Sheep camping influences soil properties and pasture production in an acidic soil of New South Wales, Australia

Yining Niu[1], Guangdi Li[2], Lingling Li[3,5], K. Yin Chan[4], and Albert Oates[2]

[1]Key Laboratory of Grassland Agro-Ecosystems, Ministry of Agriculture, College of Pastoral Agriculture Science and Technology, Lanzhou University, Lanzhou, Gansu 730000, China; [2]E H Graham Centre for Agricultural Innovation (Alliance between NSW Department of Primary Industries and Charles Sturt University), Wagga Wagga Agricultural Institute, PMB, Wagga Wagga, NSW 2650, Australia; [3]Faculty of Agronomy, Gansu Agricultural University, Lanzhou 730070, China; and [4]NSW Department of Primary Industries, Richmond, Locked Bag 4, NSW 2753 Australia. Received 17 January 2008, accepted 8 October 2008.

Niu, Y., Li, G. D., Li, L., Chan, K.Y. and Oates, A. 2009. **Sheep camping influences soil properties and pasture production in an acidic soil of New South Wales, Australia**. Can. J. Soil Sci. **89**: 235–244. This paper reports sheep camping influences on soil chemical and physical properties, and pasture dry matter (DM) production of an acidic soil on the southwest slopes of New South Wales, Australia. The experiment was conducted in the spring (October–November) of 2005 on a long-term field experimental site after 13 yr of rotational grazing. The factors considered were sheep camping (distance from the camping site), pasture type (perennial vs. annual pastures) and lime application (limed vs. unlimed treatments). Over 13 yr of rotational grazing, significant amounts of carbon (C), nitrogen (N), phosphorus (P) and potassium (K) were deposited near the sheep camping site via the deposition of animal excreta. Total C increased from 32.8 g kg^{-1} 20 m away from the camping site to 41.9 g kg^{-1} at the camping site in 0–5 cm soil depth. The Colwell P increased from 44.0 to 125.9 mg kg^{-1} from the non-camping area to the camping site in 0–5 cm soil depth. The most interesting result from the current study is that soil bulk density decreased as the intensity of camping increased. On the perennial pastures, soil bulk density was 0.96 and 1.34 g cm^{-3} at the camping site in the 0–5 and 5–10 cm soil depths, respectively, whereas soil bulk density was 1.14 and 1.39 g cm^{-3} at 20 m away from the camping site at the corresponding soil depths. Across pasture types, mean pasture DM was highest at the camping site (7.3 and 6.6 t ha^{-1} for the limed and unlimed pastures, respectively), and lowest 20 m away from the camping site (5.4 and 4.5 t ha^{-1} for the limed and unlimed pastures, respectively). The vigorous pasture growth and high organic matter at the camping site may have had a "cushioning effect", thereby reducing soil compaction. However, this camping effect was confined to within 5 m of the camping site. It is concluded that sheep camping can create spatial heterogeneity in soil chemical and physical properties. The non-uniform influence on pasture productivity and composition could be minimised by altering the grazing management strategies, such as periodic relocation of the site of shelter, or further subdivision of the grazing paddock, if necessary.

Key words: Soil carbon, nitrogen, phosphorus, bulk density, grazing management

Niu, Y., Li, G. D., Li, L., Chan, K.Y. et Oates, A. 2009. **Le pacage des moutons modifie les propriétés du sol et la production des pâturages sur un sol acide de la Nouvelle-Galles du Sud, en Australie.** Can. J. Soil Sci. **89:** 235–244. Cet article examine l'influence du pacage des ovins sur les propriétés chimiques et physiques du sol ainsi que sur la production de matière sèche par les pâturages sur un sol acide situé sur les pentes sud-ouest de la Nouvelle-Galles du Sud, en Australie. L'expérience s'est déroulée au printemps (en octobre et novembre) 2005, sur un terrain expérimental de longue durée, après 13 ans de pâturages tournants. Parmi les paramètres étudiés figuraient le pacage des moutons (distance de l'endroit où les animaux étaient parqués), la nature du pâturage (vivace c. annuel) et l'application de chaux (chaulage c. aucun chaulage). Durant les 13 années de pâturages tournants, les excréments des animaux ont laissé une quantité appréciable de carbone (C), d'azote (N), de phosphore (P) et de potassium (K) près du pacage. La concentration totale de C dans les cinq premiers centimètres du sol est passée de 32,8 g par kilo à 20 m du pacage à 41,9 g par kilo sur le pacage même. La concentration de P mesurée selon la technique de Colwell est passée de 44,0 à 125,9 mg par kilo dans les cinq premiers centimètres de sol entre le pacage et l'autre site. Le résultat le plus intéressant de l'étude est que la masse volumique apparente du sol diminue avec l'intensité de la paissance. Sur les pâturages de vivaces, elle s'établissait respectivement à 0,96 et à 1,34 g par cm^3 dans la couche de 0–5 cm et dans celle de 5–10 cm du sol, au pacage, alors qu'elle était de 1,14 et de 1,39 g par cm^3 à 20 m de là, aux mêmes profondeurs. Selon le type de pâturage, la concentration moyenne de matière sèche était la plus élevée au pacage (7,3 et 6,6 tonnes par hectare pour les pâturages chaulés et ceux qui ne l'étaient pas, respectivement) et la plus basse à 20 m de distance (5,4 et 4,5 tonnes par hectare pour les sites chaulés et non chaulés, respectivement). La croissance vigoureuse du

[5]*To whom correspondence should be addressed (lill@gsau.edu.cn)*

pâturage et la forte concentration de matières organiques au pacage pourraient avoir eu un effet « tampon » qui a atténué le compactage du sol. Cependant, cet effet disparaît au-delà de 5 m du pacage. On en conclut que parquer les moutons peut engendrer une hétérogénéité spatiale des propriétés chimiques et physiques du sol. On pourrait uniformiser l'influence du pacage sur la productivité et la composition des pâturages en modifiant les stratégies d'aménagement, notamment en relocalisant périodiquement les abris ou en subdivisant davantage les enclos, au besoin.

