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Author

Sanjari, G, Ghadiri, Hossein, A. A. Ciesiolka, Cyril, Yu, Bofu

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Comparing the effects of continuous and time-controlled grazing systems on soil characteristics in Southeast Queensland

By

Gholamreza Sanjari [1,2], Hossein Ghadiri [1], Bofu Yu [1], Cyril A A Ciesiolka [3]

[1] Griffith University, faculty of environmental science, Qld, Australia

[2] Research institute of forests and rangelands, Tehran, Iran

[3] Department of natural resources and mines, Toowoomba, Qld, Australia

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Corresponding author: Hossein Ghadiri, Griffith School of Environment, Griffith University, Nathan, QLD 4111, Australia Phone: (07) 3735 5175 Fax: (07) 3735 7459

Email: H.Ghadiri@griffith.edu.au

Abstract:

Grazing by livestock has a great influence on soil characteristics with major effects on soil carbon and nitrogen cycling in grazing lands. Grazing practices affect soil properties in different ways depending on the prescribed stocking rate and grazing periods. The new grazing system of short intensive grazing followed by a long period of rest referred to as time-controlled grazing (TC grazing) has become popular amongst many graziers in Australia and elsewhere in the world. However, little research has been carried out on the impacts of this grazing system on the physical and chemical health of the soil. To address this issue, a comprehensive field study was carried out in a sheep grazing property of Currajong in south east region of Queensland, Australia where the two grazing systems of continuous and TC grazing were compared. Results obtained on the impact of grazing management on soil characteristics over a five-year period (2001 – 2006) showed an increase in soil organic carbon (SOC) and nitrogen (SON) in the areas with favorable soil condition over the study period as compared with continuous grazing. There was also an increase in ground litter accumulation over time and no compaction in TC grazing. Nitrate and extractable P concentrations were reduced by higher grass growth occurring under TC grazing, which in turn decreases the contamination potential for downstream water bodies. This reduction was much more pronounced on a historical sheep aggregation camp turned into TC system, where a large amount of fecal materials had been deposited prior to the its convertion to TC grazing. The smaller size of the paddocks along with the long rest period provided by TC grazing in this area recognized to be the

major contributors to both physical and chemical recovery of the soil after each grazing operation.

Key words:

bulk density, ground litter, organic matter, organic carbon, organic nitrogen, extractable P, NO_3-N

Introduction:

Grazing practices are recognized as the key drivers to manage and control soil quality in grazing lands. Sustainable utilization of grazing lands requires management strategies that do not compromise the capacity of soil to function over the long-term (Liebig et al. 2006). Depending on the ecosystem resilience and disturbance feedback, grazing causes either positive or negative effects on soil properties (Franzluebbers and Stuedemann 2003).

A system of flexible, high-intensity, short period grazing followed by a long period of rest (HI-SG) was first put forward by Savory in 1978 (Savory and Parsons, 1980) and was later introduced to Australia in 1989 by Stan Parsons as “Cell Grazing” (McCosker 2000). The terms of “The Savory Grazing System”, “Short Duration Grazing” and more specifically in this paper “Time-controlled Grazing” are the common names of the new grazing system. Time-controlled grazing (TC grazing) has been increasingly popular amongst graziers in Australia and the rest of the world over the past two decades. However, little research has been carried out on the impacts of this grazing system on the soil physical and chemical characteristics.

Soil organic matter (SOM) is regarded as a major determinant of ecosystem health and stability and the largest reservoir of carbon (C) and nitrogen (N) in most grazing land ecosystems (Brady and Weil 1999; Kumar and Goh 2000; Follett 2001). It provides a primary source of many plant nutrients, improves the water-holding capacity of soil and is responsible for the formation of stable aggregates that protect the soil from erosion. In

recent years, increase in SOM to achieve higher and sustainable productivity in grazing lands is not the only objective for changing grazing strategies as it is now increasingly recognized as a solution to global warming through the sequestration of a large amount of atmospheric carbon dioxide into the soil organic carbon pool (Lal 2003).
Studies on soil organic carbon (SOC) and nitrogen (SON) accumulation in response to grazing management have been mostly focused on different types of continuous grazing under a variety of stocking rates. The results of such studies are inconsistent with some showing a decrease (Bauer et al. 1987; Frank et al. 1995; Derner et al. 1997), no change (Milchunas and Lauenroth 1993; Kieft 1994; Manley et al. 1995; Mathews et al. 1996), or increase (Ruess and Mcnaughton 1987; Dormaar et al. 1990; Dormaar and Willms 1990a) in SOC and SON under different grazing intensity. Changes in SOC and N under TC grazing however have not been well researched. Southorn (2002) is probably the only researcher who reported some increase in SOM under TC grazing and attributed it to a larger proportion of plant material being trampled, broken down, and incorporated into soil by livestock.

A high rate of SOM decomposition that eventually decreases SOC and N is attributed to intensive grazing involving excessive trampling which occurs more frequently under continuous grazing with high stocking rates (Theron 1955; Du Preez and Snyman 1993). Grazing-induced nutrient accumulation in soils, whilst desirable for increasing pasture production, has the potential of causing environmental concerns through washing off and leaching the contaminants to downstream water bodies (Correll 1996; Sharpley et al. 1996). This adverse impact on water quality may occur either through the rapid mineralization of organic material or imbalanced distribution of urine and faeces in paddocks due to the establishment of animal aggregation camps. These camp sites, which threaten downstream water quality, are more likely to occur in large paddocks under continuous grazing where animals are allowed to graze more selectively and deposit nutrients in some specific areas of the paddock. Small paddocks however are known to be more evenly grazed with evenly distributed urine and manure (Haynes and Williams 1993; Mueller and Green 1995). Time-controlled grazing which is basically carried out in a large number of small paddocks is therefore expected to contribute to more uniform distribution of urine and faeces across the paddocks by modifying animal aggregation behavior and camp sites development. However no study has been carried out to test such a hypothesis.

