Soil carbon storage potential under perennial pastures in the mid-north coast of New South Wales, Australia

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Abstract

A pilot survey to measure organic carbon storage in soils under different land uses was carried out within a 100 km radius of Taree, New South Wales, Australia in 2007. The area has a subtropical climate with annual rainfall of 900–1600 mm. Soil organic carbon (SOC) levels under forests to 20 cm depth varied from 37 to 134 t/ha C, with a mean of 77 t/ha C. Levels under pastures varied from 44 to 96 t/ha C, with a mean of 73 t/ha C. The data suggest that soils under introduced perennial pastures (mainly tropical C_4 perennials) can potentially store similar amounts of soil carbon as those under native forests (mainly woodlands with C_3 tree species). Our results indicated improved pastures can store more carbon than native pastures. Further research is needed to fully quantify the effects of pasture type, fertiliser strategies and management practices on SOC storage potential, with extension of the sampling horizons to greater depths.

Introduction

Soil carbon sequestration in relation to the mitigation of climate change is a prominent environmental issue affecting many facets of agriculture and forestry. In Australia, while wheat-cropping soils have been studied (Dalal and Chan 2001; Chan *et al*. 2003), there is a dearth of data on the quantities of soil organic carbon (SOC) likely to be stored by perennial pastures in high rainfall zones of the New South Wales coast, Australia. The long-term impact on soil carbon stocks of clearing native forests and replacing them with pastures is not known. Furthermore, since management practices affect soil carbon storage under pastures (Russel and Williams 1982; Follett *et al*. 1998; Conant *et al*. 2001; Fisher *et al*. 2007), one might expect that carbon stocks in soils managed in different ways in the region would be different, but such knowledge is not available. This information is important for assessing the soil organic carbon storage potential of the region in relation to carbon offsets in any future carbon trading scheme (Garnaut 2008).

The mid-north coast region of New South Wales, Australia (30–32°S), has a median annual rainfall range of 900–1600 mm, which is summer-autumn-dominant. The region has a subtropical climate and is a transition zone between a tropical climate to the north and a coastal temperate climate to the south. High rainfall variability and a seasonal moisture deficit from August to October are the main impediments to pasture growth and persistence, particularly for spring-flowering temperate legumes.

Soils of the region vary widely owing to the influences of elevation, geology and weathering history, with shallow texture contrast soils (Chromosols, Kurosols and Tenosols; Isbell 1996) dominating the first 60 km from the coast. Sandy Podsols occur on the coastal plain, along with riverine and estuarine alluvial soils. Further inland, deeper Ferrosols are common on the plateaux and steeply dissected valleys. The majority of the region's soils are highly erodible and unsuited to regular cultivation. Soil deficiencies of phosphorus, sulphur, nitrogen, potassium and molybdenum are common and, in association with variable soil acidity levels, severely restrict growth of sown pastures unless corrected.

Eucalypt forests and open woodlands covered 85–90% of the region before European settlement in the late 1820s. Harvesting of high quality

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softwood timbers commenced on alluvial soils in the 1840s, and after about 50 years, clearing of shallow upland soils by ringbarking commenced, with the introduction of dairying to properties that generally had some deeper cropping soils. Apart from limited areas of beans, peas and potatoes, no grain cropping was practised on non-alluvial soils, because soil fertility and moisture storage were inadequate for worthwhile cropping. Some of the cleared country was cultivated and sown to introduced perennial subtropical grasses, which currently constitute 10–15% of all permanent pastures of the region. However, often only limited amounts of fertiliser were applied at sowing, with sparing amounts applied subsequently for maintenance when surplus capital was available. The cost-price squeeze under the current economic situation is a deterrent to regular fertiliser application and pasture improvement.