Mots clés: Carbone du sol, azote, phosphore, masse volumique apparente, aménagement des pacages

Grazing animals play an important role in the movement of nutrients through the soil–plant–animal system. Animals use only a small proportion of the nutrients they ingest and 60–95% of ingested nutrients are returned to the pasture in the form of dung and urine (Haynes and Williams 1999). In the pasture, the process of nutrients recycled from excreta to soil and back to plants affects soil physical, chemical and biological properties (Haynes and Williams 1993, 1999; Iyyemperuma et al. 2007). Grazing also affects plant species composition (Güsewell et al. 2005; Proulx and Mazumder 1998), nutrient availability and litter decomposition, and modifies the productivity of the vegetation (Milchunas and Lauenroth 1993; Güsewell et al. 2005).

Nutrient and organic matter distribution and cycling in a pasture system are greatly influenced by grazing animals. One typical feature of grazing activity is spatial heterogeneity (Haynes and Williams 1999; McIntire and Hik 2002). Animals select particular landscape features for resting and ruminating (Pratt et al. 1986), such as beneath trees and hedges, around gateways and water troughs, on areas away from roadsides and on ridges and hillcrests on hill country farms (Haynes and Williams 1999; Rowarth et al. 1992). All of these lead to the build up of a large amount of animal excreta in the "camp areas" (Haynes and Williams 1999; Güsewell et al. 2005) and this transfer of excreta to the camp areas is regarded as nutrients losses for the non-camp areas. The redistribution of nutrients within the pasture results in a heterogeneous pattern of nutrient availability in the soil over the long term (Haynes and Williams 1999; Güsewell et al. 2005). In response to nutrient availability, pasture botanical composition may change and this, in turn, may affect pasture production (Olofsson and Oksanen 2002).

Grazing activity may have detrimental effects on soil physical conditions, such as soil compaction induced by animal treading (Drewry et al. 2008). Animal treading generally increases bulk density and reduces macropore spaces and infiltration (Willatt and Pullar 1985; Drewry and Paton 2000), which have long-term implications for soil fertility. However, the extent to which animal camping might alter the nature and pattern of the chemical and physical properties of soil in relation to changes in pasture botanical composition and production on acid soils is not entirely clear. In this study, a long-term field experiment, commenced in 1992, provided an opportunity for us to examine the long-term camping effects on soil chemical and physical properties, and pasture dry matter (DM) production and botanical composition under the limed pastures in comparison to the unlimed pastures in a highly acidic soil on the southwest slopes of New South Wales, Australia.

MATERIALS AND METHODS

Site Description

The experiment was conducted in the spring (October–November) of 2005 on a long-term field experiment site, known as "Managing Acid Soils Through Efficient Rotations (MASTER)", which commenced in 1992. It is located on the "Brooklyn" property, operated by the Hurstmead Pastoral Company Pty. Ltd., at Book Book (lat. 147°30′E, long 35°23′S), 40 km southeast of Wagga Wagga, New South Wales. The soil is a subnatric yellow sodosol (Isbell 1996), Typic Fragiochrept in USDA taxonomy (Soil Survey Staff 2006), with some red phases over the site. The soil profile has a strong texture contrast or duplex nature. The A horizon, overlaying a deep clay B horizon, varied from 20 to 60 cm in thickness across the site, with loamy sand to sandy loam texture. When the experiment started in 1992, Colwell phosphorus (P) was 23 mg kg^{-1} in the 0–10 cm soil depth and 6.7 mg kg^{-1} in the 10–20 cm soil depth, the average pH in 0.01 M $CaCl_2$ (pH_{CaCl_2}) in the 0–10 cm soil depth was 4.0, and subsurface pH_{CaCl2} was below 4.5 to at least 20 cm, which was typical of the more acidified soil in the region.

Lime was top-dressed at 6-yr intervals to maintain average pH_{CaCl_2} at 5.5 in the 0–10 cm soil depth. However, the initial lime was incorporated into the 0–10 cm soil depth with off-set discs followed by a scarifier and harrows on all plots of the limed treatments in 1992. Phosphorus (P) and potassium (K) were applied at 15 kg P ha^{-1} and 25 kg K ha^{-1} every year, respectively. Molybdenum (Mo) was applied at 50 g Mo ha^{-1} every 5 yr. Further details of site description were reported in Li et al. (2001).