The impact of grazing systems on soil physical characteristics such as bulk density and compaction is another aspect of this investigation. Grazing-induced compaction affects soil bulk density at different rates depending on the amount of available plant residue on the ground (Rodd et al., 1999; da Silva et al., 2003). Bulk density and porosity in turn affect water and aeration status of the soil, as well as root penetration and development. They are therefore important soil physical properties to be monitored on grazing lands. Bulk density is also inversely related to the SOM (da Silva et al. 1997; Gifford and Roderick 2003) and their interaction can become an important factor in the effectiveness of grazing systems.

Time-controlled grazing has been shown to improve soil physical condition through converting the above-ground organic matter to litter without causing soil compaction

(Goodloe 1969) and to increase the abundance of micro-arthropods in the 0 – 10 cm soil depth (Tom et al. 2006). However, Dormaar et al. (1989) reported that TC grazing had a negative effect on bulk density, due to compaction by grazing animals. This anomaly highlights that further studies are clearly needed.

This paper is based on the results of a large scale field experiment carried out over a 5 years period on a grazing paddock in southeast Queensland. The effects of the two grazing systems of TC and continuous on the physical (bulk density and ground litter) and chemical (SOC, SON, NO_3^- and extractable P) properties of soils are reported in this paper. The hypothesis tested in this study is that the TC grazing system significantly improves physical and chemical properties of grazing land soils, over the continuous grazing system, by reducing soil bulk density, incorporating ground litter into the top soil, and increasing TOC and SON.

Methods:

Study sites

The study area is located on the property of Currajong 40 km west of Stanthorpe in a semi-arid region of southeast Queensland Australia (28º 33' S, 151º 33' E , altitude 675 m) in the headwaters of Treverton Creek in the Murray-Darling Basin. Long term mean annual rainfall is 645 mm with dominant summer rain (70 percent falling in the six months of October - March). Rain in the dry season (Mar - Sep) is characterised by relatively small events both in magnitude and intensity associated with frontal depressions, while in the wet period, there is a high frequency of moderate to large events of short duration thunder storms and long duration cyclonic depressions.

Vegetation in the area is native perennial grasses dominated mostly by Queensland blue grass [*Dichanthium sericem* (R. Br.) A. Camus], different wire grasses including Aristida vegans and Barbed wire grass [*Cymbopogon refractus* (R.Br.) A.Camus] plus some remnant native gum trees. Coolatai [*Hyparrhenia hirta* (L.) Stapf] as an introduced perennial grass is spreading throughout this area.

Soils in the study area are mostly clay to clay loam in texture (Table 1). Geology comprises part of the Warroo land system, generally referred to as Traprock. This is a complex mixture of highly deformed sandstone, mudstone, inter-bedded conglomerate, limestone and volcanics (Maher, 1996). Geomorphologic characteristics of lands in this region have been described by Wills (1979).

Treatments

This research was conducted on a commercial pasture property which was in the process of converting from long term continuous grazing system to TC grazing. It thus provided us with an opportunity to study the impacts of the new grazing system on soil, water, vegetation, nutrient and sediment changes in comparison with continuous grazing. In this paper our focus is only on the soil responses to these two methods of grazing.

The application of TC grazing system required the large paddocks in the property to be sub-divided into a number of smaller paddocks (cells) using electric fences. Two such cells ranging in area from 84 to 250 hectares were used for this experiment; one for TC grazing and the other for continuous grazing. The paddocks assigned to the grazing treatments were divided each into two sections based on the physiographic features of the land (slope and soil depth) (Table 1). C1 and C2 under TC grazing, and C3 and C4 under continuous grazing, are here forth called sub-treatments. There were also some physiographic similarities between C1 and C4 on the one hand and between C2 and C3 on the other hand, which have been useful when comparing the two grazing methods.

Approximate position of table 1

A total of 52 permanent sampling sites were allocated to the treatments, of which 8 sites were on the non-grazed treatment and the rest were equally distributed between the four sub-treatments of C1 to C4 located in a down-slope catenary sequence to cover all land form components. These sites were used for periodic sampling of soil and ground litter during the 5 years life of the project.

Stocking rate, grazing duration and rest periods in TC grazing were adjusted according to the feed on offer and grass growth rate and therefore were subject to change between the cells. Maximum efforts were made to keep the stock numbers close to the optimum stocking rate (as decided by the grazier) within the cells. The stocking rates for the two management treatments are expressed as a dry sheep equivalent (dse), and given in Table 2. In continuous grazing, a fixed stocking rate of around 1.6 dse/ha was applied for the whole year.

Approximate position of table 2

Sample analysis

Ground litter and bulk density samples were randomly collected from around the permanent sampling sites using a 0.25 m^2 quadrat and a long tube soil corer (44 mm in diameter). For the soil depth, it was assumed that the top 10 cm of soil profile contained the highest amount of organic material and this layer was most likely to change in response to different grazing managements (Du Preez and Snyman 1993; Paul and Clark 1996). Composite samples were taken from the top 10 cm, oven dried at 40 °C, passed through a 2 mm sieve to remove plant material and stored at 4 °C. These samples were used for the measurement of soil TOC, TON, NO_3^-, NH_4^+, PO_4^{2-} as well as pH, EC and texture. EC and pH were measured in a 1:5 soil/water suspension (Rayment and Higginson 1992) and for soil particle size analysis, the hydrometer method was used (Kim 1996).

Total soil organic carbon (TOC) was measured using the rapid wet oxidation method (Walkley and Black 1934) modified by Sims (1976). In this method SOC content, after oxidizing by potassium dichromate and sulfuric acid, was calculated from the amount of chromic ion (Cr^{3+}) formed using a colorimetric procedure measuring absorbance at 588 nm.

