Soil carbon and soil nitrogen changes after clearing of mulga vegetation

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Abstract

Mulga (*Acacia aneura*) dominated vegetation originally occupied 11.2 million hectares in Queensland, of which 12% has been cleared. Clearing of mulga vegetation, and altered land use for a period of 20 years has caused a significant decline in soil carbon (C) and nitrogen (N) at the study site in southern Queensland.

Soil C in the top 0.05 m of soil declined by 31% and 35% under buffel pasture and cropping respectively, while in the top 0.30 m depths soil C stocks declined by 2.4 and 4.7 t/ha respectively. Light fraction carbon, a reactive (labile) component of organic carbon, comprises about 19% of the total soil C under the mulga vegetation. After 20 years of changed land use (both pasture and cropping) more than half of the carbon present in this 'pool' has disappeared. Losses of soil N exceeded those of soil C for both cropping and pasture land use, resulting in higher C:N ratios in soil under pasture and cropping compared to soil under mulga. These results confirm a decline in soil fertility in mulga soils after clearing and have implications for the long-term sustainability of the cleared lands. Based on these results and given current tree clearing rates, loss of soil C due to clearing in the Mulga Lands of Queensland results in emissions to the atmosphere of approximately 1.4 Mt CO_2-equivalents per year.

Key Words

Soil C, soil N, light fraction carbon, organic matter quality, soil fertility, greenhouse gas emissions.

Introduction

Mulga (*Acacia aneura*) is a significant Australian vegetation community, although estimates of its areal extent are complicated by its diversity in structural form – from sparse shrubland to open-forest – and its wide range of associated ground flora. Johnson and Burrows (1994) estimated the area of mulga to be 150 million hectares (Mha) or 20% of the Australian continent. The Mulga Lands Bioregion (Thackaway and Cresswell 1995) includes only a proportion of the mulga communities. In Figure 1, the distribution of approximately 100Mha of mulga vegetation is illustrated. In Queensland, about 12% of the original 11.2 Mha of mulga vegetation had been cleared by 1999 (Wilson *et al*. 2002). Between 1997 and 1999, remnant mulga vegetation in Queensland was cleared at an annual rate of about 35,000 ha (Wilson *et al*. 2002), while the clearing rate in the Mulga Lands Bioregion (Queensland only) was about 85,000 ha per year (Department of Natural Resources and Mines 2000). By 2001, the clearing rate for the Bioregion had increased to 157,950 ha per year (Department of Natural Resources- and Mines 2003). For some time, there has been concern about the sustainability of cleared mulga lands because of their occurrence in arid to semi-arid environments (250-500 mm rainfall, often exceeding 30% annual rainfall variability) and their fragile soils that are comparably low in soil organic matter and plant available phosphorus (Condon *et al*. 1969).

Soil organic matter has a variety of important functions in soils; for example it acts as a reservoir of nutrients (principally N, P and S) and improves soil structure, infiltration and water holding capacity. Because of the complex nature and diverse composition of soil organic matter, organic carbon is used as its analytical measure. In the absence of inorganic carbon components such as carbonate, soil organic C may be referred to simply as 'soil C'. Of the diagnostic tests that may be used to determine the N status of a soil, total N provides an indication of the soils long-term N-supplying capacity (Strong and Mason 1999).

Several studies report losses in soil C and soil N following land clearing in Queensland (Dalal and Mayer 1986a, Harms and Dalal 2003); especially where the land use has been changed to cropping. In a literature review on land use change from of forest to pasture, Murty *et al*. (2002) found no significant overall change in either soil C or N, although changes in soil C at individual sites ranged from -50% to +160%. These findings showed a high variability in soil C stocks both within soil landscapes and following land use change. Hence, ecosystems may lose or gain C, depending on soil type, pasture

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management (grazing intensity), plant residue retention or removal, and fertiliser applications (Fearnside and Barbosa 1998). Since most mulga soils cleared for pasture do not receive fertiliser and nutrients are removed continually in animal produce, there is likely to be a loss in soil organic matter, and hence, productivity in the long term.

