Relationships between intensive dairy stocking rates and soil ecosystem health and biodiversity in Taranaki pastures

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Executive summary

Agricultural intensification is aimed at increasing farm profitability and productivity. It typically involves increases in fertiliser use, supplementary feeding, stocking density and irrigation along with decreases in fallow duration and the presence of hedgerows, shelterbelts and remnant native vegetation. Intensification of agricultural practices has been occurring rapidly worldwide and is an issue of concern to scientists globally as numerous studies have demonstrated that it can have negative impacts on plant and animal abundance and diversity.

Reductions in levels of species diversity and abundance beyond certain thresholds can decrease ecosystem functioning and ecosystem services that are essential to support agricultural production. Such ecosystem services include nutrient cycling, maintenance of soil structure and fertility, soil carbon sequestration and pollination. Reductions in species diversity and abundance can also reduce ecosystem resilience - the ability of ecosystems to withstand disturbances and environmental perturbations. It is becoming increasingly accepted that conservation of soil biodiversity is essential to maintain agricultural productivity and resilience into the future.

However, while many studies have been conducted internationally, very little is known about the impact of intensification on biodiversity in New Zealand, or about the status of biodiversity in New Zealand's agricultural landscapes. Hence the effect of agricultural intensification on biodiversity has been identified as a critical knowledge gap and high priority for study.

One common component of agricultural intensification which has been shown to impact on species diversity and abundance are increased stocking rates. In Taranaki, dairy stocking rates have increased markedly over the last 30-40 years with average cow stocking rates having risen from 1.43 cows per hectare in 1979-1978 to 2.8 cows per hectare in 1998-2001.

This study examines whether and to what extent increased stocking rates are to the detriment of species diversity and abundance in Taranaki dairy pastures. It was conducted at the DairyNZ research farm at Whareroa near Hawera in order to take advantage of study plots which had established and maintained for the purposes of another study. The abundance and diversity of plants, earthworms, insects, spiders, mites and nematodes were compared among paddocks subject to differing stocking rates. Measurements of abiotic properties such as soil chemistry, bulk density and macroporosity were also compared between treatments.

Higher stocking rates, when compared with lower stocking rates were not found to have resulted in changes to soil chemistry, bulk density or macroporosity, although grazed paddocks were found to have lower soil macroporosity compared to the fallow and mowed paddocks. Results did however suggest that over a period of five years higher stocking rates may result in small increases in percent cover of bare ground and small decreases in percent cover of clover.

Higher stocking rates were also not found to have had significant detrimental effects on the diversity or abundance of surface dwelling insects or soil dwelling nematodes, earthworms, mites (excluding Oribatidae & Scutacaridae) and springtails [refer glossary]). However, higher stocking rates seem to have resulted in decreased abundances of Oribatid mites and in increased diversity and abundance of Collembola & anecic earthworms.

Oribatids may have been influenced by changes abundance of anecic earthworms which damage Oribatid habitat through their burrowing activity or may have been affected by changes in resource availability. Positive responses of anecic earthworms and Collembola are likely to have resulted from paddocks with higher stocking rates having increased food availability due to increased dung deposition.

These results suggest that in the short term at least, higher stocking rates do not pose a significant threat to agricultural biodiversity in Taranaki dairy pastures.

However, it is worth noting that the extent to which individual paddock management affected the diversity and abundance of some organisms in this study (especially the more mobile surface dwelling species) may have been diminished by the small size of replicate paddocks and their close proximity to those subject to different management regimes. Many studies have shown that habitat heterogeneity and presence of undisturbed habitat patches has been shown to increase species diversity in agricultural landscapes as a whole.

Gratefully acknowledged are advice and assistance provided to this study by Nicole Schon (Massey University), Dr Alec Mackay (Agresearch), Dr Pip Gerard (Agresearch), Darren Ward (Landcare Research), Bryan Stevenson (Landcare Research), Yvette Williams (DairyNZ) and Chris Roach (DairyNZ).

Technical services including sampling, soil analysis, invertebrate identification and data analysis were provided by DairyNZ, Massey University and Landcare Research.