Total soil organic nitrogen was determined with a semimicro-kjeldahl procedure (Bremner, 1996). This involved sample digestion by concentrated sulfuric acid in the presence of a copper sulfate catalyst and potassium sulfate using a block digester followed by a colorimetric determination of NH_4^+ in the digests (Lachat, 1992). SON was the difference between Kjeldahl-N and residual NH4–N. For the measurement of inorganic nitrogen (NO_3^- and NH_4^+), 2M KCL solution was used for extraction, with a 1:10 ratio of soil to extractant (Bremner and Keeney, 1966). The mixture was shaken for 1 hour then centrifuged at 2000 rpm for 20 minutes and filtered through a Whatman 42 filter paper and analyzed using an autoanalyzer (Lachat, 2001). Orthophosphate extraction was performed using Colwell method (Colwell, 1963) which is a modification of the original bicarbonate procedure (Olson et al., 1954) that employs an extracting solution of 0.5M $NaHCO_3$ adjusted to pH 8.5. The extracted phosphorous was determined calorimetrically by a molybdate blue method (Murphy and Riley 1962) using an auto analyzer procedure.

Statistical analyses

All statistical comparisons in this paper are based on 90% confident interval using SPSS 14 package; however p-values beyond the significant levels are also reported. Analysis of variance was used to test SOC, SON, nitrate, extractable p, mulch and bulk density changes over time (2001 to 2006) in different treatments (TC grazing, continuous grazing and no grazed) and Sub-treatments (C1, C2, C3 and C4). Pearson correlation analysis was performed to test the changes in residue and bulk density over the time.

Results and Discussion:

Effect of grazing methods on residue accumulation and bulk density

Ground litter accumulation was increased significantly under TC grazing as compared with continuous grazing. Both C1 and C2 (TC grazing) showed highly significant differences in mulch accumulation through time. In contrast, for the continuous grazing sub-treatments, only C4 showed a positive mulch accumulation and C3 did not change over the time (Table 3). Increased ground litter accumulation under TC grazing is attributed to the significant enhancement of aboveground pasture production over time which is presented later.

Based on the correlation between residue accumulation and time, a linear regression model is presented in Table 3 for estimation of ground litter mass at any time over the course of the study which may have application in vegetation-runoff studies under natural events.

Approximate position of table 3

The results on bulk density indicate a significant increase under C3 of continuous grazing ($p \leq 0.1$) but remained constant under all other treatments (Table 4). Similar results were shown by another set of bulk density comparisons using soil cores taken at fixed times, during the first and the last years of the trial, thus allowing investigation of possible seasonal effect. The fixed-time comparison include samples taken on May 2001, Nov 2001 and July 2002 as the first year of the experiment which was repeated on July 2005, Nov 2005 and May 2006 as the last year of experiment (Table 4). These results indicate that soil compaction can take place under continuous grazing but not under TC grazing. Bulk density in TC grazing remained unaffected (C2 & C1).

Approximate position of table 4

Lower soil compaction and damage under TC grazing in this area is basically attributed to the higher accumulation of ground litter over time. Ohu et al. 1985; Gupta et al. 1987; Wheeler et al. (2002) and Da Silva et al. (2003) reported that the presence of an organic top layer, dissipates the force of animal hooves on soil surface resulting in less compaction and lower bulk density of the soil underneath, which appears to be the case in this study. Soil bulk density has been found to increase in soils with a high quantity of fine soil particles (clay + silt) which make them more sensitive to animal traffic and compaction (Vanhaveren 1983; Abdelmagid et al. 1987). The soils of our experimental paddocks were fine in texture, mostly of clay to clay loam type. Thus the compaction observed in C3 was probably more due to the grazing management which left insufficient litter on the ground to protect the soil surface from animal traffic and compaction.

Under the no-grazing treatment, ground litter was accumulated ($p = 0.11$) over the time, which is in agreement with Su (2003) however the lack of grazing animals to break it down and incorporate into the top soil, resulted in a reduction in soil organic carbon and nitrogen and no change in soil bulk density.

Soil TOC and TON responses to the grazing treatments

As illustrated in Fig 1a & 1b an overall noticeable increase occurred in TOC ($p = 0.16$) and to a lesser extent in TON ($p = 0.29$) under TC grazing treatment from 2001 to 2006, but not at statistically significant level. Over the same period, no changes were observed in these variables under continuous grazing treatment.

Approximate position of Figure 1

The results of the sub-treatments (Fig 2a & 2b), showed more variation in soil responses to TC and continuous grazing systems, depending on differences in geomorphology features of land and soil properties. Under TC grazing, C1 showed a significant increase in TOC ($p \leq 0.10$) and TON ($p = 0.18$) over the time however, but this factor remained constant under C2. On the other hand, continuous grazing under C4 experienced small increase in soil carbon ($p = 0.31$) and nitrogen ($p = 0.39$) while in C3 showed a small decline in SOC ($p = 0.33$) and no change in SON.

Approximate position of Figure 2

It appears that the 6 years period of this study hasn't been long enough to clearly show the difference between the two methods of grazing for all the factors considered. However the results clearly indicate a relative increase in SOM through time under TC grazing over the continuous grazing. The main reasons for such an increase in SOM under TC grazing system appears to be the higher rate of grass growth and longer rest periods. The same two factors also contributed to the higher accumulation of ground litter under TC grazing, which was reported earlier.. These results appear to be consistent with those of Southorn (2002). He attributed the accumulated soil carbon to the larger proportion of plant material being incorporated into the soil under TC grazing over continuous grazing. Gillen et al. (1991) suggested that the long period of rest is a key driver in the recovery of grazed species and this has played a major role to substantially increase the above ground organic material followed by its subsequent incorporation into the soil resulting in increased SOM.