Experimental Design

The original experimental design was a 2^3 factorial structure with three main treatment contrasts: (i) limed versus unlimed treatments; (ii) perennial pastures versus annual pastures; and (iii) continuous pastures versus pasture-crop rotations (Li et al. 2001). In the current study, we focused on the four continuous pasture treatments, i.e., perennial pastures with and without lime application, and annual pastures with and without lime application as a 2×2 factorial design with four replicates. However, we added a third factor, the sheep camping distance, to evaluate the gradient effects of camping on soil properties. The treatments with pasture-crop rotations were excluded from the current study as they had only been under grazing for 50% of the time over the past 13 yr. On the continuous pasture treatments, all plots were rotationally grazed by Merino wethers. The plot size (30 by 45 m) was large enough for a minimum of three sheep per plot grazing all year round. The average stocking rates were 12 sheep ha^{-1} for the unlimed pastures and 15 sheep ha^{-1} for the limed pastures.

It was observed that sheep rested and ruminated at one of the corners where a 2×2-m shading cloth, anchored to the corner post 1 m above ground, was supplied most of the time, especially in summer. Hence, the corner with the shade area was regarded as the main camping area in each plot. The shading area was set up in 1992 using nylon mesh (2×2 mm grid) to comply with the ethical requirements concerning animal care. It was assumed that the centre of the plot was least effected by sheep camping. A transect from the corner post with the shading area to the centre of the plot at each plot was set up to assess the sheep camping effect. Five sampling locations were selected at 2, 5, 10, 15 and 20 m from the corner post, representing a decreasing gradient of the camping effect. Thus, the location at 2 m from the corner post had the greatest effect from sheep camping and the location 20 m from the corner post had the least effect, or no effect, from sheep camping.

The perennial pasture was sown to phalaris (*Phalaris aquatica* L.) cv. Australian (0.5 kg ha^{-1}) and cv. Holdfast (1.0 kg ha^{-1}), cocksfoot (*Dactylis glomerata* L.) cv. Currie (1.0 kg ha^{-1}), lucerne (*Medicago sativa* L.) cv. Aurora (3.0 kg ha^{-1}) and subterranean clover (*Trifolium subterraneum* L.) cvs. Junee, Goulburn and Trikkala (1.5 kg ha^{-1} each). The annual pasture was sown to annual ryegrass (*Lolium rigidum* Gaudin) cv. Wimmera (2.0 kg ha^{-1}) and subterranean clover cvs. Junee, Goulburn and Trikkala (2.5 kg ha^{-1} each).

Soil Sampling and Measurements

Soil Bulk Density

Above-ground plant materials, including litter, were carefully removed before sampling without disturbing the soil surface. Two soil cores were taken using the bevelled stainless steel rings (i.d. 73 mm, depth 50 mm), as described by McIntyre and Loveday (1974), at two depths (0–5 cm and 5–10 cm, both at the A horizon) at each location in duplicate. In the laboratory, the soil cores were carefully trimmed at both ends, then oven dried at 105°C to determine bulk density.

Soil Chemical Properties

A soil corer with 2.5 cm internal diameter was used to take soil samples for chemical analysis at two depths (0–5 and 5–10 cm). At each location, 10 soil samples were taken, then combined into one sample for each depth. The composite soil samples were air-dried at 36°C and then ground to pass through a 2-mm sieve for chemical analysis.

Soil electrical conductivity (EC) was measured in 1:5 soil water extract and pH was measured in 0.01 M $CaCl_2$ following Raymont and Higginson (1992). Soil total carbon (TC) and total nitrogen (TN) were determined using a Leco® CNS Analyser (Nelson and Sommers 1982). Exchangeable potassium (K) was measured using the method of Gillman and Sumpter (1986). Extractable phosphorus was determined by the Colwell method (Colwell 1963).

Pasture Sampling and Measurements

Pasture Dry Matter

At each sampling location, two quadrats (0.1 m^2) were cut before grazing at 1 cm above ground level as duplicates using electric shears. The pasture samples were oven-dried (80°C) to determine DM.

Pasture Botanical Composition

An improved dry-weight-rank method (Jones and Hargreaves 1979) was used to estimate the pasture botanical composition, replicated 10 times at each location. Pasture species were grouped into four categories, namely sown species, barley grass (*Hordeum leporinum* Link), silvergrass (*Vulpia* spp.) and other weeds. Sown species were annual ryegrass and subterranean clover on annual pastures, and phalaris, cocksfoot, lucerne and subterranean clover on perennial pastures. Other weeds were sorrel (*Rumex acetosella*), capeweed (*Arctotheca calendula*) and various minor weeds.

Statistical Analysis

Soil bulk density, soil chemical properties, pasture DM and the proportion of major species in the swards were analysed using a model of factorial design with three factors. The factors considered were pasture types (annual vs. perennial pastures), lime application (limed vs. unlimed pastures) and sheep camping effects (the distance from the camping site). The main effects and their interactions were tested for significance using the F-test. All data analysis was performed using Genstat release 10.1 (Lawes Agricultural Trust 2008).

RESULTS

Soil Bulk Density

There were significant differences in bulk density between perennial and annual pastures in both the 0–5 cm ($P<0.001$) and the 5–10 cm soil depths ($P<0.01$), but no significant differences between the limed and unlimed pastures. Across five sampling locations, mean bulk density was 1.05 g cm^{-3} for perennial pastures and 1.13 g cm^{-3} for annual pastures at the 0–5 cm soil depth, and 1.35 vs. 1.38 g cm^{-3} at the 5–10 cm soil depth for perennial and annual pastures,

