Afforestation of agricultural land with spotted gum (*Corymbia citriodora*) increases soil carbon and nitrogen in a Ferrosol

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Abstract
Planting forests onto marginal ex-agricultural land may provide a relatively cost-effective way of creating a carbon sink where more CO_2 is being removed from the atmosphere than is being released (sequestration), while simultaneously improving soil organic carbon (C) and nitrogen (N) stocks (organic matter) and fertility. Soil C and N stocks were measured in spotted gum (*Corymbia citriodora* spp. *variegata*) plantations (C_3 vegetation) established on ex-pasture (C_4 vegetation) sites compared with those in adjacent native vine scrub, pasture and peanut cropping in southeast Queensland (26°39'S, 151°45'E), Australia. The contribution of spotted gum to soil C was assessed using the natural ^{13}C isotope dilution technique ($\delta^{13}C$). Soil C and N concentrations were greater under the 4-year-old spotted gum plantation than either the adjacent grazed pasture or peanut cropping soil and similar to the original native vine scrub in the 0-0.3 m depths. Similar trends were observed in the total soil N. The quantity of C sequestered belowground was estimated to be approximately 240 Mg CO_2-e/ha in the entire 1.1 m soil profile after 25 years, indicating that afforestation may provide carbon offsets as an important source of future income as well as improved soil fertility (increased soil N) in the degraded agricultural lands of the South Burnett region in Queensland, Australia.

Key Words
Stable isotopes, $\delta^{13}C$, soil C sequestration, afforestation, hardwood plantations.

Introduction
Land-clearing for agriculture has invariably led to the loss of soil carbon (C) stocks in southern Queensland, as well as a decline in soil fertility and quality (Dalal and Mayer 1986; Bell *et al.* 1995; Saffigna *et al.* 2004). Due to the declining soil fertility and the introduction of the Vegetation Management Act (1999) that prevents tree clearing in Queensland, Australia, hardwood plantations are currently being established on degraded ex-agricultural soils. Hardwood plantations offer a viable land use for soils of the South Burnett region, Queensland, that have been cleared of native vegetation, but are marginal for agricultural production because of low fertility status or slope. Afforestation of degraded ex-farmlands with hardwoods can increase soil C (soil C sequestration) in subtropical regions (Paul *et al.* 2002; Maraseni *et al.* 2008), as well as improve soil fertility (increase soil N) and soil quality.

Currently the range of soil data to support changes in soil C and nitrogen (N) stocks estimations is limited. While it can be inferred that the impact of hardwood plantations on soil quality and C sequestration will be positive (Paul *et al.* 2002; Lima *et al.* 2006), the magnitude of this impact has not been quantified in southeast Queensland. One of the most common limitations to obtaining good data is that trees are planted before a comprehensive evaluation is made of the soil C and/or N stocks in the various land systems to be planted. In addition, there is generally no native vegetation area close by to provide the prevailing ecosystem-induced soil C and N levels. The establishment of more than 9000 ha of hardwood plantations in the South Burnett region, led us to investigate similar native vine scrub, pasture and peanut cropping areas on Red Ferrosols near Taabinga Village (26°34'59"S, 151°49'59"E), with the added land-use of an adjacent 4-year-old hardwood plantation that was planted onto ex-pasture.

The objectives of the study were to: (a) assess soil C and N changes down to 1.1 m depth for the four different land uses; (b) determine the light fraction C and N to assess the changes in soil C and organic matter quality; and (c) derive the turnover rate and time of hardwood-derived C and N in soil under plantation using delta (δ) ^{13}C isotopic natural abundance of soil organic matter to differentiate from C_4 pasture derived C.

Methods

Land Uses

The four sites used in this study were located at Taabinga near Kingaroy (26°35'S, 151°50'E) in the inland South Burnett region of southeast Queensland, Australia. The soil is classified as a Red Ferrosol according to the Australian Soil Classification of Isbell (2002) or a Tropeptic Eutrustox (i.e. Oxisol) by the Soil Survey Staff (2006). Adjacent areas of Red Ferrosols under the following four land uses were sampled for this study:

- Site 1 - undisturbed native vine scrub (26°39'56"S, 151°45'08"E);
- Site 2 - wiregrass (*Aristida ramose*)/ Rhodes grass (*Chloris gayana*) pasture (26°39'38"S, 151°45'18"E);
- Site 3 - peanut (*Arachis hypogaea*)-maize (*Zea mays*) cropping (26°39'42"S, 151°45'28"E); and
- Site 4 - 4-year-old spotted gum (*Corymbia citriodora* spp. *variegata*) plantation (established November 2001) on ex-pasture (26°39'53"S, 151°45'09"E).