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1. Background

1.1 Importance of terrestrial biodiversity in agro-ecosystems

Until very recently, the importance of conserving terrestrial species diversity and abundance (hereafter referred to as biodiversity) in agricultural landscapes has been overlooked, with conservation efforts being focused almost entirely on areas of indigenous vegetation (Dodd *et al.* 2004; Reid 2003). However, the importance of biodiversity to the productivity and sustainability of agriculture is gaining increasing attention, and biodiversity is now considered a critical environmental issue of high relevance to the agricultural sector globally (Dodd *et al*. 2004).

Primary reasons why the maintenance of biodiversity is considered important in agricultural ecosystems include:

1. The loss of biodiversity can have significant impacts on ecosystem functioning & hence productivity

Biodiversity is responsible for the provision of ecosystem services essential to agricultural production. For example, nutrient cycling, maintenance of soil structure and fertility, degradation of pollutants, soil carbon sequestration, pollination, and regulation of pest populations through predation and parasitism, all depend upon healthy ecosystems.

A certain critical number of species are required in an ecosystem in order for these functions to operate at all, but besides this, studies have shown that ecosystems with more species often function more effectively (in terms of providing ecosystem services) and are thus more productive (see; Henry *et al.* 2000; Sala 2001; Kinzig *et al.* 2002; Loreau *et al.* 2002; Hooper *et al.* 2005; Balvanera *et al.* 2006; Cardinale 2006). For example, hay yield has been shown to be up to 60 percent higher in species rich plant communities compared to species poor communities (Bullock *et al.* 2001).

Studies have demonstrated this diversity – productivity relationship in bacteria, fungi, plant and animal communities across terrestrial, freshwater, and marine ecosystems (Cardinale *et al.* 2007). There are two main theories as to the mechanism behind this relationship.

The first is that higher levels of biodiversity may enhance productivity because more diverse communities are more likely to include highly productive species.

The second is that more species rich communities show greater complementarity (Long *et al.* 2007). Complementarity is when species within a community exhibit various forms of niche partitioning (spatial and temporal differences in resource use) (Tilman *et al.* 1999), or when the resource capture by a species within a community is enhanced by positive interactions with other species (Mulder *et al.* 2001; Cardinale *et al.* 2002). Complementarity is thought to increase communities' productivity and ecosystem functioning by allowing them to more efficiently and completely capture available resources.

A good illustration of complementarity is provided in the following description by University of California researcher Michel Loreau in relation to plant communities:

"[Biological] communities operate much like a sports team, composed of both star players and supporting players. Some plants are so productive that they dominate the productivity of natural habitats. But supporting species complement the key players and enhance the productivity of …communities even further" (in Melville 2007).

A good example of species complementarity comes from a study by Cardinale *et al.* (2003). This study demonstrated that a group of predators including ladybug, damsel bug, and parasitic wasp, were able to reduce aphid density (and in turn increase alfalfa yield), to a greater extent than when each predator was acting alone.

2. High levels of biodiversity are thought to enhance ecosystem stability & robustness

The terms 'ecosystem stability' and 'ecosystem robustness' describe an ecosystem's ability to withstand and bounce back from environmental disturbance and perturbations. For example, increased stability might give an agricultural ecosystem greater resistance to invasion by pests and diseases as well as soil compaction and greater resilience in times of flooding or drought. A more stable ecosystem will also exhibit less fluctuation in ecosystem functioning and productivity through time (Hooper *et al.* 2005; Cottingham *et al.* 2001; Tilman 2006).

The theory as to how higher levels of species diversity might result in higher ecosystem stability is known as the "Insurance Hypothesis". According to this hypothesis, higher levels of species diversity (and thus functional redundancy) provide greater guarantee that in the face of environmental change there will be at least some species that respond positively to ensure that levels of ecosystem functioning are maintained (McNaughton 1977, Lawton & Brown 1993, Naeem & Li. 1997).

Cardinale *et al.* (2007) likens the stability – diversity relationship to the tradeoff between yield and stability in an investment portfolio, in that a select few species may be able to produce higher yields than a diverse community at any given time, but this might come at the expense of the stability of yield through time.

Global acknowledgement of the importance of and attention given to biodiversity in agro ecosystems has increased dramatically over recent years as a result of increasing concern over;

a) the current dramatic rate of decline in biodiversity across the globe (Millennium Ecosystem Assessment 2005) and the effects this is having and may have on ecosystem services vital for human survival and wellbeing (i.e. purification of air and water, detoxification and decomposition of wastes, regulation of climate).

b) the effects that unsustainable (in terms of requiring continual external inputs) agricultural practices can have on environmental quality (e.g. on water quality) and;

c) the increasing intensity of agricultural practices around the world and the negative effects that intensification can have on biodiversity.