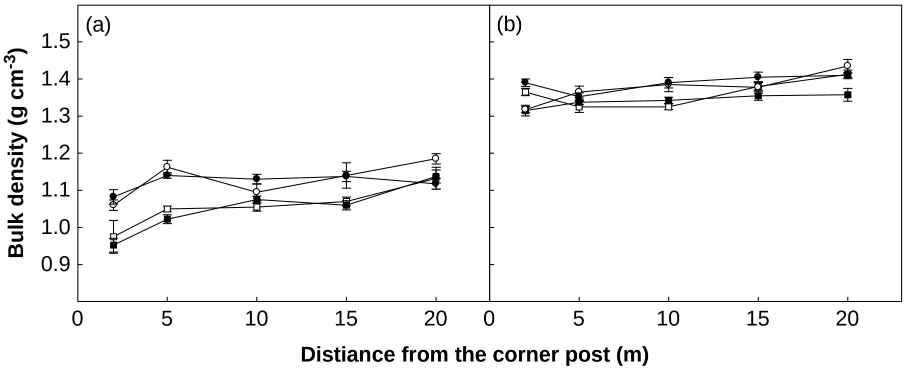

Fig. 1. Soil bulk density (mean ± SE) in (a) the 0–5 cm and (b) the 5–10 cm soil depths for the limed and unlimed annual pastures (● vs. ○) and the limed and unlimed perennial pastures (■ vs. □) 2, 5, 10, 15 and 20 m from the corner post.

respectively (Fig. 1). There were significant differences in bulk density between distances from the camping site in both soil depths ($P<0.01$). Bulk density was lower at locations close to the sheep camping site and higher at locations away from the camping site. The relationship between bulk density (y) and the distance from the camping site (x) can be expressed as $y = 0.0054\ x + 1.033$ ($R^2 = 0.36$, $P < 0.01$) at 0–5 cm and $y = 0.0033\ x + 1.333$ ($R^2 = 0.4133$, $P < 0.01$) at 5–10 cm. On the perennial pastures, bulk density was 0.96 and 1.34 g cm^{-3} 2 m from corner post and 1.14 and 1.39 g cm^{-3} 20 m from the camping site in the 0–5 and 5–10 cm soil depths, respectively. Similar trends were found for annual pastures in both soil depths (Fig. 1).

Soil pH_{CaCl_2} and Electrical Conductivity

Soil pH_{CaCl_2} was significantly higher in the limed treatments than in the unlimed treatments for both annual and perennial pastures ($P < 0.001$), as expected, but no differences in pH_{CaCl_2} were detected between annual and perennial pastures. On the limed treatments, pH_{CaCl_2} was similar across distances although pH_{CaCl_2} at 5 and 10 m were slightly higher (Fig. 2). In contrast, pH_{CaCl2} decreased nearly half pH units from the camping site to non-camping area in both soil depths on the unlimed treatments (Fig. 2).

Lime increased soil EC significantly at all distances in 0–5 cm soil depth ($P < 0.001$) compared with unlimed treatments, but had no effect on soil EC in 5–10 cm soil depth. Soil EC decreased significantly from the camping site to towards the centre of the plot in both soil depths ($P < 0.001$). In 0–5 cm soil depth, soil EC decreased from 141 μs cm^{-1} at camping site to 73 μs cm^{-1} at 20 m away from camping site on the limed treatments whereas soil EC decreased from 100 μs cm^{-1} at camping site to 55 μs cm^{-1} away from camping site on the unlimed treatments. In 5–10 cm soil depth, the soil EC averaged across limed and unlimed treatments decreased from 68 to 37 μs cm^{-1} as distance from camping site increased (Fig. 3).

Soil Total Carbon and Nitrogen

Both TC and TN concentrations in the 0–5 cm soil depth were similar at locations from 10–20 m away from camping site, but increased sharply at the camping site (Fig. 4). In the 5–10 cm soil depth, similar trends were found, but less dramatically (Fig. 4). Averaged soil TC was 41.9 and 19.5 g kg^{-1} in the 0–5 cm and 5–10 cm soil depths at the camping site, and 32.8 and 16.5 g kg^{-1} at

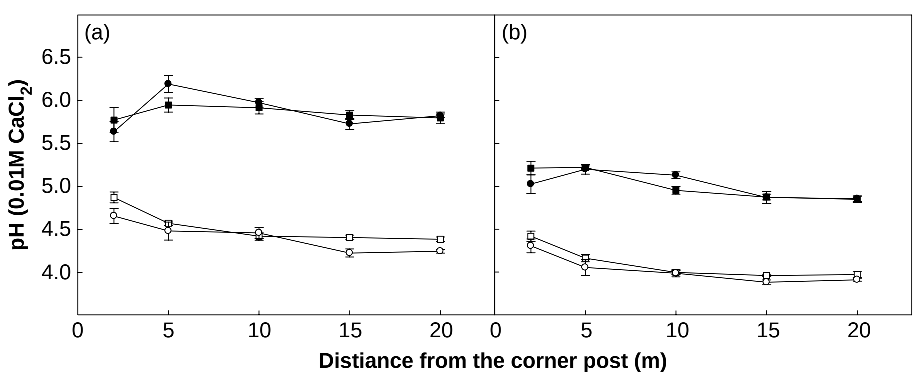

Fig. 2. Soil pH_{Cacl_2} (mean ± SE) in (a) the 0–5 cm and (b) the 5–10 cm soil depths for the limed and unlimed annual pastures (● vs. ○) and the limed and unlimed perennial pastures (■ vs. □) 2, 5, 10, 15 and 20 m from the corner post.