Root decay, even though not measured in this experiment, appears to be another reason for increasing SOM under TC grazing. It has been reported that the intensive defoliation under a single grazing event after a rest period (common in TC grazing), results in ceasing respiration leading to the death of a large amount of roots within a few hours after grazing in order to equalize the biomass (Richards 1993). The quantity of root pruned in this way depends on grazing intensity and the total root mass which is the main source of below ground soil organic matter (Jones 2000). Root mass which is mostly reported to be more than twice that of above-ground biomass (Ross 1977; Hall and Lee 1980; Christie 1981; Montani et al. 1996) provides a large amount of vertically oriented pores after dying off, facilitating better infiltration.

Less animals treading under TC grazing have probably had a positive indirect effect on soil carbon and nitrogen providing a faster soil physical and biological recovery following each grazing period. Abdelmagid et al. (1987) showed the maximum distance traveled by grazing animals under continuous grazing is around 4.8 km/day, while this distance under the short period grazing (i.e. TC grazing) is 1.6 km/day for the same stocking rate. Taking the average hoof print size of the grazing animal into consideration, the above figures suggest that around 22% of the pasture area is trampled on under the continuous grazing system while this fraction is only 7% for TC grazing.

The results of sub-treatment comparisons appear to indicate that TC grazing causes larger increase in soil carbon and nitrogen over time as compared with continuous grazing when the soil physical properties are relatively favorable (C1 vs. C4). Conversely, when the soil is shallow or on a steep slope, as it's the case for C2 and C3, SOC tend to decline in continuous grazing (C3) while TC grazing appeared to maintain its level of SOC over the time (C2).

The increased SOC in TC grazing treatment reported in this study has an added dimension of carbon sequestration. Our results show that on average 1.37 ton/ha extra carbon is locked up in the top 10cm of the soil under TC grazing compared with the continuous grazing . This figure was as high as 3.13 tons/ha in C1 where the soil condition was more favorable for plant growth and SOC increased significantly over time.

The enclosures, which were kept ungrazed for the entire 6 years period of the study, experienced a slight decline in both soil carbon and nitrogen over time (Figures 1a & 1b). While this decline over time is not statistically significant, the trend shows a possible negative effect of long term animal exclusion on soil organic matter. Grazing animals appear to positively contributing to nutrient cycling, plant growth, and soil biological activities of the paddock. Increased ground litter in the enclosures zone as compared with the grazed areas is can be the reason for the decline in soil organic matter in this zone since they would not be trampled on, broken down and incorporated with the top soil by grazing animals.. Under non-grazed treatment, another part of plant residue referred to as standing residue also does not contribute to soil organic materials. This fraction which accounts for 8 – 16% of the total above ground dry matter in our experiment is possibly one of the reasons for the reduction of SOC and SON in the ungrazed area. The important role of grazing animals in converting surface litter into SOC and incorporating it with the top soil has also been reported by Naeth et al. (1991). Schuman (1999) also reported a reduction in soil organic carbon and nitrogen in soils under grazing exclusion zones as compared with grazed areas.

Effects of grazing on soil C:N ratio, available nitrogen and phosphorus

The C:N ratio of soil organic matter varied between the treatments and over time, ranging from 11 to 15 (Fig 3). This ratio increased slightly over time in soils under TC grazing treatment, which was more noticeable in C1 ($p = 0.26$). A similar level of increase is observed in un-grazed treatment ($p = 0.21$). In contrast, the C:N ratio declined (C3) or remained unchanged (C4) under continuous grazing treatment. The C:N ratio remained unaffected over time in the less productive paddocks of C2 from TC grazing and C4 from continuous grazing. None of the above changes are statistically significant, suggesting that a longer period of study might be required for the effect of treatments on C:N ratio to become unequivocal. C:N ratio as an indicator of soil mineralization (Vallejo 1993) has been reported to increase in grazing lands with good management and decrease in the soils with poor management (Theron 1955; Du Preez and Snyman 1993). It has been also shown that excessive trampling decreases soil C:N ratio through more finely breaking down the organic material facilitating better litter-soil contact and more rapid decomposition by microorganisms (Naeth et al. 1991), which eventually decreases soil organic carbon and nitrogen resources.

Approximate position of Figure 3

The results of soil available nitrogen measurement revealed a sharp significant decrease in NO_3^- concentration in C1 and non-grazed treatments and to a lesser extent in C2 and

C4 during the study period ($p \leq 0.01$)(Fig 4c). However, nitrate concentration increased significantly under continuous grazing in C3 ($p \leq 0.01$) which is consistent with the results of Baron et al. (2001), Haynes and Williams (1993) and Whitehead (1995). The ratio of NO_3:TON which shows the soil nitrate as a proportion of total organic nitrogen pool, declined significantly in 2006 as compared to 2001 by a factor of 14, 1.3, 2.2 and 23 in C1, C2, C4 and no grazed enclosures respectively. However, this ratio increased in C3 by a factor of 2 ($p \leq 0.01$) (Fig 4b).

Approximate position of Figure 4

A marked reduction in soil nitrate concentration in C1 (Fig 4c) along with an increase in C:N ratio (Fig 3) over time probably indicate that nitrogen and carbon immobilization by plants and micro-organisms have been the dominant process over mineralization, contributing to the higher soil organic mater accumulation under TC grazing practice (Fig 1). In continuous grazing treatment however, decrease in the C:N ratio and increase in NO_3:TON ratio under C3 indicates that mineralization has been probably the dominant process resulting in a decrease in soil organic matter.