Changes in soil C over time represent a weighted average change of all the organic matter (OM) components. However, individual OM components may be accumulated or lost at different rates (Baldock and Skjemstad 1999). Based on resistance to decomposition, three major categories or ‘pools’ of OM have been identified: active, slow and passive (Dalal and Chan 2001). Charcoal is a very resistant form of OM that may be regarded as passive or inert in terms of its biological contribution. Active C pool OM consists mostly of plant debris and is characterised by its rapid rate of turnover in soil (*ie*. it is highly labile). It is usually separated from other OM by flotation in heavy liquids (‘light fraction organic matter’) or particle size fractionation (‘particulate organic matter’) (Baldock & Skjemstad 1999). In this study, the carbon content of light fraction OM has been used as an indicator of organic matter quality, and hence soil quality (Gregorich and Janzen 1996).

Materials and Methods

The study site

The study site is located on the ‘Mulga View’ property near St George (27°59’S, 148°33’E), southern Queensland (Figure 1). The soil type is a Red Kandosol (Isbell 2002), Rhodic Paleustalf (Soil Survey Staff 1998) or a Profondic Lixisol (FAO 1998) with a clay content of 12% and soil pH of 7.0 in the surface layer, changing gradually with depth to 23% clay and pH 6.0 at in the subsoil (0.9-1.2 m) (Table 1). Mean annual temperature at St George is 20°C and mean annual rainfall and pan evaporation are 516 mm and 1954 mm, respectively.

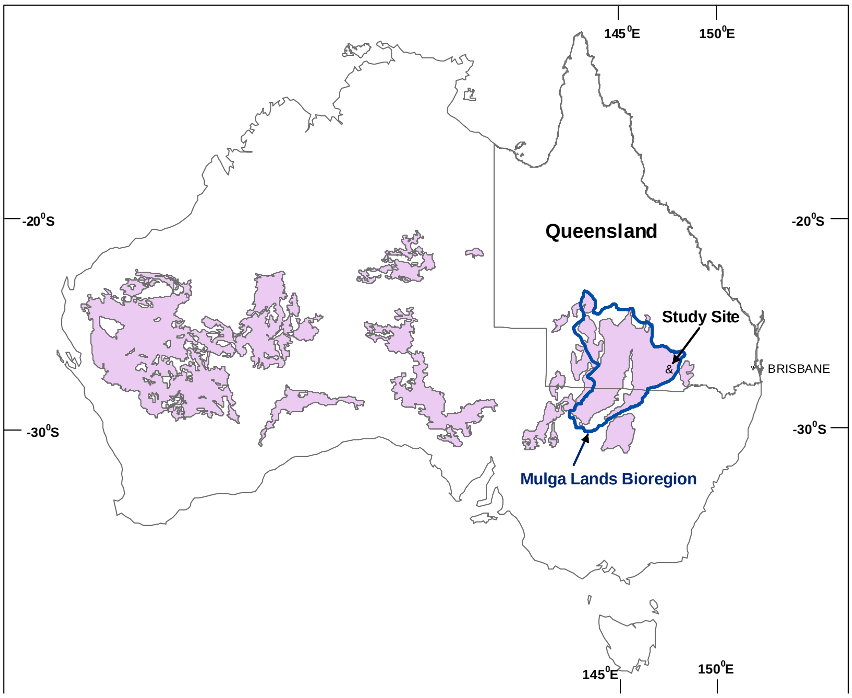

Figure 1. The location of the study site in southern Queensland and the distribution of mulga (*Acacia aneura*) woodland and open-forest in Australia. (Sources: Geoscience Australia 2003, Queensland Herbarium 2003)

Table 1. Soil characteristics at the study site.

