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# The effect of pasture utilization rate on stocks of soil organic carbon and total nitrogen in a semi-arid tropical grassland

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ABSTRACT

The influence of grazing management on total soil organic carbon (SOC) and soil total nitrogen (TN) in tropical grasslands is an issue of considerable ecological and economic interest. Here we have used linear mixed models to investigate the effect of grazing management on stocks of SOC and TN in the top 0.5 m of the soil profile. The study site was a long-term pasture utilization experiment, 26 years after the experiment was established for sheep grazing on native Mitchell grass (*Astrebla* spp.) pasture in northern Australia. The pasture utilization rates were between 0% (exclosure) and 80%, assessed visually. We found that a significant amount of TN had been lost from the top 0.1 m of the soil profile as a result of grazing, with 80% pasture utilization resulting in a loss of 84 kg ha$^{-1}$ over the 26-year period. There was no significant effect of pasture utilization rate on TN when greater soil depths were considered. There was no significant effect of pasture utilization rate on stocks of SOC and soil particulate organic carbon (POC), or the C:N ratio at any depth; however, visual trends in the data suggested some agreement with the literature, whereby increased grazing pressure appeared to: (i) decrease SOC and POC stocks; and, (ii) increase the C:N ratio. Overall, the statistical power of the study was limited, and future research would benefit from a more comprehensive sampling scheme. Previous studies at the site have found that a pasture utilization rate of 30% is sustainable for grazing production on Mitchell grass; however, given our results, we conclude that N inputs (possibly through management of native $N_2$-fixing pasture legumes) should be made for long-term maintenance of soil health, and pasture productivity, within this ecosystem.

## 1. Introduction

Grazing lands occupy nearly 40% of the world's land area, and play an important role in terrestrial total soil organic carbon (SOC) storage and nutrient cycling. The influence of grazing on the stock of SOC in tropical grasslands is an issue of considerable ecological and economic interest. Tropical grasslands—which we broadly define as relatively natural ecosystems dominated by $C_4$ grasses, growing in climates less-than-favourable for forest or crops—cover large parts of Africa, Australia, Asia and South America. In these ecosystems, grazing management interacts with primary production to influence the growth of above- and below-ground pasture biomass (Klumpp et al., 2009; Orr and Phelps 2013a). It is advisable for graziers to manage the stock of SOC, due to its important benefits for soil fertility, structural stability, water-holding capacity, and biological diversity (Rice et al., 2007), and the flow-on benefits for economic and ecosystem sustainability. Many of these benefits first become apparent in the labile fraction of SOC, for example, particulate organic carbon (POC) (Cambardella and Elliott, 1992).

SOC is closely associated with total N in the soil organic matter (Magdoff and Weil, 2004) hence any changes in SOC also affect soil total nitrogen (TN), which is dominated by the organic fraction. In unfertilized rangelands the major source of N for pasture production is from the mineralization of soil organic matter, which is replenished from above- and below-ground plant matter. Reductions in pasture growth lead to lower inputs of soil organic matter, which in turn reduces TN, and thus creates a negative feedback loop. Management effects on grazing lands must thus be assessed not only for changes in stocks of SOC and POC, but also for

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changes in TN stock, since the latter controls SOC storage and turnover (Torn et al., 1997), and any reduction in TN reduces N supply to pasture and leads to reduced pasture production (Piñeiro et al., 2010).

Excessive grazing pressure, generally expressed as the percentage utilization of pasture growth (McKeon et al., 2004), is known to lead to degradation and reduced pasture productivity in grasslands (Dyksterhuis, 1949; Phelps and Bosch, 2002). Previous studies on the influence of grazing have reported positive, negative or no effect on SOC stock (McSherry and Ritchie, 2013) and TN stock (Piñeiro et al., 2010), which is unsurprising given the evidence of the complex role of SOC in the grazing ecosystem (Allen et al., 2010; Cook et al., 2010; Piñeiro et al., 2010; McSherry and Ritchie, 2013) and interactions between grazing pressure and soil type (Pringle et al., 2011). It is likely that below-ground root biomass is also affected by grazing pressure, although its impact on SOC, POC and TN stocks is less clear (Piñeiro et al., 2010; McSherry and Ritchie, 2013).

Piñeiro et al. (2010) proposed that grazing effects on SOC and TN are expressed by three major pathways: (i) changes in C inputs through net primary production; (ii) changes in N supply; and (iii) changes in organic matter decomposition, for example expressed through changes in POC and the C:N ratio. They suggested that increasing N retention may lead to increases in both productivity and SOC stock, with smaller C:N ratio and improved quality of soil organic matter. Previous studies have not had access to direct estimates of pasture utilization as a measure of grazing pressure, and have been limited in their capacity to establish a link between pasture utilization rate and soil SOC, POC, and TN stocks and the C:N ratio.