At present, a perennial pasture base sustains beef cattle production and dairying, the dominant agricultural industries in the region. Unfertilised naturalised perennial subtropical grasses [carpet grass (*Axonopis affinis*), paspalum (*Paspalum dilatatum*) and *Sporobolus* spp.] are the dominant pasture base for beef cattle production. Introduced perennial subtropical grasses [kikuyu (*Pennisetum clandestinum*), rhodes grass (*Chloris gayana*), setaria (*Setaria sphacelata*) and *Paspalum* spp.] improve the pasture feed quality but require good soil fertility for production and persistence.

This paper reports results of a pilot investigation on: (1) soil carbon levels at paired sites containing perennial pasture and forest; (2) soil carbon levels across the range of perennial pasture types and naturalised grasses common to the coastal high rainfall zone; and (3) the potential of pasture management practices to increase storage of SOC.

Materials and methods

Site selection

A paired-site approach (Chan *et al*. 2010) was taken to investigate soil organic carbon concentrations and stocks under pastures compared with adjacent native woodlands. Soil samples were taken from 6 paired sites of adjacent native forests and pastures and SOC levels were measured. Additional perennial pasture sites consisting of native, naturalised and introduced summer grasses and lucerne were also selected. The sites selected covered different soil types and fertility levels, with annual rainfall ranging from 900 mm to 1600 mm and elevation differences from sea level to 900 masl (Figure 1). All sites had at least a 15-year pasture history, with most a known 30–50-year history.

Sampling protocol

At each sampling site, a representative 20 m x 20 m area was selected. Pasture sites were selected for uniformity of vegetation type, separation from gateways and disturbed areas and were at least 20 m (mostly 50 m) from native forests. Soil samples were collected from alternate 10 m x 10 m plots within the selected 20 m x 20 m area. Five soil cores were collected using a 20 mm (internal diameter) soil coring tube to 200 mm from each plot, and bulked to form a composite soil sample. Site coordinates were recorded and a photograph taken of the site to characterise the landscape. Sampling was carried out after sufficient rain had fallen and the soil profile was close to field capacity such that all soils had good soil moisture at sampling, thus helping to maintain sample integrity and accuracy.

All soil samples were sorted to remove any discernable plant top or root parts, and other recognisable undecomposed macro-organic matter, and dried at 40°C until constant weight. Subsamples were dried to 105°C to determine air-dry soil water content for the calculation of bulk density. Bulk density of soil was calculated from the ratio of oven-dried mass of soil and the volume of the soil core for the 2 depth intervals, 0–10 cm and 10–20 cm. The remainder of each soil sample was ground to <2 mm and subjected to laboratory analyses.

Laboratory analyses

All soil samples were analysed for pH, EC (electrical conductivity), extractable phosphorus (Bray P), total carbon and total nitrogen following Rayment and Higginson (1992). Total carbon was measured using the Leco combustion method. Soil carbon stocks to 20 cm at each sampling point were calculated from SOC concentration and bulk density data for the 0–10 cm and 10–20 cm soil layers, namely on constant depth basis. No attempt was made to correct the SOC stock results to a constant soil mass basis (Ellert and Bettanay 1995).

Isotopic carbon measurement of soils and plants

As the native forest species of the region were comprised predominantly of C_3 tree species and the tropical pastures were mostly of C_4 origin, the relative contributions of carbon originating from the 2 different plant communities to the present carbon pool under pastures could be distinguished and estimated reasonably accurately using isotopic carbon determination following Skjemstad *et al.* (1990).

The proportions of carbon isotopes, $^{13}C:^{12}C$ ratio, expressed as δ^{13} C‰ of soil samples (0–10 cm and 10–20 cm) from 2 paired sites of adjacent pastures and native forest were measured using a GV Isoprime Mass Spectrometer. Composite plant samples were also collected from the 2 paired sites, native forests as well as pastures, dried and ground and their subsamples measured for δC‰. Contribution of soil carbon from the pasture as a percentage of total SOC stocks found at the current pasture site (f) was calculated using the following equation (Skjemstad *et al.* 1990):

$$f = [(\delta C‰_{\text{past soil}} - \delta C‰_{\text{forest soil}})/ (\delta C‰_{\text{past}} - \delta C‰_{\text{forest}})]*100\%$$