Soil depth (m)	Soil pH (1:5 H_2O)	Sand (%)	Silt (%)	Clay (%)
0-0.1	7.0	81.7	5.9	12.4
0.1-0.3	6.5	79.1	5.1	15.8
0.3-0.6	6.5	78.2	3.4	18.4
0.6-0.9	6.0	75.1	3.4	21.5
0.9-1.2	6.0	73.0	4.1	22.9

The whole site was under mulga (*Acacia aneura*) vegetation for an unknown period prior to clearing in 1980. A portion of the cleared area was ploughed and sown to buffel grass (*Cenchrus ciliaris*) pasture and an adjoining portion was ploughed and sown to wheat (*Triticum aestivum*). The pasture area has been grazed (with varying intensity) by cattle while the cropping area has grown mostly wheat but also a couple of crops of sorghum. The cereal crops have usually received 20 kg/ha of monoammonium phosphate but no other fertilisers, while pastures have not received any fertilisers. The average wheat and sorghum yields have been about 0.8 t/ha (Bruce Scriven, personal communication). The uncleared mulga area carries a high-density mulga open-forest, with an estimated aboveground biomass of 50 t C/ha. The presence of charcoal in the soil indicates that occasional fires must have swept through the forest in the past, although no records exist of historical or recent fires.

Soil sampling

Soil samples were collected in November 2001 from the mulga and the adjoining pasture and cropping areas (located about 200 m apart). Representative soil samples were taken from each area by sampling a 50 m by 50 m area on a 10 m grid. The samples were taken at 0-0.05 m, 0.05-0.1 m, 0.1-0.2 m, 0.2-0.3 m, 0.3-0.6 m, and 0.6-1.0 m depths by a hydraulically operated sampler with a 50 mm diameter steel tube. Five samples, each from 0-0.05 m, 0.05-0.1 m, 0.1-0.2 m, and 0.2-.0.3 m depths, and three samples, each from 0.3-0.6 m and 0.6-1.0 m depths, were combined to obtain composite samples. At each site, five composite samples were obtained for each depth increment. The samples were sealed in plastic bags and stored at 4°C until further analysis. Additional soil sampling was done to obtain intact soil cores for bulk density measurements.

Analytical techniques

Total C concentrations in the fine-ground soil (<0.25 mm) samples were determined by dry-combustion with a LECO CNS-2000 analyser (LECO Corporation, MI, USA). Prior to LECO analyses, samples were checked with HCl for the presence of carbonate. As no carbonate was detected in any of the soil samples, the quantity of total C determined is equivalent to total organic C. Light fraction organic matter was extracted by density fractionation using sodium polytungstate solution (1.6 Mg/m^3 density) based on the method of Golchin *et al.* (1994) and its C concentration determined with the LECO analyser. Total N concentrations were determined using the procedure described by Krull and Skjemstad (2003). Briefly, fine ground soil samples were combusted and the emitted N_2 gas separated by gas chromatography and analysed for total N on a 20-20 Europa Scientific Automated Nitrogen Carbon Analysis-Mass Spectrometer (ANCA-MS). Because of low concentrations of total N in mulga soils, this method for total N determination is considered more accurate than 'LECO analysis'.

Statistical analysis

Treatment effects were assessed using an Analysis of Variance (ANOVA) in Genstat 6.1 (Payne 2002). Mulga, buffel pasture and cropping plots were the treatment plots and depth increments the sub-plots in a split-plot design for soil samples. Treatment means were compared using the least significant difference (lsd) test at $P < 0.05$.

Results and Discussion

The concentration of soil C under mulga vegetation varied from 0.96% in the top 0.05 m to 0.17% in the 0.6-1.0 m depth (Table 2). Under buffel pasture, organic C concentration was significantly lower than that under mulga in the top 0.05 m depth only. The soil under cropping had lower organic C concentration than that under mulga down to 0.3 m depth. The soil under cropping had similar organic C concentration to that under pasture except in the 0.1-0.2 m depths; the former had lower concentrations than the latter in this layer.

Table 2. Total soil C concentration under mulga, pasture and cropping.

Soil depth (m)	Soil C concentration (%) Mulga	Pasture	Cropping	lsd ($P<0.05$)
0-0.05	0.96	0.67	0.62	0.21
0.05-0.1	0.69	0.64	0.56	0.12
0.1-0.2	0.51	0.52	0.44	0.06
0.2-0.3	0.44	0.39	0.37	0.04
0.3-0.6	0.27	0.27	0.26	ns
0.6-1.0	0.17	0.18	0.18	ns

Pasture and cropping management systems tend to compact the soil, and at this site, soil bulk density was significantly higher in the top 0.3 m (Figure 2). For this reason, it is important to consider changes in soil C stocks (soil C concentration x bulk density x soil depth) in terms of equivalent soil mass. This can be done simply by considering the soil depth under mulga vegetation as the 'standard depth' and adjusting the 'soil depths' under pasture and cropping to represent equivalent soil masses.

