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Restoration of soil fertility of degraded vertisols using a pasture including a native grass (*Astrebla lappacea*)

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Abstract

Declines in soil physical, chemical and biological fertility have occurred in the vertisols in north-western New South Wales after conversion of natural pasture land to monoculture wheat cropping. The effectiveness of a pasture phase, including Mitchell grass (*Astrebla lappacea*), in restoring the fertility of degraded cropped soils in the semi-arid subtropical environment was evaluated on 2 different vertisols. For a non-sodic brown clay with higher soil organic carbon level, significant increase in soil organic carbon was detected 2 years after establishment of the pasture and this was accompanied by significant increases in available nitrogen and microbial biomass and improvement in soil structural stability. However, these changes were detected only in the top 5 cm layer even 4 years after the establishment of the pasture. Improvement in subsoil structure as indicated by a nearly 4-fold increase in sorptivity was also observed due to the creation of burrows formed by the return of native earthworms when the cropped soil was returned to pasture.

However, no change in organic carbon level and therefore all associated improvements in soil fertility were detectable in a sodic grey clay with low organic carbon level even 4 years after establishment of the pasture.

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Introduction

In north-western New South Wales around Walgett, rapid conversion of natural pasture land to wheat cropping areas has taken place in the last 20 years (e.g. the area of dryland wheat in the Walgett shire more than tripled between 1974 and 1984). The dominant soil types of the region are vertisols. The natural vegetation is pasture dominated by Mitchell grass (*Astrebla lappacea*). Under the present cropping system, which is largely wheat monoculture under continuous conventional cultivation with no fertiliser inputs, declines in soil fertility in terms of reduction in soil organic carbon, total nitrogen, available phosphorus, soil structural stability and biological activity have occurred (Chan *et al.* 1988; 1995). Similar declines in soil fertility have also been reported in southern Queensland, resulting in reduced wheat yield and grain protein levels (Dalal *et al.* 1991). The current farming system of continuous cropping is clearly not sustainable and there is a widespread recognition of the need for research into the development of sustainable systems for semi-arid vertisols (e.g. Clarke and Russell 1977; Hubble 1984; Chan *et al.* 1988).

The beneficial role of a pasture phase within a traditional ley/cropping system for maintaining soil organic carbon (OC) and soil structure is well established on other soil types in the higher rainfall areas of the Australian wheat belt (Greenland 1971). The possible benefits of incorporating a pasture phase into the cropping systems in the Walgett environment have been suggested by Chan *et al.* (1988), who reported significantly higher soil organic carbon, total nitrogen, water-stable aggregation and biological activity in the natural pasture soils compared with the adjacent cropped soils. Dalal *et al.* (1991) suggested a grass-legume pasture as a useful option for restoring nitrogen status of cropping soils in the low and unreliable rainfall areas of southern Queensland. Pastures have been effective in regenerating soil structure of degraded cropped vertisols in Texas (Puentes and Wilding 1990).

To date, incorporation of a pasture phase into the cropping system has not been a common practice in north-western New South Wales, partly because of the lack of suitable species and reliable sowing methods. Recent research has overcome some of these inadequacies (Bellotti *et al.* 1991). However, the effectiveness of a native pasture to restore chemical and physical fertility of degraded cropped vertisols in the Walgett environment needs to be demonstrated. Furthermore, the optimal duration of the pasture phase needs to be determined.

This paper reports results of a field experiment designed to evaluate the effectiveness of native Mitchell grass in ameliorating degraded vertisols within a cropping system in the semi-arid subtropics. The effect on soil properties of converting degraded cropped land back to native pasture was monitored over a 4-year period. In the same experiment, areas of original native pasture were also cropped in order to monitor the processes of degradation of soil fertility following cropping.

Materials and methods

Site description

The experiment started in 1989. Two sites near Walgett (30°01′ S, 148°07′ E), NSW were selected to represent the major vertisol soil types of the region (Stannard and Kelly 1977; Chan 1989), one on grey clay (GC) (Ug 5.1, Northcote 1979) and the other on brown clay (BC) (Ug 5.2). The climate is semi-arid subtropical with a mean annual rainfall of 474 mm, which is summer-dominant and highly variable from year to year. The mean daily maximum temperature is 23.8°C and the mean daily minimum temperature is 10.5°C.