2. Introduction to this study

2.1 New Zealand context

Intensification of agriculture is aimed at increasing farm profitability and productivity and typically involves increases in fertiliser application, supplementary feeding, stocking density, farm/paddock size and irrigation along with decreases in fallow duration and presence of woody and seral vegetation such as hedgerows, shelterbelts in paddock perimeters and remnant native vegetation.

The sustainability of intense agricultural practices is under scrutiny, being both energy intensive and dependent on importation of fertiliser, access to and pollution of declining water resources, and utilization of high levels of hydrocarbons and agrochemicals which are likely to become increasingly scarce and expensive in a post peak oil world (Thayer 2008, Lee *et al.* 2008). Intense agricultural practices have also been criticized based on their potential to negatively impact upon agricultural biodiversity, which is essential for maintaining ecosystem functioning and for maintaining agricultural production in the absence of artificial inputs.

Negative impacts of intensification of agricultural practices on biodiversity have been demonstrated in many studies from around the world for various taxa including birds, invertebrates, plants and microbes (e.g. Aebischer 1991; Sotherton 1998; Donald 1998; Krebs *et al.*1999; Chamberlain *et al.* 2000; Donald *et al.* 2001a; Wilson *et al.* 1999).

The effects of agricultural intensification on biodiversity are a particularly relevant concern in New Zealand. Here, agricultural intensification has been accelerating over the past 50 years and is likely to continue to do so for at least another decade (Moller *et al.* 2008, PCE 2004). Lee *et al.* 2008 states that;

"Intensification over the last two decades is causing loss of habitat for indigenous species and homogenization of landscapes at scales unprecedented since deforestation by colonial farmers"

Additionally, agriculture is of great importance to the New Zealand economy (Ballingall & Lattimore 2004; MacLeod & Moller 2006). Agricultural lands cover 58 percent of New Zealand's total land area and agricultural products make up 53 percent of our merchandise exports. Additionally, agriculture is New Zealand's largest export earner and also its fourth largest employer (Landcare Research website 16/06/09).

Despite this, and the fact that a Parliamentary Commission for the Environment Report (2004) identified the effects of ongoing loss of biodiversity and ecosystem services as a risk for farming that requires management, little research has been carried out to elucidate the impacts of increasing agricultural intensity on biodiversity in New Zealand; or the implications this may have for agricultural sustainability (but see Topping & Lovei 1997; Wardle *et al.* 1999 and Schon *et al.* 2008). As a result, lack of understanding with regards to the impacts surrounding agricultural intensification has been identified as a critical knowledge gap and high priority for study (Perley *et al.* 2001; Moller *et al.* 2008).

Landcare Research on their website (2009) state that;

> *"Although significant changes have occurred in agricultural land use and management practices in recent decades, the impacts of these on biodiversity and the wider agro-ecosystem are largely unknown….Without information on the environmental status and trajectory of New Zealand's agro-ecosystems, it is not possible to know where we are in terms of sustainable agricultural practice, where we are trying to go, or if we have any chance of getting there".*

Of special importance are studies relating to the effects of increased *dairying* intensity on biodiversity. Dairy is New Zealand's largest industry and supplies around 20 percent of New Zealand total export income (PCE 2004). Dairy is also one of the country's fastest growing agricultural sectors in terms of intensity and expansion. For example; between 1994 and 2002, the number of dairy cows increased by 34 percent while the area of land directly used for dairy farming increased by 12 percent (PCE 2004). Furthermore, this sector has set a key goal to increase its productivity by 50% before 2014 (PCE 2004).

Studies of the effects of intensification are particularly relevant on the Taranaki ring plain which until very recently was home to the second largest herd size in the country (now exceeded by Canterbury as well as the Waikato) and where intensification of farming practices has been occurring at a rapid rate. Over the past 30-40 years the number of cows in Taranaki has increased from 350 thousand to about 480 thousand (TRC 2009) and between the late 1970's and late 90's average stocking rates increased from 1.43 cows per hectare to 2.8 cows per hectare (TRC 2001).