Results

SOC concentrations

SOC data from the 0–10 cm layer suggest that soils under local native forests have the highest mean SOC levels (6.08%), followed by perennial improved subtropical grass pastures (4.54%)

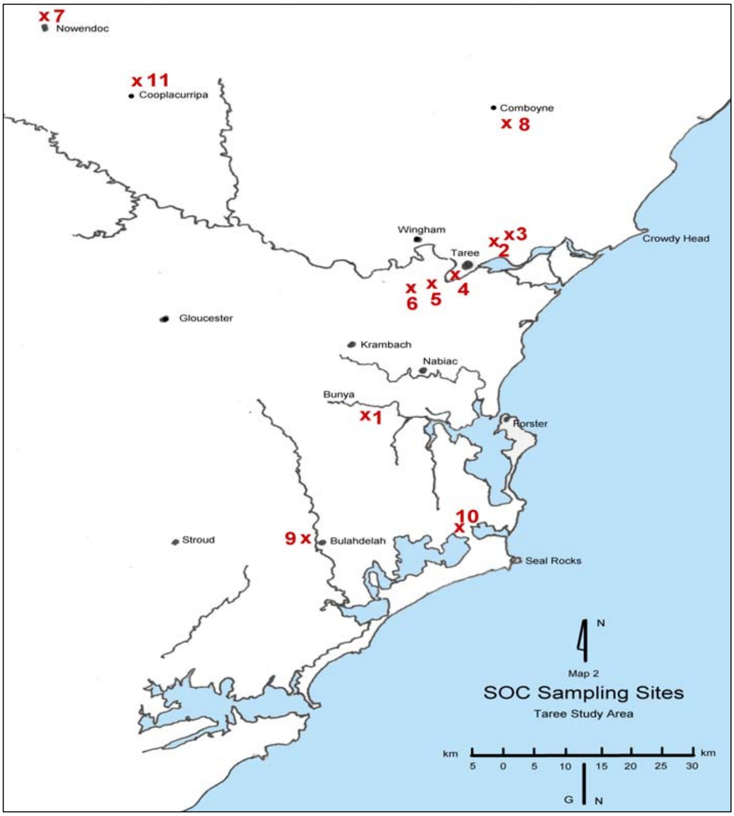

Figure 1. Location of sampling sites for soil carbon investigation in the Taree area (Taree 31º54" S, 152º29”E).

and unimproved native and naturalised grasslands (3.1%) (Table 1). The large variation in soil carbon concentration in this layer under native forests (1.7–9.8%) reflected the differences in soil fertility, soil texture, soil depth and even climatic variables of the different sampling locations in the investigation area as discussed earlier.

In general, SOC concentrations in the 10–20 cm horizon were lower than in the 0–10 cm layer for the same vegetation type, with large ranges in SOC under all vegetation types (Table 1). While SOC concentrations in this layer were similar under both native forests and improved subtropical perennial pastures, the percentage of total soil carbon in the 10–20 cm layer was higher under the improved subtropical perennial pasture than under either the forested site or unimproved and naturalised pastures.

SOC stocks under paired native forest and perennial pasture sites

Total soil carbon storage in the top 20 cm at the 6 paired sites of native forests and adjacent pastures were similar (P>0.05) at 76.5 t/ha C and 72.9 t/ha C, respectively (Table 2).

There was much greater variation under the forests than under pastures.

SOC stocks under pastures

Total soil carbon stored under pastures to 20 cm, including all pasture types sampled was quite variable (50 – 164 t/ha C, mean 76 t/ha C). SOC stocks were related to soil type, with lowest SOC levels in soils with the poorest soil properties, namely low CEC, shallow topsoil depth and low soil moisture storage (based on local knowledge) under both native pasture and native forest. The lowest SOC stock (50.4 t/ha C) was found in an infertile, sandy loam soil (Chromosol) and the highest SOC stock (164 t/ha) in a deep well structured clay loam soil (Ferrosol).