Soils from the non-grazed treatment showed the lowest nitrate concentration (0.17 mg/kg soil) after 5 years of grazing exclusion (Fig 4c) which is in agreement with the findings of Dormaar et al. (1990). This result, along with the small reduction in soil organic matter reported earlier, indicate that the grazing animals may play an important role in nutrient cycling and pasture fertility. Grazing animals use only a small proportion of the nutrient they ingest and 60- 99% of the ingested nutrients are returned to the pasture in the form of dung and urine (Barrow 1987). Therefore a pasture with long term grazing exclusion is subject to a lower productivity through decline in available soil nutrients. Unlike nitrate which declined under grazing exclusion (Fig 4c), soil ammonium concentration increased significantly from 4.56 in 2001 to 13.69 mg/kg in 2006. This result supports the concept that NH_4^+ concentration increases from a minimum in the first successional stage to a maximum in the climax and vice versa for NO3-N (Rice 1984). In other words, under grassland ecosystems when herbivores are left out of pasture for a long time, soil available nitrogen is kept more in the form of ammonium which is less subject to leaching than nitrate.

Extractable P fell markedly in all treatments over the study period ($p \leq 0.01$) (Fig 4a) at different rates. This reduction occurred by a factor of 3.5 under TC grazing and 1.3 under continuous grazing treatments. Decrease in extractable P under TC grazing can be an indication of higher P uptake by plants, thus producing better ground litter cover and higher P lock up. As phosphorous is excreted only in faeces by animals and is not mobile (Haynes and Williams 1993), losses of organic P through water erosion might be the main reason for the decrease in the extractable P concentration under continuous grazing.

Effect of the grazing methods on animal aggregation camps

Grazing practices appear to reduce and control animal aggregation behavior which leads to an imbalance distribution of faeces and urine across the paddocks that is potentially of environmental concern for the contamination of downstream water bodies. Unlike continuous grazing, TC grazing practice which encourages livestock to graze more uniformly and therefore deposit faces and urine more evenly throughout the paddocks is expected to reduce the possibility of animal aggregation camp establishment. To ascertain the extent to which TC grazing can reduce the negative effects of animal aggregation camp, a large hilltop sheep camping site was identified within the area converted to TC grazing in 2001. A long soil sampling transect which passed through this site was identified and nitrate and extractable P were measured on the samples taken along this transet. This sampling and sample analysis were carried out on May 2001 and repeated on May 2006 (only the samples taken from the top 10 cm of soil were analysed). As shown in fig 5 nitrate and extractable P concentrations decreases with distance from the sheep camp in both 2001 and 2006. The result highlights the large amount of nutrients available on sheep camp on 2001 and the subsequent levels in 2006, as compared with the immediate surrounding areas of the transect. Moreover, the high levels of nitrate and available P concentration measured in 2001, as representative of the long term sheep aggregation under continuous grazing, dropped markedly in 2006, some 5 years after its conversion to TC grazing.

Approximate position of Figure 5

The large amount of nutrient consumed by Couch grass [*Agropyron repense* (L.) P.Beauv] as the dominant sheep camp's vegetation over the rest periods is probably the first reason for the reduction of nitrate and extractable P concentrations in the soil solution with time. This grass under TC grazing has an exceptional opportunity for a rapid re-growth producing high amount of palatable herbage after each grazing period soon after the soil moisture condition becomes favorable. An example of 2650 and 3685 kg/ha dry matter re-growth recorded in our experiment within 16 and 60 days rest periods respectively show clearly the ability of this grass to take up large quantities of the available nutrients from the camping site over the rest periods. Under continuous grazing however, the yearlong presence of animals in the paddock inhibit such a re-growth resulting in less nutrient consumption by the vegetation. The second reason is the effect of smaller paddock size under TC grazing compared with continuous grazing, which reduces the uneven distribution of the fecal materials across the paddocks (Haynes and Williams 1993; Mueller and Green 1995).

According to Ewanek (1995) and Johnson and Eckert (1995), concern about losses of P and N by overland flow and the resulting contamination of down stream water, arises when nitrate and available P concentrations in soil profiles exceed 160 kg/ha and 330 kg/ha respectively. The total available nutrient measured from the soil profile inside the camp showed the concentration of nitrate decreased sharply from 126 in 2001 to 17.6 kg/ha in 2006 and similarly available P declined from 222 in 2001 to 79.3 kg/ha in 2006. Although the results indicate that the nutrient concentrations obtained in 2001 in particular for nitrate are a little below the thresholds quoted by Ewanek and Johnson nevertheless, the environmental concerns about continuous grazing still remain, as many animal aggregation sites are normally established around feed lots, water trough and in unproductive areas where no vegetation exists to uptake even minimum amounts of available nutrients. On the other hand, much lower nutrient concentrations measured on 2006 under the sheep camp, once again showed that TC grazing is able to reduce the animal aggregation behavior, which in turn significantly decreases the potential for the contamination of downstream water bodies.

Effect of grazing methods on herbage production

A full report on the results of our investigation into the impact of grazing methods on herbage mass and grazing land production is beyond the scope of this paper. As the paper concentrates on the impact of grazing on soil characteristics however some of the results obtained on herbage production are given in fig 6 as further supporting evidence for the overall superiority in herbage production of TC grazing over continuous grazing in the region, and to show that the noticeable improvement in the physical and chemical properties of soil under TC grazing translates directly into higher herbage production. Fig 6 shows the changes of herbage production under the two grazing management systems over time. Although herbage mass accumulation is strongly influenced by the variation in rainfall, TC grazing has shown a relatively higher overall trend (dotted line) of herbage mass compared with continuous grazing through time. This aspect of the research work is still in progress and the full results, once completed, will be presented separately.

