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Ploughing and grazing alter the spatial patterning of surface soils in a shrub-encroached woodland

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ABSTRACT

Grazing is known to affect the spatial patterning of soil resources through biologically-mediated processes such as the removal of plant biomass and deposition of dung. In dense shrublands, grazing is thought to reinforce the concentration of resources around shrubs (fertile island effect) by enhancing the movement of resources from the interspace to the shrub hummocks. Shrub removal practices such as ploughing, which is commonly used to manage dense shrub patches, has unknown impacts on the distribution of soil properties. In this study we examined the effects of two land management practices, grazing and ploughing, on the spatial distribution of surface soil resources. At the unploughed–ungrazed site, the connectivity (autocorrelation range) of shrub cover was about 3.9 m and there was a well-defined pattern in soil labile C that was related to the distribution of the cover of both shrubs and litter. We also observed a strong pattern of biological crust cover and an autocorrelation range of 2.5 m, similar to that of mineralisable and mineral N. At the unploughed–grazed site, the autocorrelation range of both shrub and crust cover was reduced to 1.9 m and 1.8 m, respectively, although the range of litter cover increased to 4.4 m. Under a treatment of grazing without ploughing, the autocorrelation range of soil labile C was less related to litter cover. Whilst ploughing slightly increased the autocorrelation range of both shrub and litter cover at sites that were grazed, it obliterated any spatial pattern in biological soil crusts. We attribute changes in the spatial patterns of soil N under grazing to inputs of animal dung rather than soil crust cover. Our results indicate that grazing alone, or in combination with ploughing, leads to reduced connectivity of shrub and crust cover, reduction in crust patterning, and marked effects on shrub–litter–nutrient spatial relationships. The results reinforce the notion that management of shrublands by grazing and ploughing is likely to have marked effects on the distribution of surface soils.

1. Introduction

A high degree of spatial patterning in vegetation and soil resources is a common feature of water-limited systems (e.g., Borgogno et al., 2009; Wang et al., 2009a). Such patterns can be induced by abiotic factors such as topography, fire, rainfall, wind and water erosion (e.g., Li et al., 2009; Ravi et al., 2009) or by biotic influences due to vegetation (Kefi et al., 2007), particularly the plant canopy (Wang et al., 2009a,b). Plants are strong biotic drivers of the distribution of soil properties, and their effects vary at spatial scales ranging from that of single plants (Jackson and Caldwell, 1993) to entire communities (Gross et al., 1995; Wang et al., 2007a). Individual plants modify their surrounding soils by accumulating nutrients, sediments and essential resources such as water, seed and organic matter around their canopies. Much of these materials are derived from biotic and abiotic processes occurring in the interspaces; the unvegetated areas between plants. The combined effect of these processes is to reinforce the 'fertile island' phenomenon around individual plants (e.g., Schlesinger et al., 1996; Wang et al., 2009c). Other biotic factors such as animal activity (i.e., grazing) could also directly, or indirectly, affect the distribution of soil properties. For example, trampling by herbivores alters soil bulk density and infiltration patterns (Stavi et al., 2008). Similarly, herbivores might indirectly affect the spatial distribution of soil properties either by: 1) removing vegetation or reducing its spatial distribution, thereby altering the capacity of patches to capture resources (Rietkerk et al., 2000), or 2) changing plant community composition and thus the quality (e.g., the C:N ratio) and quantity of litter (Chapin et al., 2002).

Overgrazing has been shown to lead to fragmentation of plant patches (Bisigato and Bertiller, 1997) through the removal of biomass

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of some palatable shrubs such as *Acacia aneura* (Tiver and Andrew, 1997). Wind erosion further removes fine soil particles and nutrients associated with the presence of grasses, enhancing the movement of resources from the interspaces to the plant patches (Li et al., 2009). In the semi-arid woodlands, this redistribution of resources changes markedly when areas of open grassland are encroached by shrubs. Increases in the density of woody plants alter the scale at which soil nutrients are distributed, from a fine scale, which corresponds to the average distance between former perennial grass tussocks, to one that matches the average spacing of individual shrub hummocks (Schlesinger et al., 1996). Whilst progressive nutrient accumulation under shrubs is associated with grassland degradation (Augustine and Frank, 2001), grazing could further influence the soil nutrient patterning by changing the distribution of litter inputs to the soil, fragmenting the cover of biological soil crusts (Neff et al., 2005) as well as generating inputs of dung (Afzal and Adams, 1992).

Globally, the area of land affected by encroachment of woody plants has increased dramatically over the past half century (Naito and Cairns, 2011). Perceived problems of encroachment in pastoral enterprises have resulted in an intensification of shrub control techniques, particularly mechanical methods (e.g., Herrick et al., 2006). Grazing by domestic livestock is a typical management practice following mechanical shrub removal as managers seek to recoup some of the costs of such treatments. Previous studies in the semi-arid woodlands in eastern Australia have shown that the long-term effects of ploughing tend to increase shrub cover and density (Daryanto and Eldridge, 2010), potentially increasing the connectedness of shrub canopies and therefore the connectivity of shrub-mediated resources. Although post-ploughing shrubs and their hummocks tend to be smaller than the mature plants and hummocks that they replace, they still act as nutrient-accumulating patches (Daryanto et al., 2012), suggesting that ploughing might also increase connectivity between soil nutrients. An increase in the connectedness of woody plants (trees and shrubs) would also be mirrored in increases in the continuity of shade, with positive feedback effects on stock movement, potentially altering the distribution of dung. Given that woody plants are often highly preferred areas for animal camping (e.g., Eldridge and Rath, 2002; Milton and Dean, 2001), an increased distribution of both woody patches and dung would likely increase the heterogeneity in soil N (Afzal and Adams, 1992). However, ploughing is known to reduce biological soil crust cover and recovery is slow, even two decades after ploughing (Daryanto and Eldridge, 2010). Destruction of biological crusts increases the risk of erosion because it creates areas of bare soil and destabilises soil aggregates, resulting in the reduction of nutrient accumulation and the size of fertile islands. Because of increased woody cover connectivity and reduced soil crust cover after ploughing, it could be expected, therefore, that the spatial distribution of resources at the ploughed site would be complex, depending on the interactions of multiple factors such as grazing, changes in shrub cover and biological crust cover.

