conducted. Each (ca. 30 m x 100 m) of the sampling areas under the adjacent NF, 1R and 2R hoop pine plantations, near the areas of the first soil sampling in August 2000, was divided into five subplots for soil sampling. A total of 25 soil cores (0–10 cm) were randomly collected with an auger of ca. 7.5 cm in diameter from each subplot and bulked (well mixed) in October 2001. In the 2R hoop pine plantation, the soil was sampled from areas between the windrows of harvest residues. Field moist soil samples were sieved (<2 mm) and stored at 4°C (ca. 2 weeks) for soil biological assays. A sub-sample of each soil was airdried for studying gross N transformations in laboratory and soil chemical and physical characterisation.

1.3 Soil analyses and biological assays

Total C and N, $\delta^{13}C$ and $\delta^{15}N$ were determined using an Isoprime isotope ratio mass spectrometer (Isoprime-EuroEA 3000) as reported by Xu et al. (2003). Soil gross N mineralization and immobilization as well as soil biological assays (soil microbial biomass C and N, respiration and metabolic quotient) were determined as reported by Chen et al. (2002). Five 0–10 cm soil samples from each site were used to determine (a) soil chemical properties: pH, cation exchange capacity (CEC), exchangeable cations (K, Ca, Mg and Mn), total P and total K; and (b) physical properties: bulk density, particle sizes (clay, silt and sand) and electric conductivity as reported by Xu et al. (1995).

1.4 Statistical analyses and sample size estimation

Analysis of variance was carried out for all data on soil properties and gross N transformations with Statistix for Windows version 2.2 and least significant difference (LSD) ($P < 0.05$) was used to separate the means when differences were significant. Pearson linear correlations between the soil properties were also conducted with Statistix for Windows version 2.2. The sample sizes were estimated for soil total C and N, $\delta^{13}C$ and $\delta^{15}N$ as reported by Prasolova et al. (2000b).

2 Results

2.1 Soil total C and N, $\delta^{13}C$ and $\delta^{15}N$

Soil total C and N were significantly higher in 0–10 cm depth under NF and 1R hoop pine plantation (63–64 g C kg^{-1} and 5.5–5.8 g N kg^{-1}) than those under 2R hoop pine plantation (58 g C kg^{-1} and 4.9 N kg^{-1}) (**Table 1**), while these corresponding values in 10–20 cm depth were highest under NF (47 g C kg^{-1} and 4.2 g N kg^{-1}), followed by the 1R and then 2R hoop pine plantation. Soil $\delta^{13}C$ was significantly lower in 0–10 and 10–20 cm depths under NF than those under 1R and 2R hoop pine plantations. Soil $\delta^{15}N$ was higher under NF than those under the plantations.

It is interesting to note that sample size for soil total C under NF ($n = 13$, with the sample mean relative error at 10%) appears to be smaller than those under 1R and 2R hoop pine plantations (n: 24–48) as shown in **Table 2**. The sample size pattern for soil total N is similar to that for soil total C. This suggests that soil total C and N appear to be less variable under NF than under the plantations. Only 2–3 soil samples would need to be collected for detecting differences in soil $\delta^{13}C$ between the sites, which are less than those (4–23) for soil $\delta^{15}N$.

2.2 Other soil chemical and physical properties

There were no significant differences in soil pH, CEC and exchangeable cation concentrations in 0–10 cm depth be-

Table 1: Soil total carbon (C) and nitrogen (N), and stable C and N isotope composition ($\delta^{13}C$ and $\delta^{15}N$) in 3 adjacent forest ecosystems[a]

Forest type	Total C (g kg^{-1})	Total N (g kg^{-1})	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)
	0–10 cm soil			
Natural forest	63.0ab[b]	5.5a	–25.89b	10.02a
First rotation hoop pine plantation	64.0a	5.8a	–25.36a	8.32b
Second rotation hoop pine plantation	58.0b	4.9b	–25.53a	8.03b
	10–20 cm soil			
Natural forest	47.0a	4.2a	–25.32b	10.20a
First rotation hoop pine plantation	37.0b	3.7b	–24.54a	9.04b
Second rotation hoop pine plantation	30.0c	2.9c	–24.67a	8.72b

[a] There are no significant differences in soil bulk density (BD) among the 3 forest plots (mean BD = 0.717 g cm^{-3}) for 0–10 cm soil depth
[b] Means within a column for a given soil depth followed by the same letter are not different from each other at 5% level of significance by LSD