At both sites, adjacent to the cropped areas, there were natural pasture areas that had never been cultivated. The grey clay site had been cropped for 22 years and the adjacent natural pasture was degraded, consisting of a few Mitchell grass tussocks, hard roly poly (*Bassia quinquecuspis*), soft roly poly (*Salsola kali*) and burr medic (*Medicago polymorpha*). At the brown clay site, the wheat paddock had been cropped for 12 years and the natural pasture consisted of Mitchell grass tussocks, burr medic, cutleaf medic (*Medicago laciniata*) and barley grass (*Hordeum leporinum*).

Table 1 shows the basic physical and chemical properties of the soils under cropping as well as pasture before the imposition of the treatments. Under natural pasture, the grey clay was sodic (exchangeable sodium percentage =10% at 0–10 cm depth) and had much lower OC level but higher pH than the brown clay (exchangeable sodium percentage = 4%). Both cropped soils had significantly lower OC but higher pH than the corresponding pasture soils.

Table 1. Initial soil properties (0–10 cm) of the brown clay and grey clay sites near Walgett, New South Wales.

Sites	pH	EC	OC	Exchangeable cations				Carbonate[1]
				Na	K	Ca	Mg	
		(dS/m)	(g/kg)	(cmol(+)/kg)				(g/kg)
Brown clay								
Cropped	7.27	0.158	7.9	1.06	1.64	20.60	11.91	2.0
Pasture	6.87	0.171	11.4	1.54	1.70	19.98	12.10	1.5
Grey clay								
Cropped	8.01	0.229	5.0	4.37	1.57	24.70	12.26	8.3
Pasture	7.80	0.193	6.3	3.02	1.56	25.41	13.11	5.8
LSD (P<0.05)								
Soil	0.16	0.032	1.2	0.76	ns	1.40	ns	0.7
Landuse	0.16	ns	1.2	ns	ns	ns	ns	1.0
Soil × landuse	ns	ns	ns	1.06	ns	ns	ns	1.3

[1] Assume all as calcium carbonate.

Experimental design

At each site, 2 blocks each made up of both cropped and pasture areas were fenced off. In each block, on the previously cropped area, plots (6 m x 30 m) were sown back to pasture (CP treatment), while other plots were continuously cropped (CC treatment). On the natural pasture area, some plots were converted to continuous wheat cropping (PC treatment), while others were maintained as pasture plots (treatment PP). All treatments were randomised and replicated 3 times in each block.

Establishment of pasture on previously cropped areas. The sown pasture treatment on the old cropped area consisted of curly Mitchell grass (*Astrebla lappacea*) and barrel medic (*Medicago truncatula*, cvv. Sephi and Jemalong). The Mitchell grass was sown in the spring of 1990 and again in early 1991 with a buffel grass drum seeder. The seed was dropped on the soil surface and lightly harrowed. The sowing rate was 10 kg/ha. The barrel medic was sown in the autumn of 1989 and 1990 by hand broadcasting and then dragging a set of harrows over the plots. Twice a year, in spring and autumn, yield and composition (by weight) of individual pasture plots were measured.

Wheat cropping. Wheat was grown on the CC and PC plots every year after a short summer fallow. The wheat cultivar, Hartog, was sown in 1989. However, due to crown rot problems (*Fusarium* sp.), Sunco was sown in subsequent years. The local practice of 3 conventional cultivations using a chisel plough before sowing was followed. However, stubble was not burnt but incorporated during cultivation over summer.

Soil samplings

Soils were sampled every year at around sowing time (May–July) after all the cultivation operations in the cropping treatments had been completed. In each block at each site, all 4 treatment plots, namely CC, CP, PC and PP, were sampled. For each treatment, 3–5 subsamples (10 × 10 cm) were collected from 2 depths, 0–5 and 5–10 cm, from each of the 3 replicate plots and all subsamples from the same depth were bulked to obtain a composite sample.

The composite samples were dried at 36°C and mixed thoroughly before subdividing into 2 portions. One portion was ground to pass through a 2 mm sieve and the other was sieved through a nest of sieves to collect the 9.5–12.7 mm size aggregates.

Soil physical measurements

Soil structural stability. About 20 g air-dried aggregates (9.5–12.7 mm) were weighed and placed on top of a nest of sieves of aperture 2 mm and 250 μm, and wet-sieved for 10 minutes with a stroke length of 31 mm and a frequency of 30 strokes per minute. Amount of water-stable >2 mm and 2 mm–250 μm fractions were measured. After wet-sieving, the suspension was shaken end-over-end 10 times and the amount of <50 μm material sampled by pipetting. The percentages of water-stable size fractions >2 mm, 2–250 μm, 250–50 μm and <50 μm were calculated. Stability of the soil was also expressed as the mean weight diameter (mwd) of the water-stable aggregates (van Bavel 1950).