Approximate position of Figure 6

Conclusion

Time-controlled grazing which involves short periods of intensive grazing followed by long rest periods under a flexible regeme, increases above ground organic materials and protects the soil from hoof damage over continuous grazing in the region. This practice also reduces the potential for contamination of downstream water quality through up taking by grass of larger quantities of soluble nutrients. In relation to soil carbon, TC grazing increases soil organic materials significantly only in the areas with a better soil characteristic however, longer time period of monitoring may be needed to draw firm conclusion about the positive impact of TC on SOC. Continuous grazing which excludes rest periods however increases soil damage through reducing soil protection caused by less above ground organic material accumulation and more frequent trampling. Sheep aggregation camps under continuous grazing are more of environmental concern when they are established in unproductive areas with no vegetation. In summary the results of this study appear to suggest that TC grazing, under the prevailing conditions of the study area, is superior to the continuous grazing as far as improving physical and chemical quality of soil, organic material and nutrient accumulation and plant re-growth are concerned. However, a longer period of data collection is needed for the differences between the two grazing practices become more pronounced or statistically significant.

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Figure legends:

Figure. 1. Changes with time in TOC and TON of soils under different grazing treatments. Error bars represent standard error (se)

Figure. 2. Changes in TOC and TON levels of soils in the sub-treatments of time-controlled and continuous grazing systems over the study period. Error bars represent standard error (se)

Figure. 3. Changes with time in C:N ratio of soils organic matter under different grazing treatments. Error bars represent standard error (se)

Figure 4 Changes in the available nitrogen and phosphorus of soils under different grazing systems during the study period. Error bars represent standard errors (se)

Figure. 5. Decline in nitrate and extractable P concentration as a result of the change in grazing management over time and distance from the sheep aggregation camp.

Figure. 6. Changes in herbage production in response to time-controlled and continuous grazing practices and the total rain prior to the sampling dates

Table. 1. A summary of soil characteristics in the study area

Grazing treatments	Soil depth cm	Slope %	Size fraction (%) sand	silt	clay	pH	EC mS
TC grazing							
C1	40	10.2	34.6	28.7	36.7	5.9	0.07
C2	28	15.3	28.1	34.0	38.0	5.4	0.03
Continuous grazing							
C3	27	14.8	45.6	25.3	29.1	5.1	0.06
C4	42	10.0	31.6	31.0	37.4	5.9	0.08
Not grazed	35	13.0	37.1	30.0	32.9	5.6	0.04

Table. 2, Summary of stocking details for the two grazing treatments

Grazing Treatments	Grazing periods (days)	Rest periods (days)	Stocking rate (dse/ha)	Total stocking rate† dse.day/ha
TC grazing	14 ± 9‡	(101 ± 60)‡	12.6 ± 6 ‡	3608
Continuous grazing	365	0	1.6 ± 0.2	3529

‡- Means ± SD †- Total dse days per hectare (DDH) using the original data of individual grazing operations over the whole study period of 2001 to 2006

Table. 3. Statistical analysis of ground litter accumulations in the grazing treatments over time

Grazing treatments	Values range kg/ha	Model equation†	R-Square	Correlation coefficient	p-value
C1	1618 ± 562	Y = 0.766X + 860	0.93	0.9639	0.0005***
C2	865 ± 239	Y = 0.293X + 567	0.75	0.865	0.012 **
C3	680 ± 99	Y = -0.025X + 705	0.03	-0.1762	0.7055 ^{ns}
C4	716 ± 187	Y = 0.196X + 522	0.55	0.742	0.0562*
No grazed	1702 ± 601	Y = 0.561X + 114	0.44	0.6596	0.107 ^{ns}

*- $p \leq 0.10$ **- $p \leq 0.05$ *** - $p \leq 0.01$ ns – no significant different

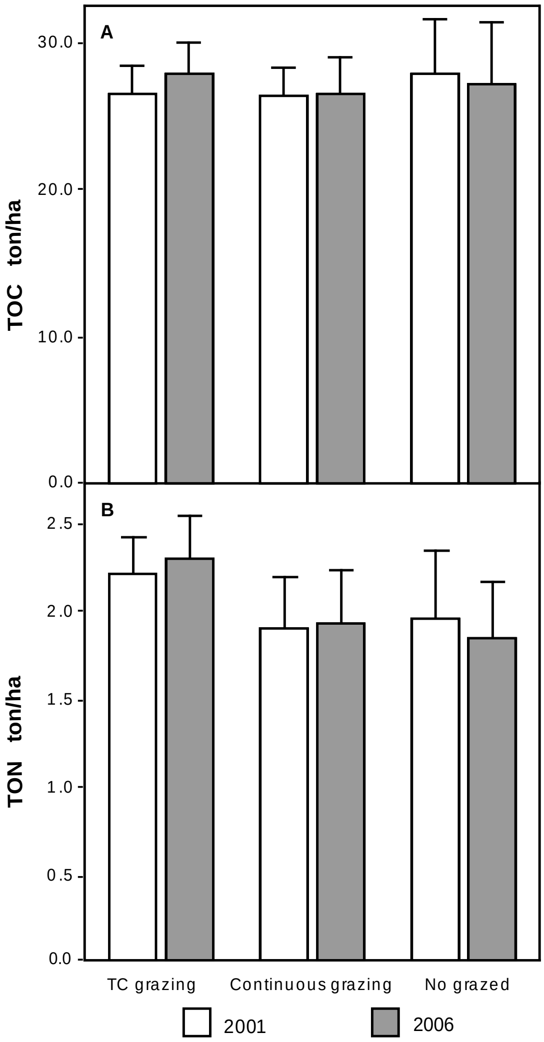
† - X shows the number of days from May 2001 and Y represents the litter mass in kg/ha

Table. 4. Soil bulk density (g/cm^3) responses to the grazing treatments over the study period and the correlation (Pearson) analysis between bulk density and time