Soil and Plant Sampling

Soil samples were collected in April 2005 using a 44 mm diameter soil coring tube driven by a hydraulically operated soil sampling rig. However, in the native scrub a hand auger (42 mm diameter) was used because the vegetation was too dense to access with the soil sampling rig. The National Carbon Accounting System (NCAS) methodology was used for soil sampling (McKenzie *et al.* 2000). Each plot was divided into four quadrats and within each quadrat a sampling point was randomly located. At each sampling point, one core was taken to 1.1 m soil depth and then four adjacent cores were taken to 0.3 m depth. Each main core was divided into 0-0.05, 0.05-0.1, 0.1-0.2, 0.2-0.3, 0.3-0.5, 0.5-0.7, 0.7-0.9 and 0.9-1.1 m depths in the field, transferred to a plastic bag and sealed. The smaller cores were divided into 0-0.05, 0.05-0.1, 0.1-0.2, and 0.2-0.3 m depths and bulked with the main core samples at the corresponding depths. All soil samples were then transported to the laboratory for further analysis.

Analysis

Soil materials were air-dried and then sieved using a 2-mm sieve. Coarse material (stones and roots) was separated and masses were recorded. Representative sub-samples of the soil and light fraction (LF) of soil were fine-ground (<0.5 mm) for soil C and N analyses. Light fraction C (LFC) and N (LFN) was determined using sodium polytungstate solution (1.6 Mg/m^3 density) as described by Dalal *et al.* (2005a,b). Total soil organic C (TOC), soil total N, LFC, LFN, and natural abundance ^{13}C of soil, LF and litter samples were determined using an Isoprime isotope ratio mass spectrometer (IRMS) coupled to a Eurovector elemental analyser (Isoprime-EuroEA 3000) with 10% replication. The isotope ratios were expressed using the 'delta' notation (δ), with units of parts per thousand (‰), relative to the marine limestone fossil Pee Dee Belemnite standard (Craig 1953) for $\delta^{13}C$ using the relationship in equation 1 below:

$$\delta^{13}C\ (‰) = (R_{sample} / R_{standard} - 1) \times 1000 \qquad (1)$$

where R is the molar ratio of $^{13}C/^{12}C$ of the sample or standard (Ehleringer *et al.* 2000).

Results

Table 1. Key properties of the top layer of the Red Ferrosol under different land uses (n=4).

Property	Crop (0-0.05 m)	Pasture (0-0.1 m)	4yo plantation (0-0.1 m)	Native vine scrub (0-0.05 m)
pH (1:5 water)	4.56	5.10	4.56	4.46
EC ($\mu S\ cm^{-1}$)	92.5	41.0	57.7	169.6
C/N ratio	11.5	11.8	12.8	13.8
Sand (%)	58.0	46.0	45.0	49.4
Clay (%)	34.0	37.3	32.2	29.8
Silt (%)	8.0	8.0	10.0	19.2
Bulk Density ($g\ cm^{-3}$)	1.62	1.21	0.95	1.16

The distribution of TOC and soil N concentrations decrease with depth and vary with land use but below 0.5 m depth the TOC and soil N concentrations were similar across land uses except in the cropped soil (Figure 1). In the top soil layer (0-0.05 m depth) at Taabinga, the native vine scrub exhibited the greatest soil TOC concentration with 4.9%; followed by the 4-year-old plantation at 3.9%, pasture at 2.8% and lastly, the cropped site with 1.0% TOC. Soil C and N stocks were also calculated on equivalent soil mass basis, taking into account the changes in bulk density following land use change.

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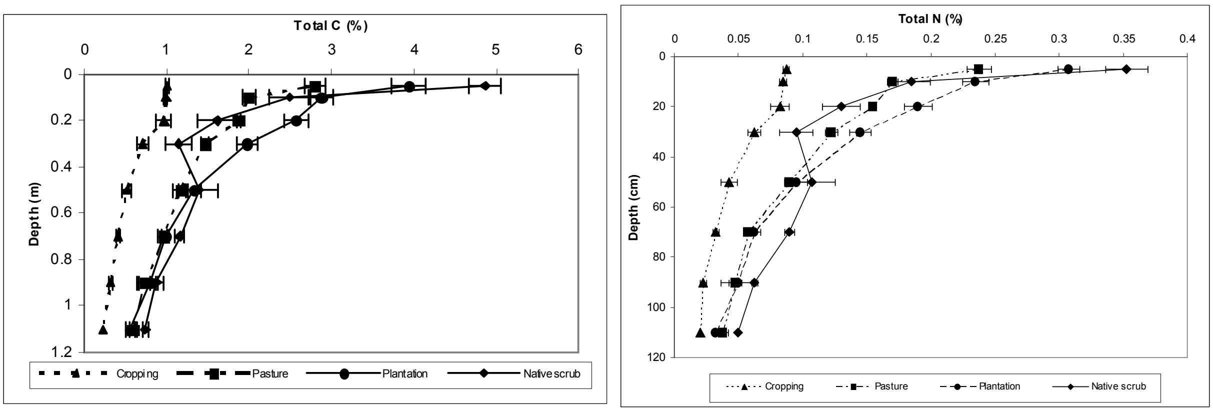