Hydraulic properties. Sorptivity of the soil under different treatments was measured using a disc permeameter (Perroux and White 1988) at 2 water potentials (0.1 kPa and ponded) in May 1993, after considerable rain had fallen and all the shrinkage cracks of the vertisols had disappeared. In each plot, a small area (1 m × 1 m) was selected at random and the top 0.1 m layer removed carefully using a spade. To remove any smeared layer, 2 small areas (≈0.2 m × 0.2 m) were then covered with a thin layer (≈2 mm) of quick-set Araldite^R resin. After setting, the resin was peeled off to expose the natural surface structure. Sorptivity measurements at the 2 potentials were then carried out over the 2 areas. Earthworm channels as indicated by the segmentation markings on the inside wall linings were clearly evident on some treatment plots. Where earthworm holes were clearly evident in the ponded infiltration areas, the holes were blocked off using wet clay after the initial run and sorptivity measurements repeated. The sorptivity measurements at the 2 potentials were replicated on each plot for all 4 treatments in each block.

Soil chemical measurements

These were carried out on the air-dried <2 mm subsamples.

pH, electrical conductivity and organic carbon. pH was determined in 1:5 soil:water and 1:5 soil:0.01 M $CaCl_2$ after shaking for 1 hour. Salinity level was determined by measuring electrical conductivity (EC) of the 1:5 soil:water suspension after the pH measurement, using a conductivity meter.

Soil organic carbon was determined as the difference between total and inorganic carbon. Total carbon of the soil samples was determined by the combustion method using the Leco^R carbon analyser (Nelson and Sommers 1982). Carbonate carbon was determined manometrically.

Mineralisable nitrogen. This was determined in 1993 following Keeney (1982), which involved measuring the amount of ammonium nitrogen production after incubation under waterlogged conditions.

Soil microbial biomass

Soil microbial biomass was determined only once, in July 1993, by the fumigation-extraction method following Wu *et al.* (1990).

Results and discussion

Pasture composition change and yield

In 1989, the natural pasture (PP) at the grey clay site consisted of only a few Mitchell grass tussocks and a little naturalised burr medic (Table 2). The rest of the pasture was made up of black or hard roly poly (*Bassia quinquecuspis,* 17%), Nardoo (*Marsilea drummondii,* 18%) and dead dry matter. By 1994, the roly poly component had decreased slightly while the Mitchell grass and medic components had increased markedly. At the brown clay site in 1989, the natural pasture plots (PP) contained little Mitchell grass but a lot of naturalised burr medic (43%) and annual barley grass (52%). By 1994, the Mitchell grass component had increased (from 1 to 30%) and annual grasses had declined markedly. At both sites, there was a fluctuating annual broadleaf component, mainly rape (*Brassica rapa*) and turnip weed (*Rapistrum rugosum*). The changes in composition of the natural pasture plots was probably due to the exclusion of grazing livestock.

Table 2. Changes in composition of Mitchell grass *(Astrebla lappacea)* and burr medic *(Medicago polymorpha)* (% by weight) in (a) permanent pasture (PP) and (b) resown pasture (CP) on 2 soils in 1989 and 1994.

(a) Permanent pasture (PP)		1989	1994
Brown clay	Mitchell grass	1	30
	Medic	43	30
Grey clay	Mitchell grass	5	22
	Medic	trace	60
(b) Resown pasture (CP)			
Brown clay	Mitchell grass	4	70
	Medic	1	25
Grey clay	Mitchell grass	8	40
	Medic	1	5

The pasture sown into the previously cropped area at the grey clay site (CP) showed a 4-fold increase in the Mitchell grass (8% to 40%) (Table 2) and medic (1% to 5%) components over time, and a large but fluctuating annual grass component, mostly annual phalaris (*Phalaris paradoxa*). The pasture sown into the cropped areas (CP) at the brown clay site also had large increases in Mitchell grass (4% to 70%) and medic components (1% to 25%) over time. There was always a large amount of annual grass present.

At the brown clay site, the total dry matter yield was higher from the CP plots in autumn than from the PP plots (5.5 *vs* 3.0 t/ha) but yields on both CP and PP plots in spring were similar (2.2 *vs* 2.9 t/ha). This was probably due to differences in the annual grass component. At the grey clay site, the CP plots had higher yields than the PP plots in the first 2 years (e.g. in autumn 1992, 2.5 *vs* 1.2 t/ha), but by autumn 1994, there was little difference between the treatments (2.6 *vs* 2.7 t/ha).