Table 2: Sample size required for estimation of mean soil total carbon (C) and nitrogen (N), and stable C and N isotope composition ($\delta^{13}C$ and $\delta^{15}N$) in 3 adjacent forest ecosystems (9.6 m x 12.0 m for each of the 3 forest areas) with the sample mean relative error at 10% ($P_\alpha^{10\%}$) and 20% ($P_\alpha^{20\%}$) with 95% confidence[a]

Forest type	Total C (g kg^{-1})		Total N (g kg^{-1})		$\delta^{13}C$ (‰)		$\delta^{15}N$ (‰)	
	$P_\alpha^{10\%}$	$P_\alpha^{20\%}$	$P_\alpha^{10\%}$	$P_\alpha^{20\%}$	$P_\alpha^{10\%}$	$P_\alpha^{20\%}$	$P_\alpha^{10\%}$	$P_\alpha^{20\%}$
	0–10 cm soil							
NF	13	6	12	5	3	3	23	8
1R	24	9	16	7	3	3	17	7
2R	39	13	20	7	3	3	8	4
	10–20 cm soil							
NF	13	6	11	5	3	2	9	5
1R	48	15	31	10	3	3	10	5
2R	30	10	20	7	3	2	6	4

[a] Forest type: NF – natural forest; 1R – first rotation hoop pine plantation; and 2R – second rotation hoop pine plantation

Table 3: Other chemical properties in 0–10 cm soil in 3 adjacent forest ecosystems[a]

Forest type	pH (1:5 H_2O)	CEC ($cmol\ kg^{-1}$)	Exchangeable cation ($cmol\ kg^{-1}$)				Total P ($mg\ kg^{-1}$)	Total K ($mg\ kg^{-1}$)
			K	Ca	Mg	Mn		
NF	5.0a[b]	35.7a	0.49a	3.85a	0.76a	0.046a	1477a	701b
1R	6.0a	38.7a	0.67a	6.85a	1.55a	0.018a	1116b	1191b
2R	5.4a	28.5a	0.52a	3.96a	1.13a	0.082a	748c	5588a

[a] Forest type: NF – natural forest; 1R – first rotation hoop pine plantation; and 2R – second rotation hoop pine plantation; and CEC – cation exchange capacity

[b] Means within a column followed by the same letter are not different from each other at 5% level of significance by LSD

Table 4: Microbial properties and gross nitrogen (N) transformations in 0–10 cm soil in 3 adjacent forest ecosystems[a]

Forest type	MBC ($mg\ kg^{-1}$)	MBN ($mg\ kg^{-1}$)	CO_2-C respired ($mg\ kg^{-1}\ h^{-1}$)	*q*CO_2-C ($\mu g\ mg^{-1}$ MBC h^{-1})	5 g soil incubated with 5 µg $^{15}NH_4$-N in 50 ml solution (99% ^{15}N excess)		
					PMN($mg\ kg^{-1}$) (mg/kg)	*M* ($mg\ kg^{-1}$) (mg/kg)	I *($mg\ kg^{-1}$)* (mg/kg)
NF	951a[b]	113.1a	0.503a	0.552a	114.6a	140.2a	25.6b
1R	686a	102.3b	0.414a	0.672a	62.6b	78.3b	15.8c
2R	930a	142.6a	0.571a	0.626a	58.7b	95.9b	37.2a

[a] Forest type: NF – natural forest; 1R – first rotation hoop pine plantation; and 2R – second rotation hoop pine plantation; MBC – microbial biomass carbon (C); MBN – microbial biomass nitrogen (N); *q*CO_2-C – metabolic quotient; and potential mineralizable N (PMN), gross N mineralization (*M*) and gross N immobilization (*I*)

[b] Means within a column followed by the same letter are not different from each other at 5% level of significance by LSD

tween the 3 adjacent sites under NF and hoop pine plantations (**Table 3**). Soil total P in 0–10 cm depth was highest under NF (1477 mg P kg^{-1}), followed by those under 1R (1,116 mg P kg^{-1}) and then 2R plantation (748 mg P kg^{-1}). This indicates that close attention would need to be paid to the depletion of soil total P from NF to 1R and from 1R to 2R plantations, when P deficiency might become a major factor limiting hoop pine plantation productivity and soil microbial activity. However, soil total K was significantly higher under 2R plantation than those under NF and 1R plantation.

