THE SUSTAINABILITY OF MULGA LANDS AFTER CLEARING – WHAT DO CHANGES IN SOIL CARBON AND SOIL NITROGEN SHOW?

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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 soil nitrogen (N) at one site in southern Queensland. Soil C in the top 0.05 m of soil declined by 28% and 35% under buffel pasture and cropping respectively, while in the top 0.3 m depth soil C stocks declined by 2.7 and 5.0 t/ha respectively. 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.

Additional Keywords: soil C loss, soil N loss, C/N ratio, soil fertility decline, greenhouse gas emissions.

Introduction

Mulga (*Acacia aneura*) is an important Australian vegetation community, although estimates of its areal extent are complicated by its diversity in structural form – from a 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 has been cleared (Wilson *et al*. 2002). Between 1997 and 1999, mulga vegetation in Queensland was cleared at an annual rate of about 35,000 ha (Wilson *et al*. 2002), while the clearing rate for the Mulga Lands Bioregion as a whole (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 soil’s long-term N-supplying capacity (Strong and Mason 1999) and therefore has wide application.

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 and N stocks both within soil landscapes and following land use change. Hence, ecosystems may lose or gain these nutrients, depending on soil type, pasture 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 any fertiliser despite the continual removal of nutrients in the animal produce, there is likely to be a loss in soil organic matter, and hence, productivity in the long term.

Materials and Methods

The study site

The study site is located on the ‘Mulga View’ property near St George ($27^0$59’S, $148^0$33’E), in southern Queensland (Figure 1). Here the mulga open-forest has attained high structural development with approximately 800 stems/ha at heights of 10-15 m, an above ground biomass of 80 t/ha, and a foliage projective cover of about

40%. The red, sandy soil is typical of 'mulga soil' in Australia, and is classified as a Kandosol (Isbell 1996) or a Paleustalf (Soil Survey Staff 1998). The soil reaction is neutral to slightly acid, and the clay content increases with depth from about 12% at the surface to 23% in the subsoil (0.9-1.2 m) (Table 1). The mean annual temperature at St George is 21^0C and mean annual rainfall and pan evaporation are 517 mm and 1954 mm, respectively.

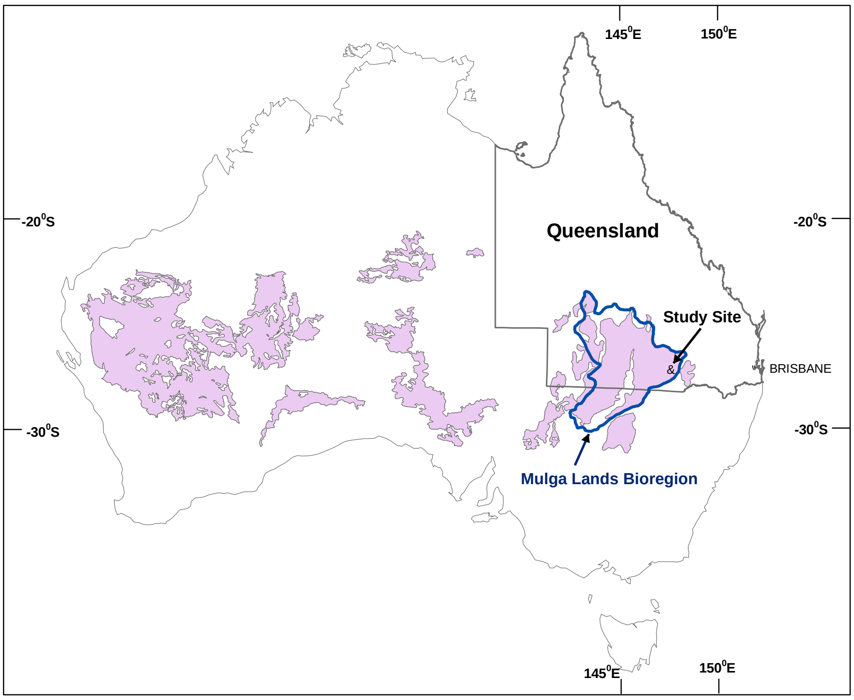

Figure 1. Map showing the study site and the distribution of mulga (*Acacia aneura*) woodland and open-forest in Australia. (Sources: Geoscience Australia 2003, Queensland Herbarium 2003)

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 mulga (*Acacia aneura*) open-forest 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 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. 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. For each plot, five composite samples were obtained for each depth increment, sealed in plastic bags in the field and stored at 4^0C 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. 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 of total N determination was considered to be more accurate than 'LECO analysis'.

Statistical analysis
Treatment effects were assessed using the Analysis of Variance (ANOVA) in Genstat 6.1 (Payne 2002). Mulga, buffel pasture and cropping plots were the main treatment plots and depths 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, soil C concentration was significantly lower than that under mulga in the top 0.05 m depth only. The soil under cropping had lower C concentrations than soil under mulga down to 0.3 m depth. The soil under cropping had similar C concentrations to soil under pasture except in the 0.1-0.2 m depths; the former had lower concentrations than the latter in this layer.

Table 2. Soil C concentrations under mulga, pasture and cropping

Soil depth (m)	Soil C concentration (%)			lsd ($P<0.05$) ns = not significant
	Mulga	Pasture	Cropping	
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.