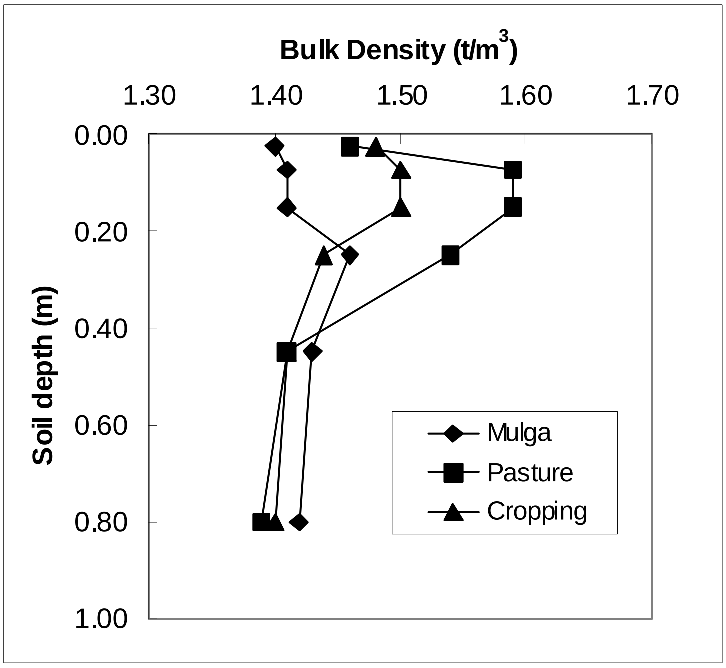

Figure 2. Soil bulk density under different land uses.

Table 3 shows the quantities of soil C under the different land uses, adjusted for bulk density differences. The amounts of soil C in the top 0.05 m were 6.69, 4.60, and 4.35 t/ha under mulga, pasture and cropping, respectively. Compared to soil C stocks under mulga, there was a decrease in soil C of 31% and 35% under pasture and cropping, respectively. In the top 0-0.3 m, land use change from mulga to pasture led to a decline in soil C by 2.4 t/ha (-10%), while the conversion from mulga to cropping led to a decrease in soil C of 4.7 t/ha (-19%). The total amounts of C in the top 1 m soil depth were 46.0, 44.4, and 42.4 t/ha under mulga, pasture and cropping, respectively.

Table 3. Cumulative quantities of soil C under mulga, pasture and cropping. (Soil C quantities under pasture and cropping have been adjusted for bulk density differences; soil depth under mulga is the 'standard' soil depth.)

'standardised' soil depth(m)	Cumulative soil C (t/ha) Mulga	Pasture	Cropping	lsd ($P<0.05$) ns = not significant
0.05	6.69	4.61	4.35	0.84
0.10	11.52	9.21	8.32	1.24
0.20	18.69	16.59	14.89	1.61
0.30	25.08	22.66	20.35	2.25
0.60	36.49	34.28	31.92	ns
1.00	46.04	44.35	42.42	ns

The 28% decrease in soil C in the top 0.10 m depth after 20 years of cropping is within the range of values (19-45%) reported by Dalal and Mayer (1986a) for a number of southern Queensland soils converted from native vegetation to cereal cropping. Similarly, Harms and Dalal (2003) reported an average decrease of 24% in soil C in the top 0.10 m at 11 cropping sites in central and southern Queensland with an average clearing age of 14 years. Of the two mulga sites included in the 2003 report, one site recorded significant decreases of 13% and 9% for cropping and pasture respectively, while the other recorded a significant decrease (11%) for pasture, with the cropping site showing no significant change. A variable response in soil C stocks after land use change from forest to cropping was also reported by Murty *et al*. (2002) who in a review of the literature, found an average loss in soil C of 22± 4% (for 33 studies where appropriate corrections to bulk density had been made). It is likely that most of the C loss occurred in the first 5-10 years of cropping, since Dalal and Mayer (1986b) found little change in soil C density after 10 years of cropping in a Red Kandosol in southern Queensland.