There were no significant differences in soil physical properties in 0–10 cm depth between the 3 sites: bulk density (0.69 – 0.74 g cm^{-3}), electrical conductivity (0.10–0.13 dS m^{-1}), clay (39–45%), silt (22–29%) and sand (32–35%) (detailed data not presented here).

2.3 Soil microbial properties and gross N transformations

There were no significant differences in soil microbial biomass C, CO_2 respiration and metabolic quotient among the 3 sites (**Table 4**). Soil microbial biomass N was significantly lower in 0–10 cm depth under 1R hoop pine plantation than those under NF and 2R hoop pine plantation. Soil potential mineralizable N and gross N mineralization were significantly higher under NF than those under the plantations. Soil gross N immobilization was highest under 2R, followed by those under NF and then 1R hoop pine plantation.

2.4 Relationships between soil properties

Soil microbial biomass C was significantly related to soil microbial biomass N ($r = 0.655$, $P < 0.01$) as shown in **Fig. 1**. Soil respiration was significantly related to soil microbial biomass N ($r = 0.646$, $P < 0.01$), but not related to soil microbial biomass C ($P > 0.05$).

Soil $\delta^{13}C$ was negatively related to soil total C ($r = 0.666$, $P < 0.01$) as shown in **Fig. 2**. In addition, soil total N was significantly related to soil total C ($r = 0.945$, $P < 0.01$), potential mineralizable N ($r = 0.833$, $P < 0.01$), and gross N mineralization ($r = 0.863$, $P < 0.01$) (detailed data not pre-

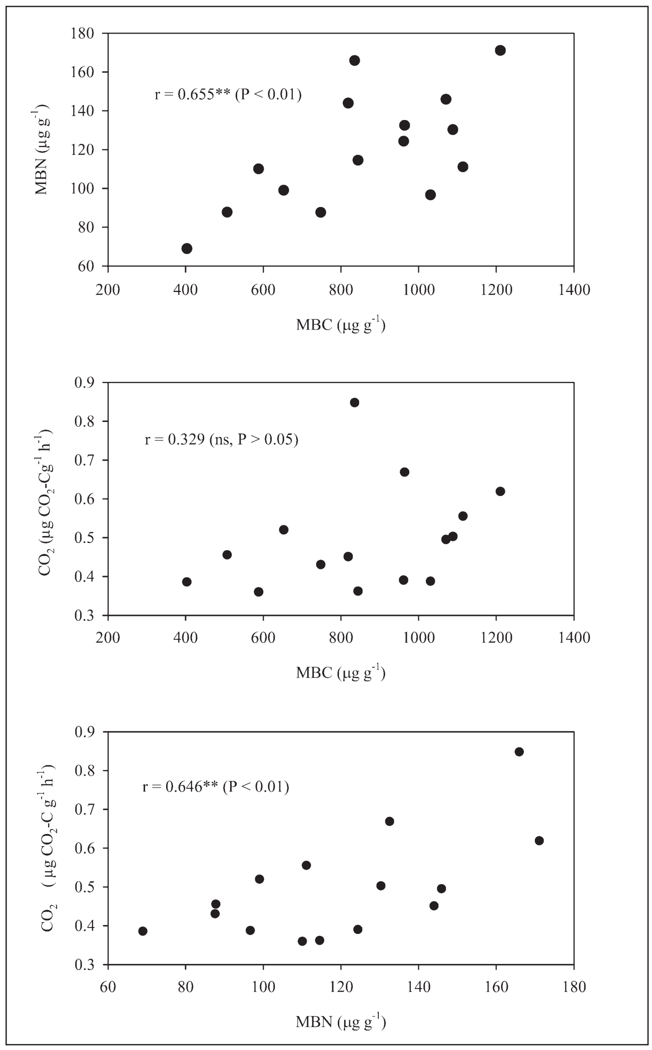

Fig. 1: Relationships determined between microbial biomass C (MBC), microbial biomass N (MBN) and CO_2 respiration in soils under adjacent natural forest, 1st rotation and 2nd rotation hoop pine plantations at the Yarraman site, southeast Queensland, Australia (n=15)