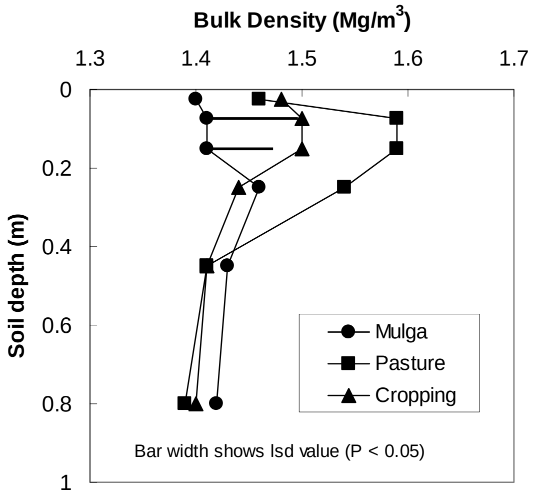

Figure 2. Soil bulk density under different land uses

Table 3 shows the cumulative stocks 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 6.72, 4.81, and 4.39 t/ha under mulga, pasture and cropping, respectively. Compared to soil C stocks under mulga, there was a decrease in soil C of 28% 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 2.65 t/ha, while the conversion from mulga to cropping led to a decrease in soil C of 5.0 t/ha. The total amounts of C in the top 1 m soil depth were 46.4, 44.4, and 42.3 t/ha under mulga, pasture and cropping, respectively.

Table 3. Cumulative quantities of soil carbon under mulga, pasture and cropping

(Quantities have been adjusted for bulk density differences; soil depth under mulga is the 'standard' soil depth.

Cumulative 'standardised' soil depth (m)	Soil C (t/ha)			lsd (P<0.05)
	Mulga	Pasture	Cropping	ns = not significant
0.05	6.72	4.81	4.39	0.84
0.10	11.59	9.25	8.34	1.24
0.20	18.77	16.42	14.65	1.61
0.30	25.20	22.55	20.20	2.25
0.60	36.78	34.97	32.57	ns
1.00	46.44	44.42	42.26	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.

The concentration of total soil N under mulga vegetation varied from 0.074% in the top 0.05 m to 0.017% in the 0.6-1.0 m depth (Table 4). Under buffel pasture, total N concentration was significantly lower than that under mulga in the top 0.05 m depth only. The soil under cropping had significantly lower total N concentrations than soil under mulga down to 0.3 m depth (except for the 0.1-0.2 m depths). The soil under cropping had similar total N concentrations to that under pasture

Table 4. Total soil N concentration under mulga, pasture and cropping

Soil depth (m)	Soil N concentration (%)			lsd (P<0.05)
	Mulga	Pasture	Cropping	ns = not significant
0-0.05	0.074	0.053	0.044	0.010
0.05-0.1	0.050	0.043	0.036	0.009
0.1-0.2	0.037	0.036	0.035	ns
0.2-0.3	0.033	0.031	0.027	0.004
0.3-0.6	0.022	0.024	0.024	ns
0.6-1.0	0.017	0.018	0.017	ns

Cumulative stocks of total soil N were significantly lower in the top 0.30 m depths for both cropping and pasture when compared to soil under mulga (Table 5). The declines in soil N are of a greater magnitude compared to soil C losses (Table 3). For example the decline in soil N under cropping in the top 0.10 m layer was 36% 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 1986c).

Table 5. Cumulative total soil nitrogen in profile under mulga, pasture and cropping
(adjusted for bulk density differences between sampling sites: ns - not significant at $P<0.05$)

Cumulative 'standardised' soil depth (m)	Cumulative total soil N (kg/ha)			lsd ($P<0.05$) ns = not significant
	Mulga	Pasture	Cropping	
0-0.05	525	371	308	50
0.05-0.1	878	674	560	89
0.1-0.2	1400	1182	1053	154
0.2-0.3	1882	1643	1452	197
0.3-0.6	2826	2689	2509	308
0.6-1.0	3792	3723	3555	ns

Mulga soils are susceptible to windsheeting, watersheeting, rilling and gullying (Walker and Fogarty 1986). Because the quantity of organic matter in these soils is already low and concentrated in the surface layers (Tables 2 and 4), it is vitally important that soil erosion is minimised. According to Mills (1986), land degradation in mulga lands due to soil erosion 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 the populations of woody weeds.

Besides causing a decline in soil fertility, loss of soil C also leads to increased CO_2 emission into the atmosphere, contributing to the enhanced greenhouse effect (Houghton 1999; Dalal and Chan 2001). At least 1.3 Mha of mulga vegetation has been cleared in Queensland since European settlement (Wilson *et al*., 2002). Assuming a loss of soil organic C of 2.65 t C/ha in the top 0.30 m of soil, as recorded in this study, for the entire 1.3 Mha cleared, the total CO_2 emission from mulga lands in Queensland would be about 13 Mt CO_2-equivalents in the 20-year period following mulga clearing. 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 mulga communities, particularly in relation to changed fire regimes (Hodgkinson 2002).

Conclusions

The quantity of soil C and soil N declined when mulga vegetation was cleared and used for pasture and cropping over a period of 20 years. Soil N losses exceeded soil C losses for both pasture and cropping in the top 0.30 m depths, thereby reducing the capacity of the soil organic matter to supply mineralised-N for plant use. 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.

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