Changes in soil chemical properties

Soil organic carbon. All treatments at the brown clay site contained more OC than those at the grey clay site (Figures 1a and 1b). For the brown clay, no significant increase in OC in the CP soil compared with the CC soil was detected until 1992, 2 years after the pasture was sown (3 years after the commencement of the experiment, Figure 1a), when significantly higher OC was detected in the 0–5 cm layer. By the end of the fourth year (1994), OC of CP in 0–5 cm was 26.4% higher than that in CC. No significant difference was detected in the 5–10 cm layer between CP and CC even 4 years after the pasture had been sown (results not shown).

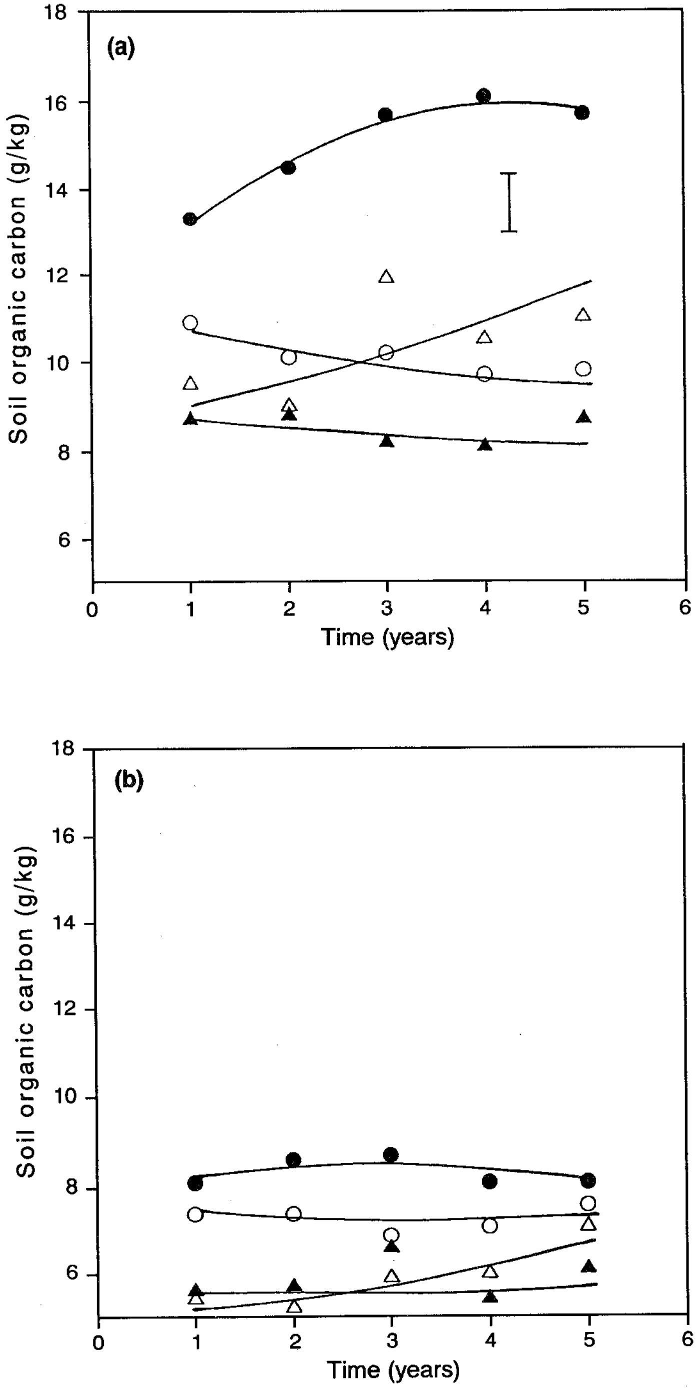

Figure 1. Changes in soil organic carbon levels with time (in years after the commencement of the experiment) in the 0–5 cm layer under different treatments for (a) brown clay (b) grey clay (pastures were sown in the first year) (●, pasture–pasture; ○, pasture–cropping; ▲, cropping–cropping; △, cropping–pasture). The vertical bars represent necessary differences between treatments for significance ($P<0.05$).

Conversion of pasture land to cropping (the PC treatment) led to large decreases in OC and the largest decrease, compared with PP, occurred in the 0–5 cm layer in the first year of cropping after conversion from pasture (Figure 1a). Changes in OC in subsequent years were small and not significantly different.

For the grey clay site, OC was similar in CP and CC treatments and no significant change was detected in the 0–5 (Figure 1b) and 5–10 cm layers of CP over the 4 years.