The importance of management practice is highlighted by the 2 paired pasture sites with contrasting management included in this investigation. In the first example, soil under introduced subtropical grasses (kikuyu) had higher (almost double) SOC concentration in the 0–10 cm layer than adjacent soil under native pasture (*Bothriochloa* spp.; Table 3). Introduced, perennial, subtropical grasses have the capacity to produce a

Table 1. Soil N and OC concentrations (means and ranges) for 20 sites on mid-north coast of NSW: (a) 0–10 cm; and (b) 10–20 cm.

(a)

Vegetation type	Soil OC (%)		Soil N (%)		Sites sampled
	Mean	Range	Mean	Range	
Native forests	6.08	1.7 – 9.8	0.31	0.12 – 0.53	6
Improved summer perennial pastures	4.54	2.7 – 5.9	0.37	0.22 – 0.53	8
Unimproved native and naturalised perennial pastures	3.1	2.8 – 3.3	0.24	0.2 – 0.31	3
Perennial subtropical/temperate pastures	3.4	2.3 – 4.5	0.36	0.22 – 0.49	2
Improved perennial temperate grass	7.3	N.A.[1]	0.48	N.A.	1

(b)

Vegetation type	Soil OC (%)		Soil N (%)		Sites sampled
	Mean	Range	Mean	Range	
Native forests	2.1	0.89 – 4.9	0.14	0.06 – 0.31	6
Improved summer perennial pastures	2.21	1.1 – 3.6	0.16	0.09 – 0.34	8
Unimproved native and naturalised perennial pastures	1.2	1 – 1.4	0.09	0.07 – 0.13	3
Perennial subtropical/temperate pastures	1.6	1.5 – 1.7	0.17	0.16 – 0.18	2
Improved perennial temperate grass	5.2	N.A.	0.33	N.A.	1

[1] N.A. = not available.

high biomass under average rainfall patterns and to achieve high SOC, providing soil fertility is appropriate. In fact, soil analyses indicated that soil under kikuyu pasture had higher soil P, pH and soil N, all indicators of higher soil fertility (Table 3). SOC stocks to 20 cm depth were 67.2 t/ha C for the kikuyu pasture and 44.2 t/ha C for the native pasture, a difference of 23 t/ha C. In the second example, higher SOC was found under the pasture (mixed lucerne, rye and white clover) which had been irrigated with a dairy effluent than under the adjacent one which was fertilised with inorganic fertilisers over the last 20 years. Soil analyses also indicated a higher level of Bray P and lower C:N ratio in the former soil. The difference in SOC stocks between the 2 pastures was 20.7 t/ha C (75.5 *vs* 54.8 t/ha C) (Table 3).

While total SOC in the top 20 cm was similar under native forests at the 2 paired sites (85 and 79 t/ha C), soil under kikuyu had much higher SOC than that under setaria (80 *vs* 61 t/ha C, Table 4). For both of the C_4 pasture soils, carbon isotope studies indicated that considerable amounts (>50 %) of the carbon from the original vegetation (C_3 native forest) still remained in the total SOC pool (Table 4). However, contribution of carbon from the 2 pastures to the

Table 2. Soil carbon stocks (t/ha C, 0–20 cm) for paired sites of adjacent native forest and pasture on the north coast of NSW, Australia.

	Native forest	Pastures
Range	37.4–133.7	50.4–96.4
Mean	76.5	72.9
SD	35.6	20.4

Table 3. Soil P, N and OC levels and properties (0–10 cm layer) and SOC stocks (0–20 cm) at 2 paired sites with contrasting nutrient histories.