Whilst there have been numerous studies of the effects of grazing on the spatial distribution of vegetation, there are fewer studies of soil- and soil surface-related effects, particularly in response to the physical removal of woody plants by ploughing. To fill this knowledge gap, we aimed to understand how both grazing and ploughing affected the spatial distribution of soil and surface features. In this study, we explore the effects of two land management practices, shrub removal by ploughing, and grazing by domestic herbivores, on the spatial distribution of soil nutrients and the underlying mechanisms forming such spatial patterns in an arid shrubland. First we compared differences in the spatial organisation of soil nutrients between a grazed and ungrazed site, which both had an intact shrub layer (grazing effect). Our second comparison examined potential ploughing effects at two sites, both of which have been grazed for more than 150 years (ploughing effect). Specifically, we expected that grazing would reduce the connectivity of shrub patches, reduce the cover of biological soil crusts, but increase the range of litter, compared with the ungrazed site. This would be expected to occur due to livestock-induced trampling and the effect that grazing animals have on the dispersal of surface litter. As the cover of litter and biological crusts could affect both soil surface carbon (C) and nitrogen (N) pools, we expected that the spatial pattern (i.e., autocorrelation range) of litter and biological crust cover would change with grazing, and be more closely aligned with the autocorrelation range of C and N, respectively. The increasing density of shrubs at the ploughed sites compared with the unploughed site would increase the connectivity i.e. the autocorrelation range, of shrub and litter cover and thus the connectivity of soil C. Similarly we expected that the autocorrelation range of biological crust cover and thus N would decline with ploughing due to the poor recovery of crusts after ploughing.

2. Methods

2.1. Study area

The study was conducted at ‘Wapweelah’, an extensive grazing property about 35 km west of Engonia near Bourke in north-western New South Wales, Australia (29° 16′S, 145° 26′E). The site falls within Gumbalie Land System (Walker, 1991), which is dominated by mulga (*A. aneura*) woodlands. The landscape is characterised by sandplains with low west–east trending sandy rises and dunes of Quaternary aeolian alluvium. Minor to moderate windsheeting and watersheetings are common. The sandplain unit is mostly level, with few undulations and the slopes are less than 1%. The soils at Wapweelah are classified as red sodosols with strong texture contrast between the non-strongly acidic A horizons and sodic B horizons. These soils support a wide array of native vegetation communities, including *Acacia* and *Casuarina* shrublands in Queensland and New South Wales (Isbell et al., 1997; Isbell, 2002). Mean annual rainfall is about 312 mm, and about 45% more rain falls during summer than winter (Robson, 1995).

The sandplain unit of Gumbalie landsystem is characterised by dense shrubs dominated by turpentine (*Eremophila sturtii*), narrow-leaf hopbush (*Dodonaea viscosa* var. *angustissima*), green turkey bush (*E. gilesii*), budda (*E. mitchellii*) and wild orange (*Capparis mitchellii*). There are few scattered trees of mulga, ironwood (*A. excelsa*), bimble box (*Eucalyptus populnea*), belah (*Casuarina cristata*), rosewood (*Alectryon oleifolius*), leopardwood (*Flindersia maculosa*), supplejack (*Ventilago viminalis*), wilga (*Geijera parviflora*), gidgee (*A. cambagei*) and brigalow (*A. harpophylla*). The understorey layer is sparse, and at the time of observation consisted of heavily grazed wollybutt (*Eragrostis eriopoda*), mitchell grass (*Thyridolepsis mitchelliana*), mulga oats (*Monochather paradoxa*), speargrass (*Austrostipa scabra*), other grasses and forbs. This land system is typical of areas targeted for blade ploughing (Robson, 1995; Walker, 1991).

2.2. Experimental design

In 1990, one area of 200 m × 400 m was established and divided into four linear plots of 100 m wide by 200 m long. Two of the four plots were then enclosed in herbivore-proof fence 6 m tall, and the unfenced-plots were subject to grazing by sheep, goats, cattle, kangaroos, rabbits and camels. One of both the fenced and unfenced plots was then ploughed and left the remaining unploughed, resulting in four combinations of grazing and ploughing: ploughed–grazed, ploughed–ungrazed, unploughed–grazed and unploughed–ungrazed. Ploughing was conducted with a single pass of a 4.2 m wide single-tyned ‘Stationmaster’ blade plough pulled by a 90 kW crawler tractor. Only shrubs were targeted, and examination of fallen shrubs confirmed a satisfactory ploughing effect over most of the treated area (Robson, 1995). Here we report the spatial heterogeneity of soil in three of these plots. We excluded the ploughed–ungrazed plot because it is unlikely to be applied widely be land managers as a management tool.