Nitrogen availability. After 4 years of cropping and 3 years of pasture (i.e. in 1993), significant increases in both soil organic carbon and mineralisable nitrogen were detected in the 0–5 cm layer of CP when compared with that in CC at the brown clay site (Table 3). Interestingly, while there was a 31% increase in OC, the corresponding increase in mineralisable nitrogen was much higher (58%). This suggests that, when the cropped soil was converted back to pasture land, the increase in organic matter levels may have also been associated with a change in the quality of soil organic matter which resulted in higher nitrogen availability. In contrast, the PC soil had significantly lower OC and mineralisable N than PP soil (Table 3). OC and mineralisable nitrogen levels in the 5–10 cm layer were similar for CP and CC (results not shown).

Table 3. Soil organic carbon (g/kg) and mineralisable nitrogen (mg/kg) levels in the 0–5 cm layer of both brown and grey clays under different treatments measured in 1993 near Walgett, New South Wales. CC = cropping-cropping; PC = pasture-cropping; CP = cropping-pasture; PP = pasture-pasture.

	Treatments				
	CC	PC	CP	PP	LSD (P = 0.05)
Brown clay					
OC	8.1	9.7	10.6	16.4	3.2
Min N	64	83	101	163	34
Grey clay					
OC	4.6	6.6	5.4	7.8	ns
Min N	26	41	51	83	28

At the grey clay site, there were no significant differences in OC levels in the 0–5 cm layer amongst the 4 treatments. Mineralisable nitrogen was significantly higher in the PP treatment than in the other treatments, which were all similar (Table 3).

pH. The pH of CP was similar to that for CC, and both were significantly higher than for the PP soil (Table 4). For both brown and grey clay in the 0–5 cm layer, pH of PC was significantly higher than that of PP. Examination of the individual year data for PC indicated that most of the increase in pH occurred in the first year of cropping and little change was detected in subsequent years. For the 5–10 cm layer, pH was similar for PC and PP.

Table 4. Mean (over time) pH of brown and grey clays at 2 depths under different treatments near Walgett, New South Wales. CC = cropping-cropping; PC = pasture-cropping; CP = cropping-pasture; PP = pasture-pasture.

		Treatments				
Soil type	Depth	CC	PC	CP	PP	LSD (P = 0.05)
	(cm)					
Brown clay	0–5	7.39	7.11	7.33	6.87	0.19
Grey clay		8.60	8.40	8.48	8.13	0.17
Mean		8.00	7.76	7.90	7.50	0.11
Brown clay	5–10	7.64	7.34	7.73	7.30	0.19
Grey clay		8.70	8.56	8.72	8.50	0.17
Mean		8.17	7.95	8.22	7.91	0.11

The higher pH found in the cropped soil compared with virgin pasture soil has been reported previously (Chan *et al.* 1988) and was probably due to the higher amounts of carbonate present in the 0–10 cm of the PC, CP and CC soils when compared with PP soils (Table 1), a direct result of tillage.

Exchangeable cations and electrical conductivity (EC). With the exception of K, no significant differences in exchangeable cations were found amongst the different treatments. Exchangeable K in the cultivated soils (CC and PC, mean=1.83 cmole(+)/kg) was significantly ($P<0.001$) higher than that of the pasture soils (CP and PP, mean=1.5 cmole(+)/kg).

Year-to-year fluctuations of EC were observed, probably as a reflection of seasonal conditions such as antecedent rainfall conditions prior to sampling. However, analysis of variance of mean (over time) EC results indicated significant soil, treatment and depth effects as well as a soil x treatment x depth interaction. EC values for the brown clay under different treatments were generally lower than those of the grey clay (Table 5). The significant interaction ($P<0.05$) indicates that, for the grey clay, CC had significantly higher EC in the 0–5 cm than did PP and CP (Table 5). For the brown clay, CC had significantly lower EC than did PP and CP. Therefore, conversion of the cropped soil to pasture (CP) led to an increase in EC in the case of the brown clay. It is interesting to compare the present findings with those of Dalal (1990), who reported increases in exchangeable sodium percentage but a decrease in salt concentration in the soil profile to 1.2 m as a result of cropping on a number of vertisols in southern Queensland. In our study, no significant changes in exchangeable sodium percentage were found amongst the different treatments for the 2 soils. However, the grey clay had significantly higher exchangeable sodium percentage than the brown clay (Table 1). Therefore, the effect of cropping on EC might depend on the sodicity level of the soil. Cultivation and cropping tended to increase leaching (lower EC) in a less sodic soil but decrease leaching (higher EC) for a more sodic soil. The reverse changes were observed when the cropped soils were converted to pasture.