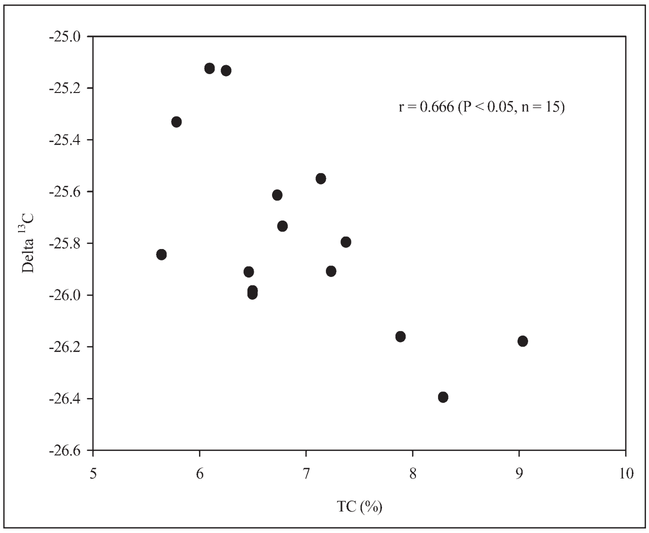

Fig. 2: Relationship between soil total N (TN) and stable C isotope composition (delta ^{13}C, ‰)

sented here). It is not surprising that there were close correlations between potential mineralizable N and gross N mineralization ($r = 0.991$, $P < 0.01$) (data not presented here).

3 Discussion

Soil total C and N in 0–10 cm depth were significantly lower under 2R hoop pine plantation than those under NF and 1R hoop pine plantation. There were significant reductions in soil total C and N from NF to 1R and from 1R to 2R hoop pine plantations in 10–20 cm depth. This highlights potential N deficiency in the 2R hoop pine plantations, and application of N fertilizers may be required to improve the productivity of 2R hoop pine plantations as reported by Bubb et al. (1999) and Xu et al. (2002). Hoop pine families, particularly selected for better tree growth and higher water use efficiency (WUE) in the dry environment (Prasolova et al. 2000a, 2001, Prasolova & Xu 2003, Prasolova et al. 2005), were used in the hoop pine plantations of south-east Queensland, and therefore would be expected to have higher WUE and consequently higher plant $\delta^{13}C$, compared with those of natural forest plant species without any genetic selection. The signature of higher soil $\delta^{13}C$ in hoop pine plantations reflects the incorporation of hoop pine litter and harvest residues into soil organic matter in the past 5 decades, compared with that of NF. The higher soil $\delta^{15}N$ under NF, compared with hoop pine plantations, perhaps reflects the higher soil microbial populations (He et al. 2005) and activity as well as N transformation rates (such as nitrification) (Burton et al. 2007a, b), thereby leading to higher ^{15}N fractionation and enrichment in the soil as reported by Makarov et al. (2003). The sample sizes for soil total C and N in the hoop pine plantations reported here were similar to those of Prasolova et al. (2000b) and Blumfield et al. (2007) for hoop pine plantations in southeast Queensland of subtropical Australia.

There were no significant differences in other soil chemical and physical properties in 0–10 cm depth among the 3 sites under NF, 1R and 2R hoop pine plantations, except for soil total P and K. The significant reduction in soil total P, with about 24% decrease from NF to 1R and a further 33% reduction from 1R to 2R hoop pine plantation, is of particular concern, and warrants attention and further investigation, since the scale of reduction in soil total P appears to be much greater than those for soil total C and total N from NF to 1R and from 1R to 2R plantation. However, some of ecosystem P might be retained in the windrows of 1R harvest residues, which might be released for plant uptake following residue decomposition. This suggests that P deficiency may become a secondary growth-limiting factor in the 2R hoop pine plantations once N deficiency is corrected by fertilizer N application. Indeed, this is supported by another fertilizer experiment on a relatively wet site of south-east Queensland, where application of 60 kg P ha^{-1} in addition to 300 kg N ha^{-1} applied has significantly improved tree growth, compared with the only application of 300 kg N ha^{-1} to a 7-year-old 2R hoop pine plantation (Xu et al. 2000). The higher soil total K in 0–10 cm depth under 2R hoop pine plantation, compared with those under NF and 1R hoop pine plantation, might be due to the major harvest residue distribution at plantation establishment and leaching and mineralization of residue K into the surface soil. Soil total K on the 2R site would be expected to decline as the plantation is more established, since some of the soil total K would be taken up by the growing trees during the rotation period.