Treatments	First year †	Last year †	Difference	Correl cf	*p*-value
Mean TC grazing	1.18 ± 0.02	1.19 ± 0.02	0.01 ns		
C1	1.20 ± 0.04	1.17 ± 0.02	-0.03 ns	-0.2201	0.4891
C2	1.16 ± 0.01	1.19 ± 0.05	0.02 ns	0.2852	0.4569
Mean Continuous grazing	1.22 ± 0.04	1.26 ± 0.03	0.04 ns		
C3	1.19 ± 0.03	1.28 ± 0.04	0.09 *	0.6051	0.0843*
C4	1.25 ± 0.08	1.25 ± 0.04	0.00 ns	-0.142	0.7155
Not grazed	1.15 ± 0.01	1.16 ± 0.01	0.01 ns	0.4119	0.2706

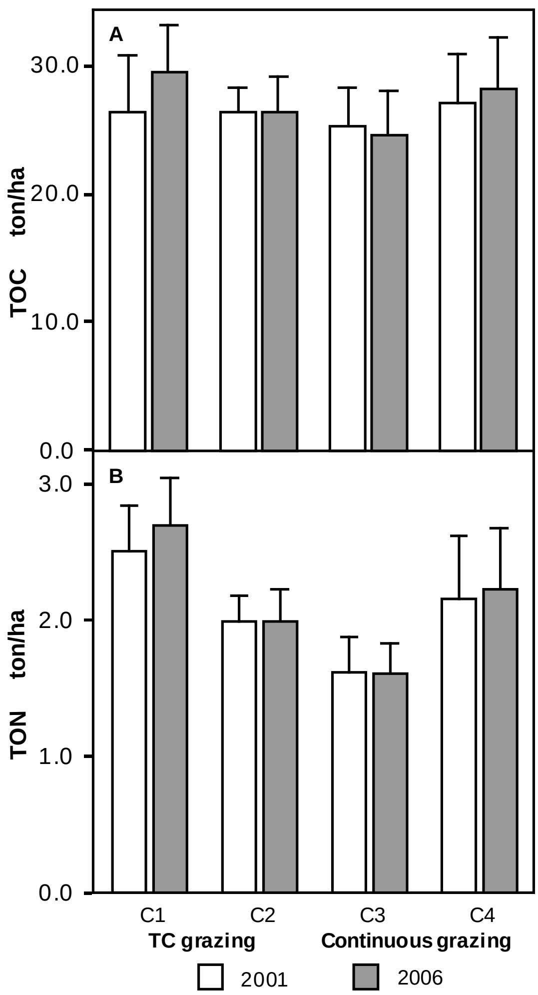
*- $p \leq 0.10$; ns – no significant different; † - Mean ± SD

Figure 1



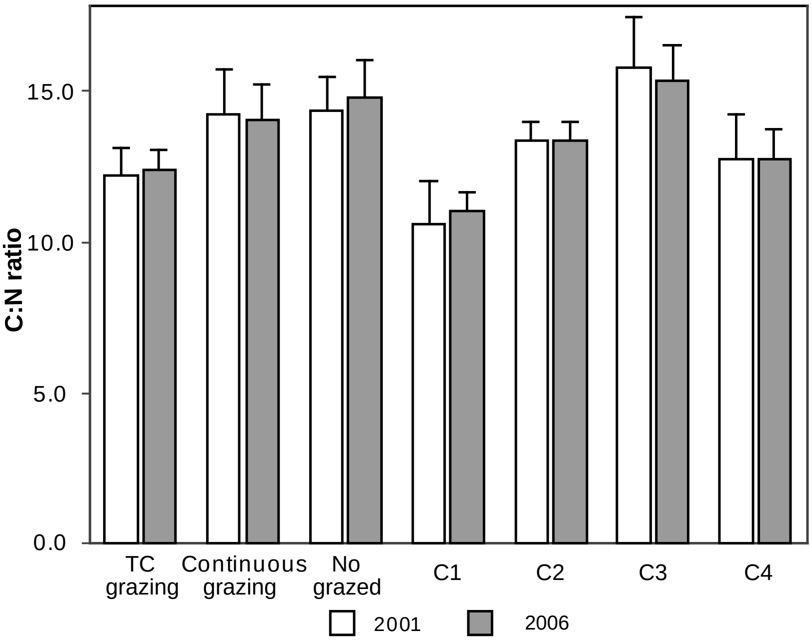
A
30.0
20.0
10.0
0.0
TOC ton/ha
B
2.5
2.0
1.5
1.0
0.5
0.0
TON ton/ha
TC grazing
Continuous grazing
No grazed
2001
2006

Figure 2



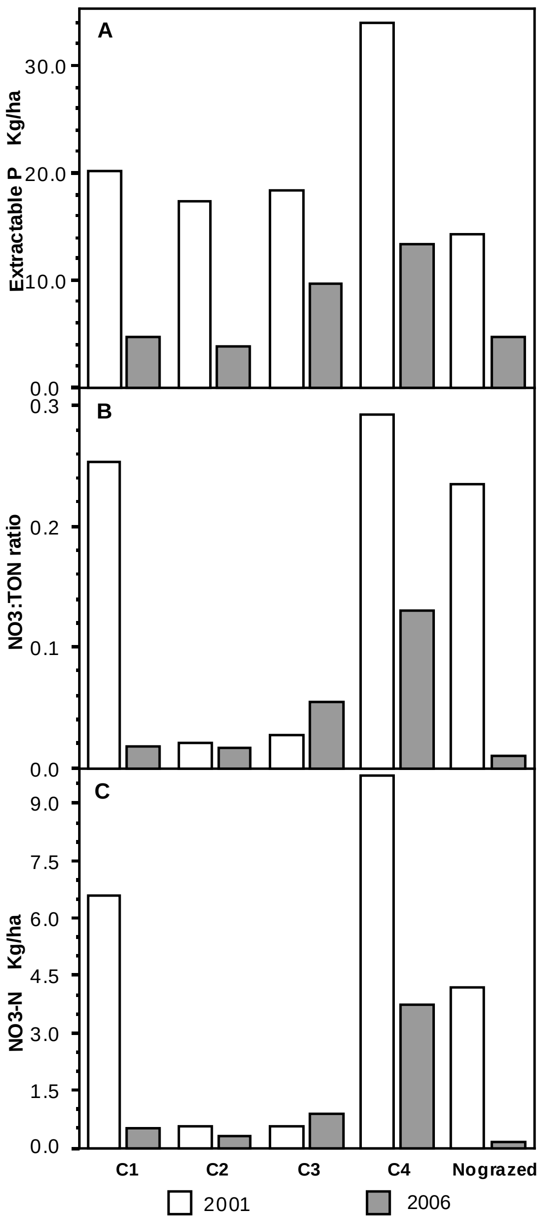
A
B
TOC ton/ha
TON ton/ha
30.0
20.0
10.0
0.0
3.0
2.0
1.0
0.0
C1
C2
C3
C4
TC grazing
Continuous grazing
2001
2006