Orr and Phelps (2013a,b) reported on a long-term sheep-grazing study where annual utilization rates were set by "calculating the number of stock required to utilize a percentage of the herbage over the following year, in the absence of further growth". Orr and Phelps (2013a) found that the aboveground biomass of *Astrebla* spp. (Mitchell grass) was reduced at high utilization levels, with large inter-annual fluctuations resulting from an interaction with rainfall amount and distribution. High utilization levels ($\geq$50%) also led to local depletion of legumes over the 26-year study period. Presumably, reduced biomass and a lack of legumes could result in lower soil organic matter, and reduced N mineralization and inputs. Livestock grazing could also remove N through the off-take of animal product, in this case as meat and wool (Van Horn et al., 1996).

The aim of this study was to examine the effect of 26 years of continuous grazing (by sheep) of tropical Mitchell grass (*Astrebla* spp.) on the stocks of SOC, POC, TN, and the C:N ratio.

## 2. Methods

### 2.1. Study area

The Toorak pasture-utilization experiment was located in the Mitchell Grass Downs bioregion (Department of the Environment, 2012) of western Queensland, Australia (Fig. 1). This bioregion covers 45 million ha across Australia and is characterized by undulating plains of Mitchell grass (*Astrebla* spp.), a $C_4$ perennial that provides valuable year-round feed for domestic livestock (Orr and Phelps, 2013a). Mitchell grass is nutritious, long-lived (>20 years), and resilient to grazing and drought (Orr, 1975; Orr and Holmes, 1984; Orr and Phelps, 2013a). Median annual rainfall is 429 mm and strongly summer-dominant, with the July–September median being 0 mm (based on 1912–2011 data from Julia Creek 40 km to the north, the nearest meteorological station). Rainfall is highly variable from year to year with the 1st decile being 274 mm and the 9th decile 766 mm.

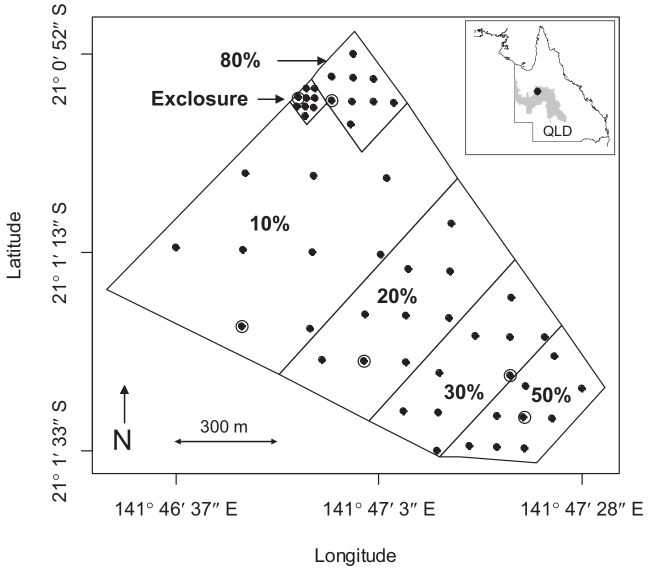

**Fig. 1.** Layout of the Toorak pasture-utilization experiment. Closed circles represent where soil was sampled; open circles represent where an additional soil sample was taken within 1 m of a closed circle. Inset: the location of Toorak (closed circle) in relation to the Mitchell Grass Downs bioregion (grey polygon) of Queensland, Australia.

The characteristic soil of the Mitchell Grass Downs is a Vertisol (IUSS Working Group WRB, 2006). Clay content is relatively uniform in the soil profile, at around 55–60% to 1.2 m depth. Soil pH increases from about 7 to 8 between the surface and 1.2 m depth. Vertisols shrink and swell depending on the moisture content. When dry, Vertisols form deep and wide cracks, creating a harsh environment for plant roots. Consequently, tree cover in the region is sparse, but Mitchell grass thrives due to its deep and vertically aligned root system (Orr and Holmes, 1984).

The experiment was established in 1984, consisting of five unreplicated nominal rates of pasture utilization by sheep (10%, 20%, 30%, 50%, and 80%) and an exclosure (ungrazed by sheep, termed 0% herein) (Fig. 1). These we refer to as 'treatments'. Orr and Phelps (2013a)—who were responsible for running the experiment—state that, given their limited resources, it was more effective to use a wide range of unreplicated treatments than a narrower range with replication. Moreover, they consider the Mitchell Grass Downs bioregion to be sufficiently uniform for the results of the experiment to be reliably extrapolated. The extent of each treatment was initially determined by the area required to feed 20 sheep at the nominal pasture utilization rate. Following that, stocking rates were adjusted at the end of each summer, to meet the intended pasture utilization rate for the coming year. By the late 1990s, results of the experiment were suggesting that Mitchell grass responds positively to moderate grazing: the 80% treatment had become dominated by annual species that could not sustain sheep for 12 months of grazing, while Mitchell grass in the 0% treatment had partially died out (Orr and Phelps, 2013a). The experiment was decommissioned in May 2010.

### 2.2. Soil sampling, laboratory analysis, and computation of stocks

In May 2010, $n = 60$ soil-sampling locations were proposed across the experiment, 10 per treatment in a grid pattern. To help capture the short-range variability of soil attributes we randomly chose one grid node and moved it to within 1 m of another randomly chosen grid node (Fig. 1). At each of the 10 locations a core of soil (average diameter of 0.043 m) was extracted by a