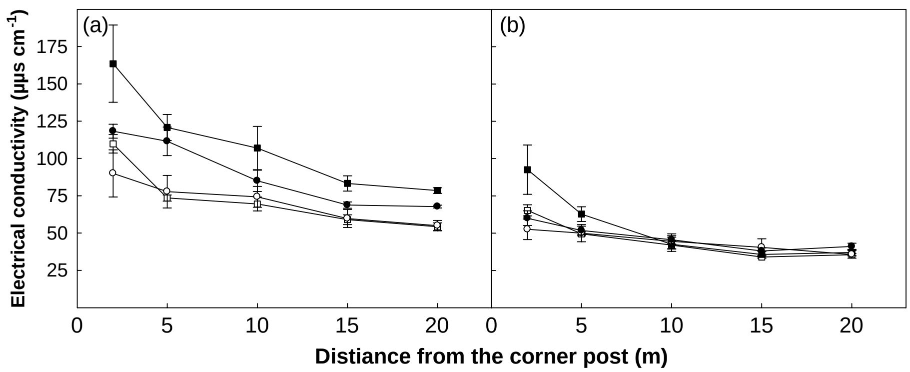

Fig. 3. Soil electrical conductivity (mean ± SE) in (a) the 0–5 cm and (b) the 5–10 cm soil depths for the limed and unlimed annual pastures (● vs. ○) and the limed and unlimed perennial pastures (■ vs. □) 2, 5, 10, 15 and 20 m from the corner post.

the location 20 m away from the camping site in the corresponding soil depths, respectively (Fig. 4). Averaged soil TN were 3.8 and 1.8 g kg^{-1} in the 0–5 cm and the 5–10 cm soil depths at the camping site, and 2.8 and 1.4 g kg^{-1} at a location 20 m away from the camping site in the corresponding soil depths, respectively (Fig. 4). Sheep camping had a significant effect on the C:N ratio. The C:N ratio increased from the camping site

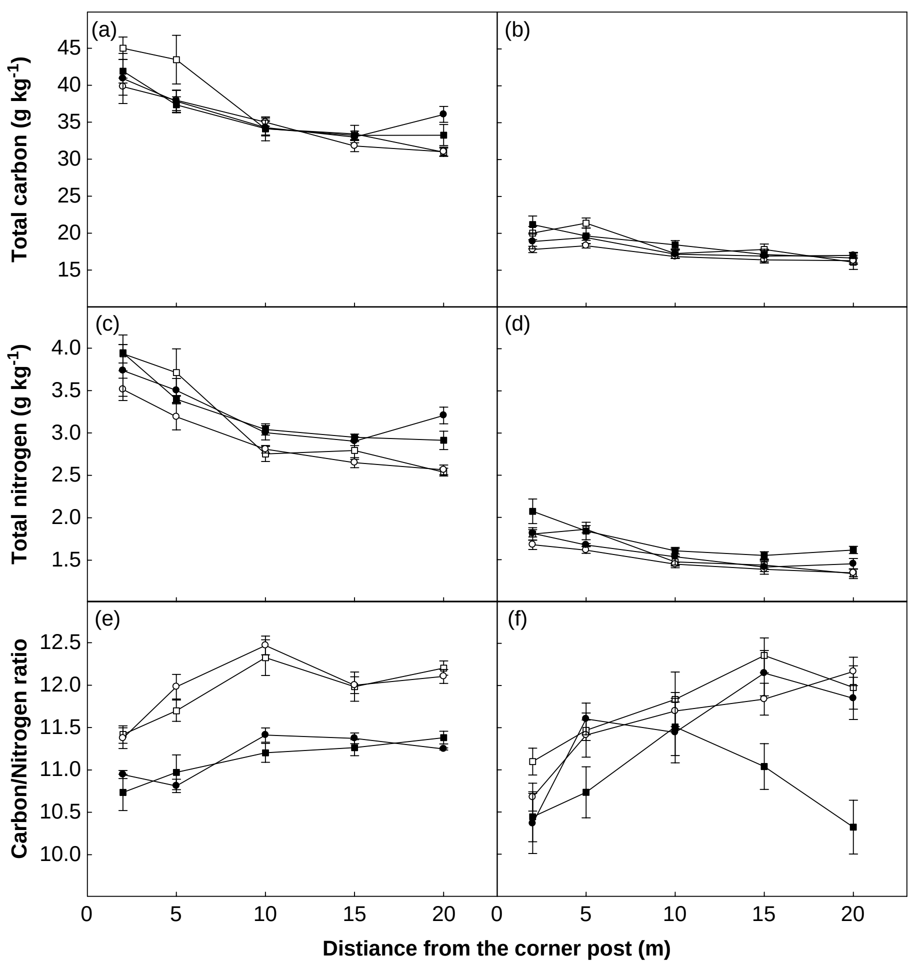

Fig. 4. Soil total carbon (a and b), total nitrogen (c and d) and carbon to nitrogen ratio (e and f) (mean ± SE) in the 0–5 cm and the 5–10 cm soil depths for the limed and unlimed annual pastures (● vs. ○) and the limed and unlimed perennial pastures (■ vs. □) 2, 5, 10, 15 and 20 m from the corner post.