Light fraction carbon comprises 18.8% of the total soil C in the top 0.05 m. After 20 years cropping and pasture, this has decreased to 9.6% and 8.7% respectively (Table 4).

Table 4. Percentage of soil C as light fraction carbon (LFC) under mulga, pasture and cropping.

Soil depth (m)	LFC (% of total soil C) Mulga	Pasture	Cropping	lsd (P<0.05)
0-0.05	18.8	8.7	9.6	2.5
0.05-0.1	17.0	7.6	9.3	2.0
0.1-0.2	15.7	7.7	8.1	2.7
0.2-0.3	15.8	7.6	8.1	4.4
0.3-0.6	15.5	7.4	8.0	3.5
0.6-1.0	15.9	7.2	7.4	7.1

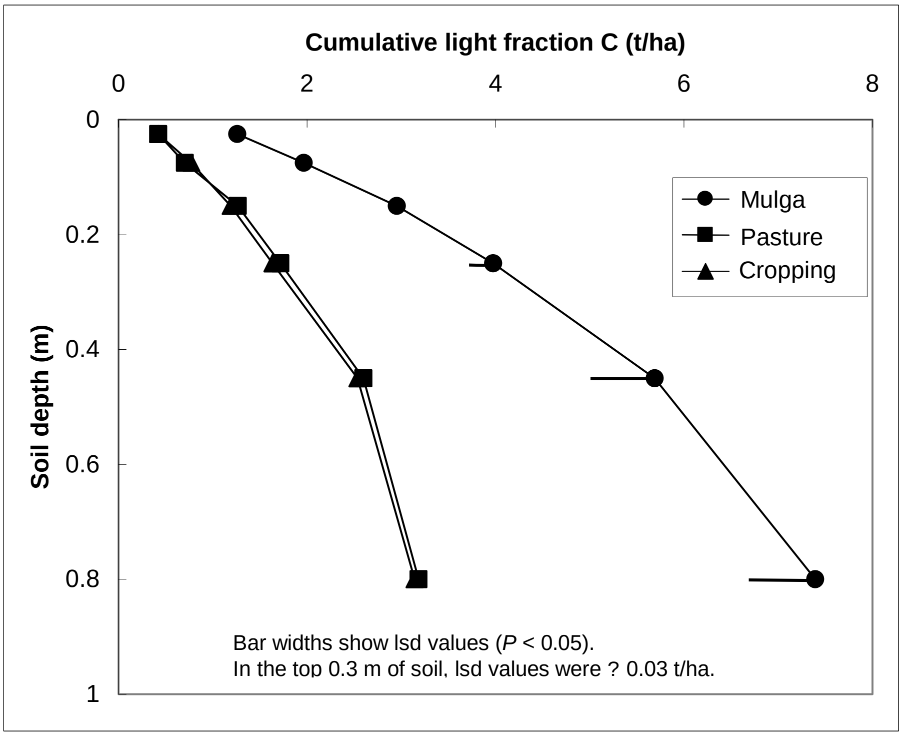

Figure 3. Cumulative light fraction carbon (LFC) in the soil under different land uses. (adjusted for bulk density differences)

When cumulative quantities of light fraction C are considered (Figure 3), it can be seen that under both pasture and cropping, light fraction C declined significantly throughout the full 1.0 m soil profile. The percentage loss is fairly consistent throughout the soil profile, ranging from 67% for both cropping and pasture in the top 0.05 m depths to 56% for cropping and 54% for pasture in the top 0.60 m depths.

Percentage losses of light fraction C far exceed those of total soil C, which were significant only in the top 0.30 m depths (Table 3). This confirms earlier studies that found light fraction C to be a labile component of soil organic matter (Dalal and Mayer 1986c; Christensen 1992; Gregorich *et al.* 1995; Gregorich and Janzen 1996; Dalal and Chan 2001). Declines in light fraction C of this magnitude will clearly result in a reduction of organic matter quality (Gregorich and Janzen 1996), and hence soil quality and soil fertility and biomass productivity.