Table 5. Mean electrical conductivity (dS/m) of soil extract (1:5 soil:water) of brown and grey clays at 2 depths under different treatments near Walgett, New South Wales. CC = cropping-cropping; PC = pasture-cropping; CP = cropping-pasture; PP = pasture-pasture.

		Treatments			
Soil type	Depth	CC	PC	CP	PP
	(cm)				
Brown clay	0–5	0.088	0.094	0.111	0.116
	5–10	0.096	0.099	0.115	0.099
Grey clay	0–5	0.175	0.163	0.158	0.153
	5–10	0.197	0.192	0.197	0.186

LSD ($P < 0.05$)
— treatment 0.006; — soil × treatment × depth 0.014.

Changes in soil physical properties

Hydraulic properties. Analysis of variance indicated significant soil, treatment and potential effects as well as a soil x treatment x potential interaction. When measured at –0.1 kPa, no significant difference in sorptivity at 10 cm depth was found amongst the different treatments for either soil (Table 6). However, under ponded conditions, marked increases in sorptivity were observed in PP and CP in the brown clay but not in the grey clay. At the brown clay site, the highest sorptivity was found in PP which was more than 10 times that of CC. A significant increase in sorptivity under ponding was also found in CP which was nearly 5 times that of CC. In contrast, sorptivity of PC was lower than those of PP and CP and not significantly different from that of CC. At the grey clay site, sorptivity was similar for the 2 different potentials and for the different treatments.

After plugging the earthworm holes, a significant reduction in sorptivity, measured under ponding, was detected in both PP and CP soils (Table 6). Therefore, presence of the earthworm channels contributed to the much higher sorptivity observed in PP and CP measured under ponded conditions in the brown clay site. For the grey clay, sorptivity was lower than for the brown clay even in PP, and no earthworm channels were detected in the measured areas. This indicates that a significant increase in the density of earthworms occurred in the brown clay but not in the grey clay when the degraded cropped areas were converted to pasture land. Results of 2 years of monitoring indicated that PP at the grey clay site had a significantly lower earthworm population than that of the brown clay site (Friend and Chan 1995).

Table 6. Sorptivity ($\text{mm/h}^{1/2}$) of the brown and grey clays at 10 cm depth under different treatments at 2 different antecedent water potentials. CC = cropping-cropping; PC = pasture-cropping; CP = cropping-pasture; PP = pasture-pasture.

	Treatments							
	CC		PC		CP		PP	
Soil type	–0.1 kPa	Ponded	–0.1 kPa	Ponded	–0.1 kPa	Ponded	–0.1 kPa	Ponded
Brown clay	9.7	22.3	10.1	46.8	13.4	104.5 (39.8)[1]	20.9	234.9 (19.6)
Grey clay	9.5	6.7	12.7	33.7	31.6	27.8	25.3	16.4

[1] Values inside brackets are sorptivity results after plugging of worm holes.

LSD ($P < 0.05$) — treatment 16.4; — soil × treatment × potential 32.8.

Evidence of improvement in subsoil structure as indicated by sorptivity results was attributed to the re-appearance of earthworm channels in the brown clay after the cropped soil was returned to pasture. Image analysis results of Puentes and Wilding (1990) also indicate increases in percentages of macroporosity and vertically oriented macropores (biopores) when vertisols were returned to pasture. They attributed these changes to enhanced shrink-swell potential and biotic activities under pasture conditions.

The sorptivity results obtained in PC in the brown clay also indicated rapid disappearance of macropores created by earthworms with a consequent reduction in ponded sorptivity. Three years after conversion of the pasture to cropping, sorptivity under ponded conditions was reduced to the level of the continuously cropped soil (CC) (Table 6).

Soil structural stability. Stability of PP soil to wetting changed significantly over the 5-year period of the experiment, probably as a result of seasonal variation. To assess the change of other treatments relative to PP, ratios of mean weight diameter (mwd) of the treatment to that of PP for the particular year ($\mathrm{mwd}_{\mathrm{other\ treatment}}/\mathrm{mwd}_{\mathrm{pp}}$) were used. For the brown clay, no improvement of water stability of CP was detected until the fourth year, when it increased to 82.7% that of PP (Figure 2). By the fifth year, it was similar to that of PP. In the case of PC, a marked decrease in stability occurred in the first season of cropping but subsequent decline was slow. For CC, no significant decline in stability was observed during the 5 years of cropping. Instead, there was some evidence suggesting a slight increase in the fifth year. Stability of the grey clay was significantly lower than that of the brown clay and no significant difference was detected amongst the different treatments (results not shown).