Figure 1. Profile distribution of total C (%) and total N (%) in a Red Ferrosol under four different land uses at Taabinga. Bars indicate standard errors of the means (n=4).

Soil $\delta^{13}C$ was most negative (most depleted in ^{13}C) in the native vine scrub with a value of -25.9‰ in the surface 0.05 m of soil while $\delta^{13}C$ under pasture was -21.7‰ and -22.2‰ under cropping (Figure 2). The $\delta^{13}C$ values at Taabinga under pasture were enriched (or more positive) due to the presence of C_4 grasses that have a $\delta^{13}C$ range of -12 to -18‰, while the peanut crop utilises the C_3 pathway (-24 to -32‰) giving it a lower value than that for pasture. The $\delta^{13}C$ values of the LFC under pasture showed significant ^{13}C enrichment throughout the soil profile (Figure 2) compared to the native scrub, whereas under the spotted gum plantation, significant enrichment of ^{13}C of LFC occurred mostly in the top 0.3 m depths, where C_3 carbon from the spotted gums would be mixing with the C_4 carbon from the pasture that the spotted gums were planted on the pasture soil.

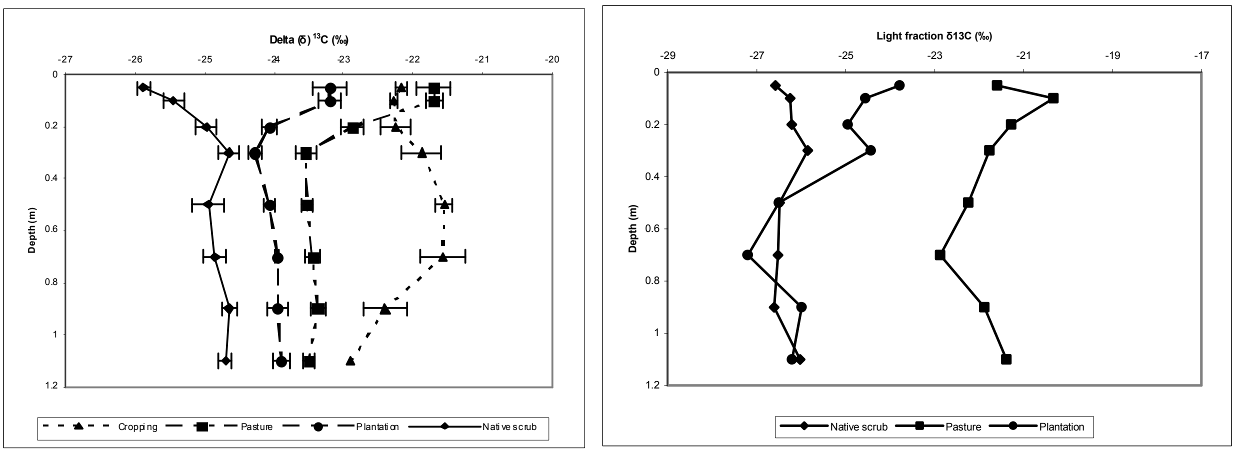

Figure 2. Natural abundance $\delta^{13}C$ (‰) of soil total organic C and light fraction C down the soil profile under different land uses at Taabinga. Bars indicate standard errors of the means (n=4).

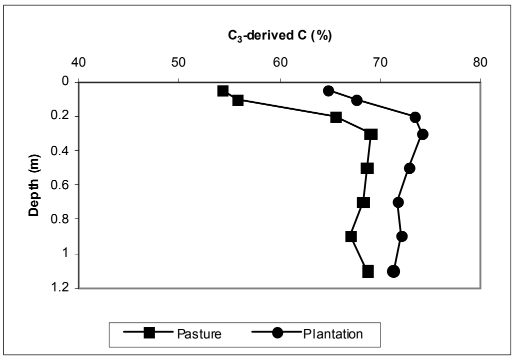

Figure 3. Proportion of C_3-derived C in soil under 4-year-old plantation as compared to adjacent pasture having C_3-derived C from native scrub.