Land use change also caused losses of soil nitrogen (N). Cumulative stocks of total soil N were significantly lower in the top 0.30 m depths for both pasture and cropping when compared to soil under mulga (Table 5). For example the decline in soil N under cropping in the top 0.10 m layer was 34% compared to 28% for soil C. Because soil N losses exceed soil C losses, the C:N ratios of the organic matter in both the pasture and cropping soils have increased compared to the mulga soil. C:N ratios of organic matter provide an indication of N mineralisation and immobilisation in soil (Campbell 1978). An increase in the C:N ratio means that the remaining organic matter would mineralise N less readily than previously. For plant nutrition, N is required in a mineralised form, predominantly nitrate (NO_3^-) and ammonium (NH_4^+). Fertility loss at sites such as this (exemplified by a reduced rate of N-mineralisation) may be disproportionately greater than indicated by the loss of total soil N alone (Dalal and Mayer 1986d).

Table 5. Cumulative total soil N under mulga, pasture and cropping. (adjusted for bulk density differences between sampling sites)

'standardised' soil depth (m)	Cumulative total soil N (kg/ha) Mulga	Pasture	Cropping	lsd (P<0.05) ns - not significant
0.05	518	369	298	50
0.10	866	680	574	89
0.20	1417	1200	1057	154
0.30	1856	1664	1490	197
0.60	2839	2703	2528	308
1.00	3810	3725	3541	ns

Mulga soils are susceptible to windsheeting, watersheeting, rilling and gullying (Walker and Fogarty 1986). As the quantity of organic matter in these soils is already low and concentrated in the surface layers (Table 2), an important management objective is to ensure that soil erosion is minimised. Measurements of wind erosion over 30 years indicate that soil in the mulga lands may have been lost at a rate of 0.75-1.25 mm/year (Miles and McTainsh, 1994). Mills (1986) suggests that land degradation due to erosion in mulga lands can be minimized by reducing grazing pressure (particularly during drought and post-drought periods), controlling the grazing pressure exerted by native and feral animals, and using fire in good seasons to reduce populations of woody weeds.

Besides causing a decline in soil quality, loss of soil C also leads to increased emissions of CO_2 to the atmosphere, potentially contributing to the enhanced greenhouse effect (Houghton 1999; Dalal and Chan 2001). Simple extrapolation of the soil C loss reported in this study (2.4 t soil C/ha in the top 0.30 m) to the total area of woody vegetation currently being cleared in the Mulga Lands Bioregion (157,950 ha/yr, 2001 figures, as cited in the introduction to this paper) indicates that clearing in the Mulga Lands Bioregion in Queensland results in emissions to the atmosphere of approximately 1.4 Mt CO_2-equivalents per year. However, the net contribution of mulga clearing to greenhouse gas budgets needs to be assessed in the context of overall changes that may be occurring in the structure of mulga communities, particularly in relation to changed fire regimes (Hodgkinson 2002).

Conclusions

Both the quantity and quality of soil C declined when mulga vegetation was cleared and used for pasture and cropping over a period of 20 years. Light fraction C declined by more than 50% for both cropping and pasture throughout the 1.0 m soil profile investigated. Soil N losses exceeded soil C losses for both pasture and cropping in the top 0.30 m depths. Therefore, there is immediate concern for the sustainable use of mulga lands cleared for pasture and cropping with a continuing decline in soil fertility and potential biomass productivity. Understanding the C and N dynamics in these mulga lands is essential for the development of soundly researched management strategies that will ensure their long-term sustainable use.

Acknowledgements

We thank Ian Hill of 'Mulga View', St George, for his permission to access the site; Bruce Scriven for providing the past history of the site; Evelyn Krull for the mass-spectrography; Rory Whitehead, Christine McCallum and NRME Analytical Services Staff for their technical assistance; and Kamal Sangha for statistical analysis.

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