Changes in microbial biomass

There was a significant ($P<0.05$) difference in microbial biomass of the 2 soils with the mean microbial biomass of the brown clay 26% greater than that of the grey clay. Analysis of variance indicated that there were significant treatment and treatment x depth interaction effects only in the brown clay and not in the grey clay. In the former case, microbial biomass in CP was significantly higher than that of CC in the 0–5 cm but not in the 5–10 cm depth (Table 7). Microbial biomass was significantly higher in the 0–5 cm

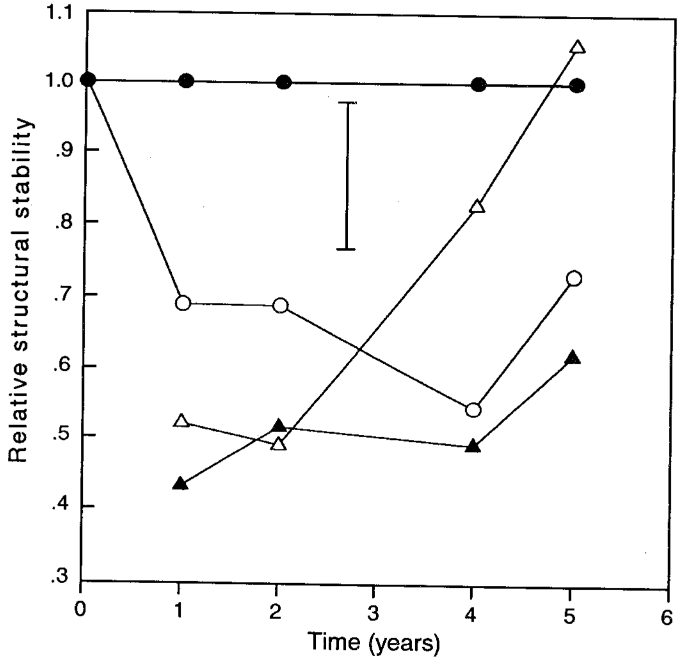

Figure 2. Changes in soil structural stability under different treatments relative to natural pasture with time after the commencement of the experiment (●, pasture–pasture; ○, pasture–cropping; ▲, cropping–cropping; △, cropping–pasture). The vertical bar represents necessary difference between treatments for significance ($P<0.05$).

than in the 5–10 cm layer in both pasture soils (PP and CP) but was similar for both depths for the cropped soils. Microbial biomass in the 0–5 cm was significantly lower in PC than in PP. Microbial biomass was similar for the different treatments in the 5–10 cm layer. No significant difference in microbial biomass was observed amongst the different treatments in the grey clay.

Table 7. Soil microbial biomass (μg/g) of the brown clay under different treatments measured in 1993. CC = cropping-cropping; PC = pasture-cropping; CP = cropping-pasture; PP = pasture-pasture.

	Treatment			
Depth	CC	PC	CP	PP
(cm)				
0–5	590	691	820	1142
5–10	524	609	555	652

LSD ($P < 0.05$)
— treatment 166; — treatment × depth 235.

General discussion

Importance of soil organic carbon levels. Our results highlight the importance of soil organic matter in maintaining the chemical as well as physical fertility of these soils. A significant linear relationship between OC and mineralisable nitrogen was established (Figure 3). Therefore, available nitrogen reserves of these soils are determined by the soil organic carbon levels. A similar relationship showing depletion of the nitrogen reserves with declining soil organic carbon levels under cropping was obtained for a range of vertisols in the region (Chan *et al.* 1995). Our present results demonstrated the effectiveness of a pasture phase including Mitchell grass-medic in increasing both OC and mineralisable nitrogen in the brown clay after 3 years.

Our results also highlight the importance of soil organic carbon in maintaining the structural stability of these soils. Water stability of macro-aggregates (>250 μm) increased significantly ($P<0.001$) with increasing OC. In contrast, the proportion of <50 μm particles (lt50) decreased significantly ($P<0.05$) with increasing OC (Figure 4), indicating a reduction in the tendency of the soil to slaking and dispersion, *i.e.* higher stability with higher OC under pasture. Therefore, maintaining the soil organic carbon level of these soils is a prerequisite for sustainable farming systems.