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Figure 3 indicates the proportion of C_3-derived C in the 4-year-old spotted gum plantation compared to the adjacent pasture at all depths. In the 0-0.05 m depth, the pasture soil still retains 54% of its C from the previous C_3 sources, while the soil under plantation has increased C_3 source C from 54% to 65%. Thus, in 4 years, the plantation has increased its C_3-derived C by at least 10.6% in the 0-0.05 m soil depth (Figure 3); although at the 1.1 m soil depth there is only a 2.6% increase in C_3-derived C.

Conclusion

This study has demonstrated the major impact of cropping and pasture on decreasing the soil C and N concentrations to a depth of 1.1 m compared to the native vine scrub soil in the Burnett region of southeast Queensland, Australia. Many studies have reported a decrease in soil C and N with afforestation of ex-pasture, but this study indicates that soil C and N may increase after afforestation of ex-pasture land with hardwoods in subtropical Australia. Thus, there is considerable potential for C sequestration in soil under hardwood forest plantations in southeast Queensland and hence, carbon trading incentives. Natural abundance ^{13}C isotope analysis of these four adjacent soils indicated that differences in soil TOC due to the introduction of crop and pasture species were evident down the soil profile. However, the largest differences occurred in the top 0-0.05 m soil depth; with a 10.6% increase in C_3-derived soil C four years after hardwoods were planted onto the pasture soil. A portion of this C_3-derived C from the original native vine scrub was replaced by C_4-derived C from the pasture species and maize crops in the pasture and cropping soils, respectively.

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References

Bell MJ, Harch GR, Bridge BJ (1995) Effects of continuous cultivation on Ferrosols in subtropical southeast Queensland. I. Site characterization, crop yields and soil chemical status. *Australian Journal Agricultural Research* **46,** 237-253.

Craig H (1953) The geochemistry of the stable carbon isotopes. *Geochimica et Cosmichimica Acta* **3,** 53-92.

Dalal RC, Harms B, Krull E, Wang W (2005a) Total soil organic matter and its labile pools following Mulga (*Acacia aneura*) clearing for pasture development and cropping 1. Total and labile carbon. *Australian Journal of Soil Research* **43**, 13-20.

Dalal RC, Harms B, Krull E, Wang W, Mathers NJ (2005b) Total soil organic matter and its labile pools following mulga (*Acacia aneura*) clearing for pasture development and cropping. 2. Total and labile nitrogen. *Australian Journal of Soil Research* **43,** 179-187.

Dalal RC, Mayer RJ (1986) Long-term trends in fertility of soils under continuous cultivation and cereal cropping in Southern Queensland. II Total organic carbon and its rate of loss from the soil profile. *Australian Journal of Soil Research* **24,** 281-292.

Ehleringer JR, Buchmann N and Flanagan LB (2000) Carbon isotope ratios in belowground carbon cycle processes. *Ecological Applications* **10,** 412-422.

Isbell RF (2002) The Australian Soil Classification, CSIRO Publishing, Collingwood, Vic, Australia.

Lima AMN, Silva IR, Neves JCL, Novais RF, Barros NF, Mondonça ES, Smyth TJ, Moreira MS, Leite FP (2006) Soil organic carbon dynamics following afforestation of degraded pastures with eucalypts in southeastern Brazil. *Forest Ecology and Management* **235,** 219-231.

Maraseni TN, Mathers NJ, Harms B, Cockfield G, Apan A, Maroulis J (2008) Comparing and predicting soil carbon quantities under different land-use systems on the Red Ferrosol soils of southeast Queensland. *Journal of Soil and Water Conservation* **63,** 250-256.

McKenzie N, Ryan P, Fogarty P, Wood J (2000) Sampling, measurement and analytical protocols carbon estimation in soil, litter and coarse woody debris. National Carbon Accounting System, Technical Report No. 14. Australian Greenhouse Office, Canberra.

Paul KI, Polglase PJ, Nyakuengama JG, Khanna PK (2002) Change in soil carbon following afforestation. *Forest Ecology and Management* **168**, 241-257.

Saffigna PG, Moody PW, Mathers NJ (2004) Impact of cropping on the soil C and N, and the potential for C sequestration under hardwood forestry in a krasnozem soil in subtropical Queensland, Australia. In 'ISCO 2004: 13th International Soil Conservation Organisation Conference'. 4-9 July, Brisbane, Queensland, Australia. Oral presentation.

Soil Survey Staff (2006) 'Keys to Soil Taxonomy, 10th ed'. (USDA-Natural Resources Conservation Service: Washington, DC).