Pasture comparisons	Soil P	pH	SOC	Soil N	C:N	Carbon stock[1]
1st paired site	(mg/kg)		(%)	(%)		(t/ha C)
Kikuyu (fertilised)	37	5.2	5.2	0.53	9.8	67.2
Native grass (*Bothriochloa* spp., unfertilised)	9.6	4.8	2.8	0.31	9.0	44.2
2nd paired site						
Pasture irrigated with dairy effluent	220	6.3	4.5	0.49	9.2	75.5
Pasture (adjacent but not irrigated with dairy effluent)	65	6.0	2.3	0.22	10.5	54.8

[1] Soil carbon storage (0–20 cm).

Table 4. Soil carbon stocks, δ^{13}C (‰) at two depths under two paired pasture and native forest sites and percent of carbon stocks contributed by the pasture at the pasture sites as measured from carbon isotopes.

Paired sites	Land use	Depth	SOC (t/ha)	(δ^{13}C‰)	% contribution by pasture
1. Kikuyu site	Kikuyu pasture	0–10cm	44	-17.0[1]	41.1
	Kikuyu pasture	10–20cm	36	-20.9	21.9
	Native forest	0–10cm	57	-21.9	-
	Native forest	10–20cm	28	-23. 5	-
2. Setaria site	Setaria pasture	0–10cm	34	-20.6	25.9
	Setaria pasture	10–20cm	27	-23.9	13.1
	Native forest	0–10cm	50	-24.5	-
	Native forest	10–20cm	29	-25.7	-

[1] Negative sign of δ^{13}C‰ values in the Table is a result of its definition based on a standard of PDB (Skjemstad *et al*. 1990).

total SOC stock of the current pasture soils was quite different between the kikuyu and setaria sites. The contribution from the kikuyu pasture was higher than that from the setaria pasture in both 0–10 cm and 10–20 cm layers (Figure 2). In fact, 70 % of the difference in SOC stocks (to 20 cm depth) between the two pasture sites could be attributed to the higher carbon contributed by the kikuyu pasture. This is direct evidence of the higher effectiveness of introduced pastures under improved management in increasing SOC storage.

Discussion

Results of this pilot study highlight the amounts of soil carbon which can be stored under subtropical pastures in coastal NSW. It is interesting to note that the mean SOC stocks we measured under perennial pastures were significantly higher (>double) than those measured over the same depth interval in inland Tableland soils of 36 t/ha C (range 21–59 t/ha C) (Chan *et al*. 2010). The difference could be at least partly related to the higher rainfall in the coastal areas. However, much of the stored carbon did not originate from the pasture but was residual carbon from the original forest vegetation. We estimate that 80% of the soil OC under a setaria pasture and 68% of the soil OC under a kikuyu pasture had been contributed by the original forest.

Based on the estimates by Keith *et al*. (2009) for above-ground biomass carbon of NSW coastal forests of 218–447 t/ha C, and given the considerably larger carbon stocks in above-ground biomass in forests than in grassland, *e.g*. up to 16 times higher (Mannetje 2007), clearing of the native C_3 forests of coastal regions in the past and replacement with pastures would have resulted in huge losses of total carbon stocks in the system. In many situations, this loss in above-ground carbon storage has also been accompanied by loss of soil carbon (Lal *et al*. 2007). The latter authors estimated that globally most agricultural soils have lost 30–75% of their antecedent soil organic carbon pool, representing a loss of 30–40 t/ha C. For soils in the wheat belt of Australia, it has been estimated that >50% of soil carbon stocks has been lost (Dalal and Chan 2001), in spite of the fact that many of the crops are grown in rotation with pastures. In contrast, our results indicate that, in the coastal region of NSW, SOC stocks of pasture soils can approach those of the native forests. This discrepancy could reflect the higher rainfall of the coastal region compared with the Australian wheat belt. Tarre' *et al*. (2001) also reported that SOC stocks under a 9-year-old pasture of *B. humidicola*, sown following clearing, were similar to those under the original Atlantic forest vegetation in east-central Brazil.