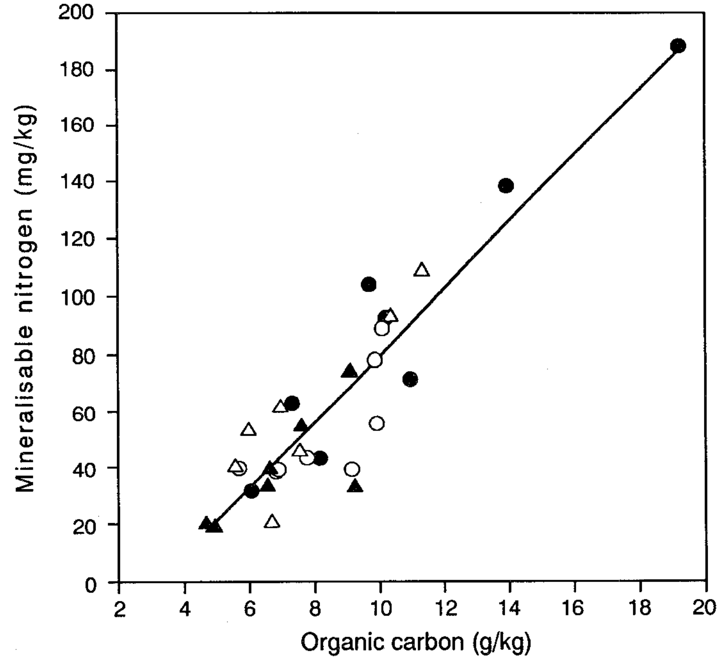

Figure 3. Relationship between mineralisable nitrogen and soil organic carbon level for the two vertisols; N = 116 OC − 37.09; r = 0.913***. (●, pasture–pasture; ○, pasture–cropping; ▲, cropping–cropping; △, cropping–pasture).

Rate of improvement — differences in response between soil types. Our results indicate significant increases in soil organic carbon 2 years after establishment of pasture, and increases in available nitrogen and improvement in soil structure were clearly evident by the third year. However, the increases were evident only in the brown clay and not in the grey clay. Furthermore, most of the improvement in OC and aggregate stability occurred only in the top 5 cm, as has been reported previously in other soil types and climatic regimes (Greacen 1958; Clarke *et al.* 1967). Changes in OC and aggregate stability tended to occur at a much slower rate in the deeper layers, a result consistent with other studies (e.g. Jenkinson 1988). For the brown clay, average OC in the 0–5 cm of CP at the end of the fourth year was 11.0 g/kg, the increase over CC representing 32% of the difference between PP and CC.

In contrast to the brown clay, little evidence of improvement in soil properties was evident in the sodic grey clay. This was probably due to its inherent lower fertility and therefore pasture productivity. Improvement in structural stability is dependent on the productivity of the pasture (Clarke *et al.* 1967).

Conclusions

Returning degraded vertisols to a native pasture (*Astrebla lappacea*) can lead to significant increases in soil organic carbon and available nitrogen as well as an improvement in soil structure, but these changes are dependent on soil types.

Acknowledgements

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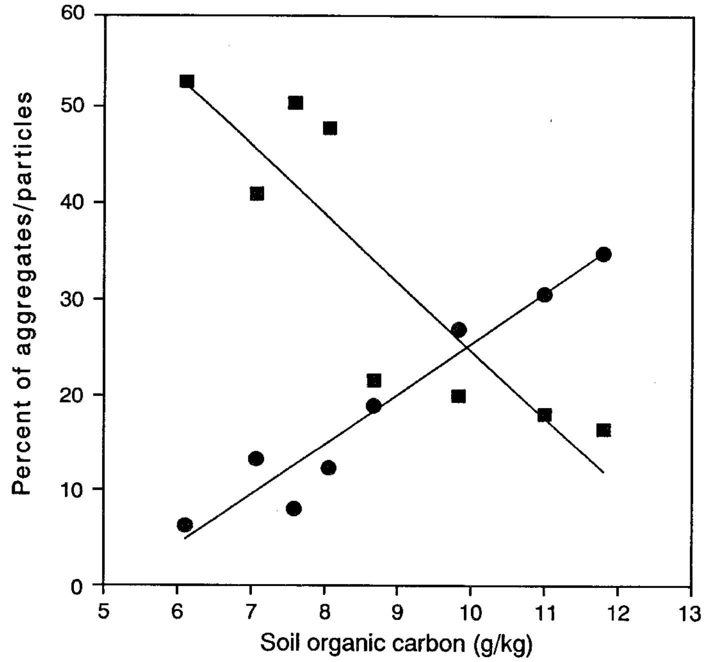

Figure 4. Water-stable aggregation of the brown clay (0–5 cm) as a function of soil organic carbon levels measured in 1993 (●, %>250 µm: $y = 5.27x - 27.44$, $r^2 = 0.939$***; ■, %<50 µm: $y = 95.78x - 7.125$, $r^2 = 0.780$**).

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