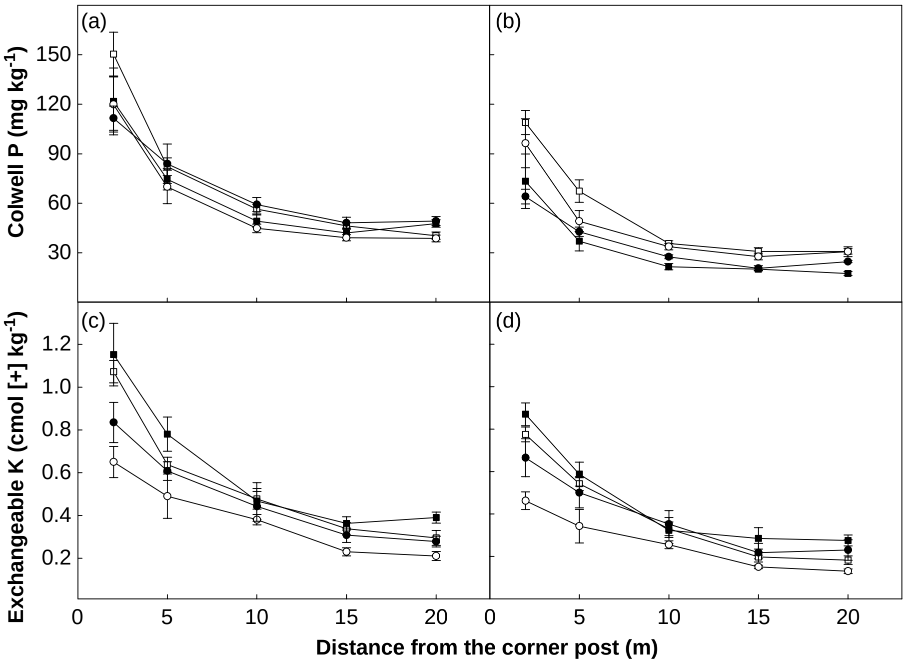

Fig. 5. Soil Colwell phosphorus (a and b) and exchangeable potassium concentrations (c and d) (mean ± SE) in the 0–5 cm and the 5–10 cm soil depths for the limed and unlimed annual pastures (● vs. ○) and the limed and unlimed perennial pastures (■ vs. □) 2, 5, 10, 15 and 20 m from the corner post.

towards the centre of the plot and reached a plateau 10 m away from the camping site in the 0–5 cm soil depth. The C:N ratio had a similar trend in the 5–10 cm soil depth, except for the limed perennial pasture, where the C:N ratio decreased sharply from locations 10 to 20 m away from the camping site (Fig. 4).

There were significant differences in C/N ratio between limed and unlimed treatments in both 0–5 cm ($P < 0.001$) and 5–10 cm ($P < 0.05$). The limed treatments had lower C/N ratio (11) than the unlimed treatments (12) (Fig. 4).

Soil Colwell Phosphorus and Exchangeable Potassium

Lime had a significant effect on Colwell P in the 5–10 cm soil depth, but not in the 0–5 cm soil depth. There were no significant differences in Colwell P between annual and perennial pastures in both the 0–5 and the 5–10 cm soil depths. Sheep camping, however, had a significant effect on Colwell P in both soil depths. Colwell P increased sharply at the camping site, then gradually decreased to 44.0 and 25.9 mg kg^{-1} in the 0–5 and the 5–10 cm soil depths 20 m away from the camping site (Fig. 5). The highest Colwell P was 125.9 mg kg^{-1} in the 0–5 cm and 85.7 mg kg^{-1} in the 5–10 soil depth at the sheep camping site. A similar trend was found for exchangeable K across distances from the camping site in both soil depths (Fig. 5). There were significant differences in exchangeable K between perennial and annual pastures in both soil depths. Perennial pastures had higher exchangeable K than annual pastures in both soil depths (Fig. 5).

Pasture Dry Matter and Botanical Composition

At all sampling locations, pasture produced more DM on the limed pastures than unlimed pastures except at 5 m from the corner post. There was no difference in pasture DM between pasture types. Averaged across pasture types, pasture DM increased significantly at camping site. On the limed treatments, pasture DM was 7.3 t ha^{-1} at the camping site and 5.4 t ha^{-1} at 20 m away from the camping site, whereas pasture DM was 6.6 and 4.5 t ha^{-1} at the camping site and at 20 m away from the camping site on the unlimed treatments (Fig. 6).

The proportion of sown species was higher near the camping site (location at 2 and 5 m) compared with all other locations away from the camping site on perennial pastures, but no obvious differences were observed on annual pastures (Fig. 7). There were significant differences in two important weeds, barley grass and silvergrass, between limed and unlimed pastures. The proportion of barley grass was much higher and the proportion of *Vulpia* was much lower on the limed treatments compared with unlimed treatments. The proportion to barley grass was similar at all distances on the limed treatments, but significantly higher at the camping site on the unlimed treatments (Fig. 7).

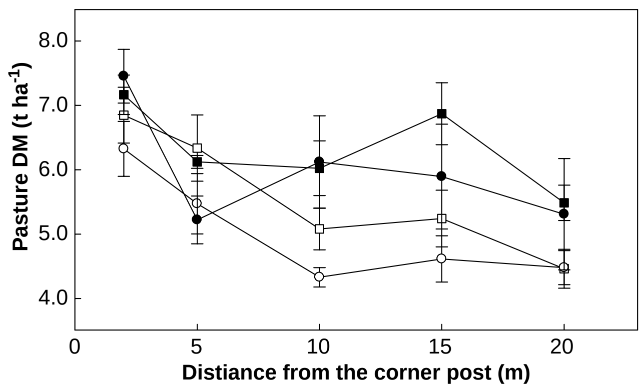

Fig. 6. Pasture dry matter (mean ± SE) for the limed and unlimed annual pastures (● vs. ○) and the limed and unlimed perennial pastures (■ vs. □) 2, 5, 10, 15 and 20 m from the corner post.