The observed variation in SOC stocks amongst different pastures on the same soil types

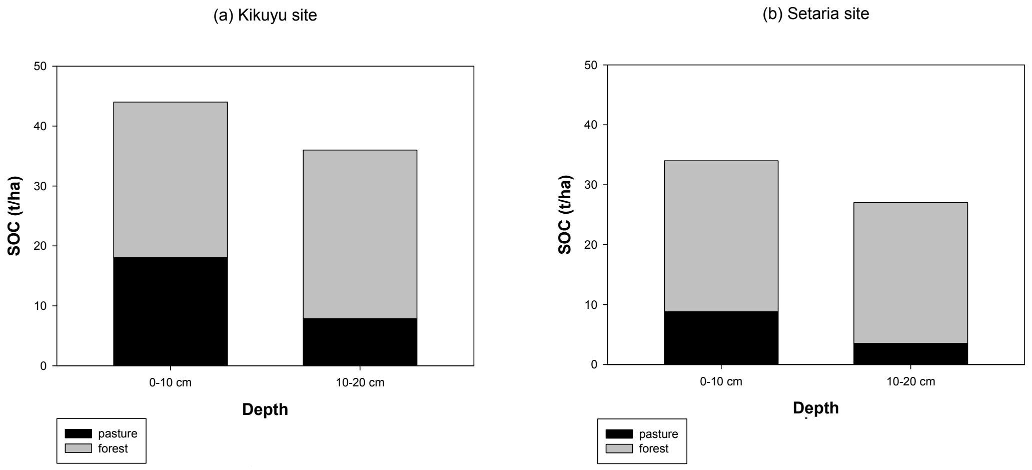

Figure 2. Total SOC stocks and contribution from the original forest (grey) and subsequent pasture (black) to the total soil carbon storage under: (a) a kikuyu; and (b) a setaria pasture.

and environmental conditions highlights the wide variations which can occur under apparently similar situations. It appears that improvement in soil fertility and management practices can have marked influences on storage of SOC. While our results are preliminary, they do indicate that SOC stocks under pastures with different fertiliser regimes can vary by as much as 20 t/ha C. It seems that improving nutritional management of pastures can not only increase the productivity of pasture land but also store more carbon in the soil. Currently, many coastal soils are marginal in terms of soil P status and more widespread use of P fertiliser on pastures should have the combined benefits of increased pasture productivity and increased soil carbon stored – a win-win option as pointed out by Fisher *et al.* (2007).

Other site differences which might account for the SOC differences are pasture type and mean temperatures. There was also likely to be an elevation effect as Ferrosols of this region are mostly located at higher elevations, where environmental temperatures are lower. Given the limited nature of the current project, these comments are speculative and no definite conclusion can be drawn from the results.

Additional research is needed to further quantify the effects of pasture types and pasture management on soil carbon storage in different soil types, under a range of topography and rainfall conditions. A better planned, more systematic and more intensive sampling schedule is needed to delineate the influence of the different factors on soil carbon stocks. Use of a corer with greater diameter would remove concerns (expressed by reviewers) about accuracy of our assessments of bulk density. Depth of sampling should be increased to at least 1 m to fully quantify the impact of pasture type and pasture management on SOC storage. Nearly half of the soil C stored under a 6-year-old *Andropogon gayanus* pasture (237 t/ha C) was found in the 40–100 cm deep soil layer (Fisher *et al.* 2004). Sampling to at least 30 cm is required to comply with the Kyoto protocol for soil carbon stock accounting. Research should also be carried out on the soil carbon storage capacity of some of the deep-rooting African grass species, *e.g.* some of the *Brachiaria* spp. (Fisher *et al.* 2007) under Australian coastal conditions.

Conclusions

This preliminary investigation has indicated that on the mid-north coast of NSW, Australia, soil organic carbon stored under introduced perennial pastures can potentially be as great as soil carbon stores under native forests. The wide variation in SOC levels under both forests and pastures indicates that many other factors may influence storage levels, *e.g.* soil type, elevation, fertiliser strategies and pasture management. Further research is needed to elucidate the impact of these factors on SOC levels in soils in the region.

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