Figure 3



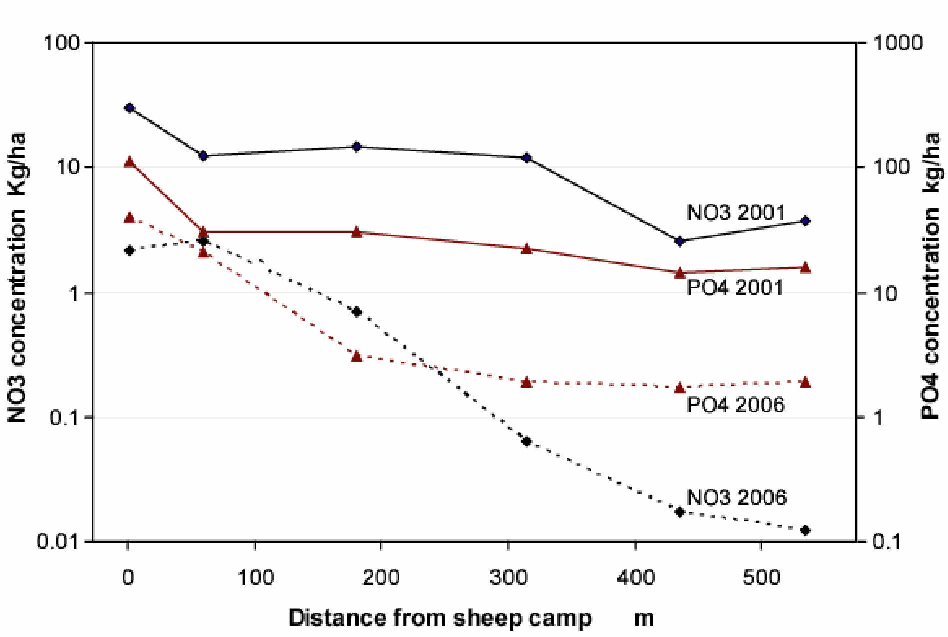
15.0
10.0
5.0
0.0
C:N ratio
TC grazing
Continuous grazing
No grazed
C1
C2
C3
C4
2001
2006

Figure 4



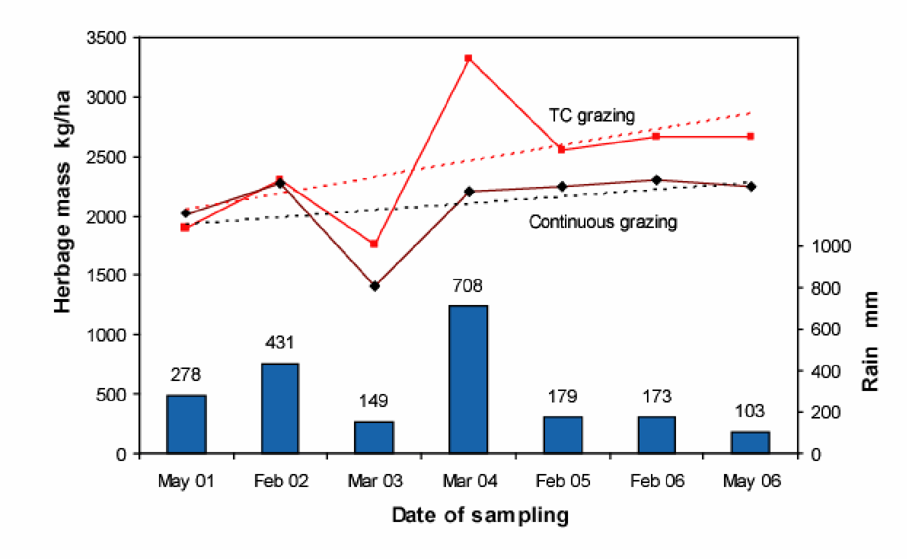
A
Extractable P Kg/ha
30.0
20.0
10.0
0.0
B
NO3:TON ratio
0.3
0.2
0.1
0.0
C
NO3-N Kg/ha
9.0
7.5
6.0
4.5
3.0
1.5
0.0
C1
C2
C3
C4
Nograzed
2001
2006

Figure 5



100
10
1
0.1
0.01
1000
100
10
1
0.1
NO3 concentration Kg/ha
PO4 concentration kg/ha
NO3 2001
PO4 2001
PO4 2006
NO3 2006
0
100
200
300
400
500
Distance from sheep camp m

Figure 6



3500
3000
2500
2000
1500
1000
500
0
Herbage mass kg/ha
TC grazing
Continuous grazing
278
431
149
708
179
173
103
1000
800
600
400
200
0
Rain mm
May 01
Feb 02
Mar 03
Mar 04
Feb 05
Feb 06
May 06
Date of sampling