DISCUSSION

Effects of Sheep Camping on Soil Property

The most interesting finding from the current study is that soil bulk density decreased as the intensity of camping increased, although one would assume more treading would occur at the camping area than at other areas. There are many reports on topsoil compaction caused by animal treading (e.g. Drewry and Paton 2000; Kurz et al. 2006). Drewry and Paton (2000) found animal treading reduced soil macroporosity, increasing soil bulk density. On the current study site, the average stocking rates were 12 wethers ha^{-1} for the unlimed pastures and 15 wethers ha^{-1} for the limed pastures, which were slightly higher than the district average. However, sheep were confined in the 30 × 45-m plot and grazed rotationally over the past 13 yr. It is unlikely to cause severe treading damage or soil compaction at the camping site. On a commercial farm, however, the number of sheep available to compact the stock camp site would be much greater due to a bigger mob of sheep and larger paddock size compared with those on the current site, although the average stocking rate on the site was slightly higher than district average. Thus, sheep would have a great impact, such as trampling or over-grazing, near the camping site due to their social behaviour. In addition, a three-plot rotational grazing system gave each plot reasonable time to recover after each grazing especially in wet season.

On the other hand, sheep camping activity brought more nutrients to the camping site as evidenced by higher TC, TN, Colwell P and exchangeable K (Fig. 5) at or near the camping site compared with locations away from the camping site. This would stimulate more root growth, resulting in greater pasture productivity at the camping site as shown in Fig. 6. However, this excessive pasture growth was always under-grazed due to certain level of contamination of dungs and urine. Over the long-term, the camping site built up more soil organic matter, which plays a significant role in formation and maintenance of soil structure (Loveland and Webb 2003). The vigorous pasture growth and high

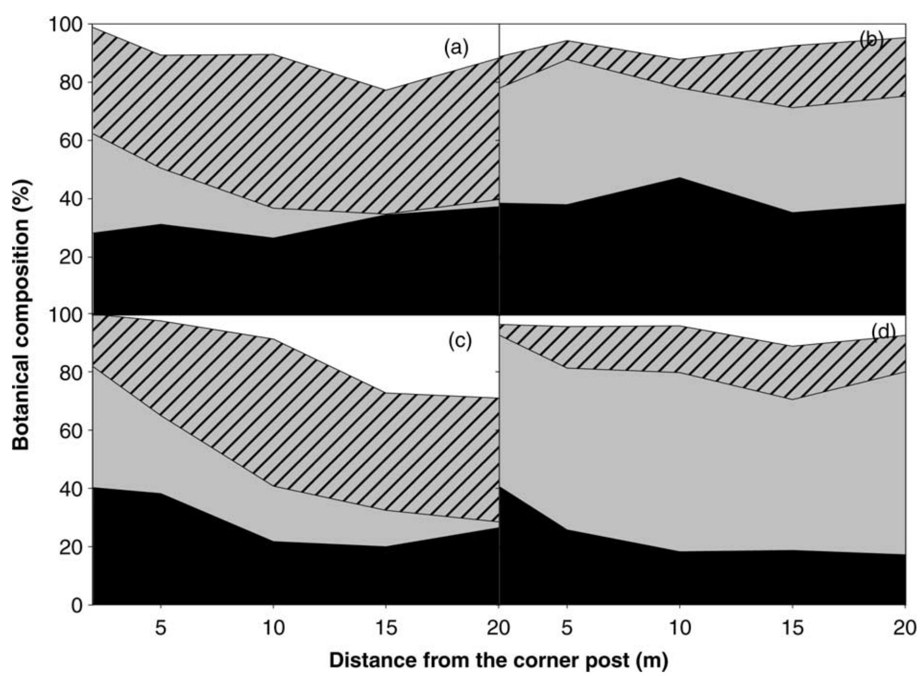

Fig. 7. Pasture botanical composition for (a) the unlimed, (b) the limed annual pastures, (c) the unlimed, and (d) the limed perennial pastures 2, 5, 10, 15 and 20 m from the corner post. Areas in black are for the sown species, grey for barley grass, hatched for silvergrass and white for other weeds.

organic matter would provide a "cushioning effect" at the camping site, thereby reducing soil compaction. It is concluded that after 13 yr of rotational grazing, there was no significant adverse impact on soil physical condition, particularly soil compaction, by trampling at the camping site; hence, this grazing practice appears sustainable with beneficial effect on soil chemical properties, such as increased Cowell P, on a long-term basis.