Soil microbial biomass C, CO_2 respiration and metabolic quotient did not differ among the 3 sites assessed, perhaps mainly due to these biological variables being too sensitive to variations in soil chemical and physical properties and thereby being associated with a larger variability in the soil biological properties, as reported previously (Chen et al. 2002). However, soil potential mineralizable N, gross N mineralization and immobilization were rather sensitive to the conversion of NF to hoop pine plantation and forest management practices. This is consistent with research findings reported elsewhere (Chen et al. 2002, Mathers & Xu 2003, Burton et al. 2007a,b). There were close relationships between soil total N and total C, and between soil total N and potential mineralizable N (or gross N mineralization), which are similar to those reported by Xu et al. (1996) and Chen et al. (2002).

4 Conclusions

Total C and N in the top 20 cm soil were highest under NF, followed by 1R and then 2R hoop pine plantations, indicating that N deficiency may become a growth-limiting factor in the 2R hoop pine plantations and subsequent rotations of hoop pine plantation. The sample size for soil $\delta^{13}C$ seems to be much smaller than those for soil total C and N as well as $\delta^{15}N$. The significant reductions in soil total P from NF to 1R and then from 1R to 2R hoop pine plantations highlight that P deficiency might become another growth-limiting factor in the second and subsequent rotations of hoop pine plantations. Soil microbial properties may be associated with large spatial variations due to these biological properties being too sensitive to the variations in soil chemical and physical properties in these forest ecosystems. Soil potential mineralizable N, gross N mineralization and immobilization were useful indices of soil N availability in response to forest types and management practices.

5 Recommendations and Perspectives

Soil potential mineralizable N, gross N mineralization and immobilization were useful indices of soil N availability in response to forest types and management practices. The sampling size for soil $\delta^{13}C$ was much smaller than the other soil chemical and biological properties due to the different patterns of spatial variation in these soil properties.

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Effect of Overlying Windrowed Harvest Residues on Soil Carbon and Nitrogen in Hoop Pine Plantations of Subtropical Australia

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Abstract

Background, Aims and Scope. Harvest residues were formed into windrows to prevent nitrogen (N) losses through volatilisation and erosion that occurred following pile and burn operations in hoop pine (*Araucaria cunninghamii* Aiton ex A. Cunn.) plantations of subtropical Australia. We selected second rotation (2R) hoop pine sites where the windrows (10–15 m apart) had been formed 1, 2 and 3 years prior to sampling in order to examine soil carbon (C) and N in the areas beneath and between the windrows.

Methods. We used conventional chemical methods, anaerobic incubation assay, ^{13}C and ^{15}N natural abundance analyses and, solid-state ^{13}C nuclear magnetic resonance (NMR) spectroscopy.

Results. Percent mineralisable N (PCMN) was the only parameter in the underneath windrow position at the Year 1 site that did not show a significant difference to the rest of the positions along the transect. However, positions adjacent to windrows did have significantly greater PCMN at the Year 1 site than other positions along the transect. PCMN, total N and total C were significantly greater underneath the windrows at the Year 3 site, whilst δ^{13}C was significantly more negative in the underneath windrow positions.

Discussion. PCMN was the most sensitive biological indicator of the changes occurring in the soil due to decomposition of the windrows, with the beneath-windrow position having a significantly higher PCMN than the inter-windrow position ($p<0.001$) at the Year 3 site. Isotopic natural abundance for both ^{13}C and ^{15}N was able to detect the influx of labile materials from new residues. Solid-state ^{13}C NMR was able to detect inputs of labile C from the windrows at the Year 1 site, whilst the increase in aromatic C at the Year 3 site was indicative of the more advanced stages of windrow decomposition.

Conclusions. Decomposition of windrowed residues had a beneficial effect on soil N and C pools. However, the effect remained localised after 3 years, indicating that trees needed to be planted close to the windows to gain any benefit from residue decomposition.

Recommendations and Perspectives. The use of windrows allows a clear planting area and provides a good barrier against soil erosion. However, trees can only gain access to the nutrients from the decomposing residues if they are planted close to the windrows. Limiting the width of the cleared areas to allow for only 2 planting rows will give the maximum benefit to the developing trees.

Keywords: Australia, subtropical; hoop pine; plantations; residue management; soil C and N; windrows