The results show that soil pH was generally higher at or near the camping site compared with the non-camping grazing area, especially on the unlimed pastures in both soil depths. The major factor contributing to the higher pH was due to the transfer of alkalinity in the form of excreta to camping areas by grazing animals (Haynes and Williams 1999; Sinclair 1995). Soil pH regulates soil organic matter turnover by its effect on microbial activity in agricultural soils (Adams and Adams 1983; Curtin et al. 1998; Kemmitt et al. 2006). In mixed pastures, N is supplied primarily by biological N fixation. In order to balance the organic anions derived from photosynthesis, plants take up more cations (such as K, Na, Ca and Mg) than anions and release H^+ ions to the soil, thus leading to acidification of the soil. Those cations are then released in excreta when plants are consumed by animals (Sinclair 1995). Animals generally deposit more excreta on areas where they congregate for resting and ruminating (i.e., stock camps), resulting in a higher soil pH in camp areas compared with non-camp areas in pastures (Haynes and Williams 1999; Sinclair 1995). On the other hand, high organic matter accumulation in the soil surface can increase the soil pH buffering capacity (Aitken et al. 1990; Chan et al. 1992; Haynes 1983; Haynes and Williams 1993) and decomposition of organic matter could lower soil pH under the legume and grass pasture (Haynes 1983). This is probably the reason for the relatively low pH at camping site on the limed treatments. Thus, the final pH in the treatment plot is driven by the balance of ions released and taken up by plants and organic matter decomposition.

Grazing activity plays an important role in nutrient redistribution and nutrient recycling in the field. Haynes and Williams (1993) reported that about 60% of dung and 55% of urine is typically deposited on stock camp areas on hill country, and Hilder (1966) found that 31% of dung was deposited on less than 5% of the total area of the field on flat land. In the current study, high concentrations of C, N, P and K were found at the camping site, largely due to organic matter and nutrient transfer from non-camping areas via animal excreta. However, this camping effect was confined within 5 m from the camping site. In the long term, this uneven distribution of nutrients and changes in soil properties due to sheep camping add to the spatial heterogeneity of soil fertility and might even contribute to the productivity variability across the field.

Haynes and Williams (1999) observed that soil biological activity increased in the camp area compared with non-camping area. An increase in soil microbial activity is also likely to boost the mineralization and turnover of soil organic matter. This, in turn, may lead to an increase in soil N, P and K concentration in the camping area (Figs. 4 and 5). However, the accumulation of nutrients appeared to be less significant 10 m away from camping site, indicating that physical transfer of nutrients from animal excreta plays a large role, and other factors, such as microbial activity, are secondary.

Effects of Sheep Camping on Pasture Production

Pasture DM was much higher at the camping site compared with non-camping areas (Fig. 6) due to much better nutrient status at the camping site, as discussed above. Haynes and Williams (1999) also reported that soil organic matter content and nutrient accumulation increased in the camp areas compared with non-camping areas. The avoidance of grazing at the camping sites due to contamination by dung and urine is also one of the reasons that contribute to greater pasture DM at the camping area.

Results showed that the limed pastures produced more DM than unlimed pastures (Fig. 6), which is consistent with previous work on the same site (Li et al. 2006), where the limed pastures produced 0.9 t ha^{-1} more DM during the growing season compared with the unlimed pastures. The higher pasture DM production on the limed treatments was probably due to amelioration of soil acidity and the alleviation of Al toxicity (Scott et al. 2000) from long-term liming, resulting in increased rooting volume and root health. In addition, the lower C:N ratio on the limed treatments indicates that lime application increased microbial activity and organic carbon decomposition (Chan and Heenan 1999), accelerating the nutrient recycling rate and improving soil fertility on the limed treatments.

The striking difference was found in pasture botanical composition between limed and unlimed pastures (Fig. 7), which was also reported previously by Li et al. (2003) on the same site. On the limed pastures, there were much higher proportions of desirable species, such as lucerne, phalaris and subterranean clover, whereas on the unlimed pastures, there were much more weeds, such as silvergrass and sorrel. The acid-sensitive species barley grass became dominant on the limed pastures, whereas silvergrass was the dominant species on the unlimed pastures.

In general, the camping effect on botanical composition was less obvious on the limed pastures than on the unlimed pastures. On the limed pastures, the proportion of sown species was higher at the camping site than at the non-camping area for the limed perennial pastures, but this was not the case on the limed annual pastures. In the latter case, the sown species on the annual pastures, such as subterranean clover, were more acid tolerant than sown species on the perennial pastures, such as phalaris and lucerne, and thus less responsive to increased pH at camping site. On the unlimed pastures, there was more barley grass and less silvergrass at the camping site than at the non-camping area due to high pH and more soil nutrient input in camp soils, which agreed with Nguyen and Goh (1992). Barley grass can provide high-quality feed early in the season, but its head causes many animal health problems when mature.

Long-term liming practice increased pasture DM production and changed pasture botanical composition as subsoil acidity was gradually ameliorated and soil fertility was improved. Perennial pastures, with their robust root systems, showed more influence in improving soil structure, as evidenced by lower bulk density compared with annual pastures but, in the current study, no differences were found in soil nutrient status between perennial and annual pastures. Nevertheless, perennial-based pastures should be promoted for their environmental benefits in terms of alleviating soil acidity problems and reducing the risk of dryland salinity in the high rainfall zone in southeastern Australia.

CONCLUSIONS

Sheep camping had significant effects on soil chemical and physical properties via redistribution of organic matter and nutrients and increased variability of soil properties. Over 13 yr of rotational grazing, more organic matter and nutrients were deposited near the camping site, resulting in greater pasture DM production at the camping site. However, this camping effect was confined within 5 m from the camping site. No obvious soil compaction was observed at the camping site under rotational grazing over 13 yr due to vigorous pasture growth and the high organic matter content of the soil, which may make soil more resilient to sheep treading. It is concluded that sheep camping can create spatial heterogeneity in soil chemical and physical properties, affecting pasture productivity and composition, but this can be minimised by altering grazing management strategies, such as periodic relocation of the site of shelter, or further subdivision of the grazing paddock.

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