Increased stocking rate is one mechanism by which increased dairy intensity might impact on biodiversity. Higher stocking rates could potentially impact on biodiversity though the effects of defoliation, treading and/or defecation and urination by grazing animals which may kill plants and invertebrates directly or have negative effects by modifying their living space, microclimate and food supply (East & Pottinger 1983). Higher stocking rates result in decreased selectivity in the foliage eaten by stock, increasing treading of the sward/soil and organisms therein as well as increasing the levels and spatial uniformity of dung deposition.

A number of studies have investigated the effect of higher stocking rates on invertebrate diversity and abundance, many of which have found negative associations (e.g. Hutchinson & King 1980; Kruess & Tscharntke 2002). However, very few studies have been carried out in New Zealand, and most have been carried out in natural and semi-natural grasslands which are quite different to the entirely artificial grasslands used for dairy farming here. Furthermore, these studies have used different grazing regimes and pressures and invertebrate and plant populations and communities may respond quite differently under different climatic conditions and in soil types. Those studies that have looked at the effect of stocking rate in New Zealand have been focused on sheep stocking rather than dairy (e.g. Schon *et al.* 2008).

2.2 This study

The effects of intensification of agricultural practices on biodiversity, and more specifically impacts of increasing dairy grazing intensity in Taranaki were the focus of the study described in this report, which tested the hypothesis that increased stocking rates and subsequent increases in grazing pressure lead to a decrease in species diversity and abundance for invertebrates including Oligochaeta (earthworms), Arthropoda (insects and spiders) including Acari (mites), and Collembola (springtails) as well as Nematoda (nematodes) in Taranaki pastures. To test this hypothesis diversity and abundances of these taxa were compared between paddocks subject to differing stocking rates. It was hoped that this study would contribute to a closing of the knowledge gap surrounding the effects of agricultural intensification on terrestrial biodiversity in New Zealand.

Measurements of plant cover and diversity as well as chemical properties, bulk density and macroporosity were also taken and compared between treatments as changes in these characteristics are mechanisms through which increased stocking rates and grazing pressure might impact on biodiversity. Additionally Visual Soil Assessment as per Shepherd (2007) was conducted to provide a general indication of the soil and pasture health for each treatment.

3. Methods

3.1 Site description and sampling design

This study was carried out in 2007 at the DairyNZ Whareroa Research Farm, near Hawera in South Taranaki (39°36'S 174°18'E). The research farm, which is located close to the sea, had an average air temperature of 12.9^{o}C and annual rainfall was 1124mm in the year prior to August 2007. The soil is classified as an Andosol (Egmont black loam).

The following five treatments were imposed at this site during spring 2002, each in four replicate 0.1 ha grazing plots, and continued for five years:

1. Fallow - ungrazed and uncut with no fertiliser applied

2. Cut and carry – ungrazed with pasture mown and removed at similar times as grazing of treatments 3-5. Farm dairy effluent applied to replace nutrients removed.

3. Grazed at the equivalent of three Friesian/Jersey cows per hectare. Fertiliser application of 700kg kg 30 percent potassic superphosphate was applied in October each year to maintain soil test levels.

4. Grazed at the equivalent of four Friesian/Jersey cows per hectare fed with silage to maintain feed intake similar to that for Treatment three. Fertiliser application of 700kg 30 percent potassic superphosphate was applied in October each year to maintain soil test levels.

5. Grazed at the equivalent of five Friesian/Jersey cows per hectare with silage to maintain feed intake similar to that for Treatment three. Fertiliser application of 700kg 30 percent potassic superphosphate was applied in October each year to maintain soil test levels.

Each of treatments 2-5 were rotationally grazed or mown at 3-4 weekly intervals. Treatments 3-5 were grazed by 6-50 cows for 24 hours. Post cutting pasture masses in treatment 2 (the cut and carry treatment) were similar to post grazing pasture masses in treatments 3-5 (the grazed treatments) Appendix 2 contains details of mean pasture heights & residual pasture masses for each of the grazed treatments pre & post grazing.

Photo 1 View of farmlets on left of centre race looking east

Photo 2 View of the border between two 0.1 hectare farmlets, the one on the right being a replicate of the fallow treatment, the one on the left being a replicate of the cut and carry treatment

Photo 3 View showing one of four 0.1 hectare farmlets that were subject to a stocking rate of four cows per hectare

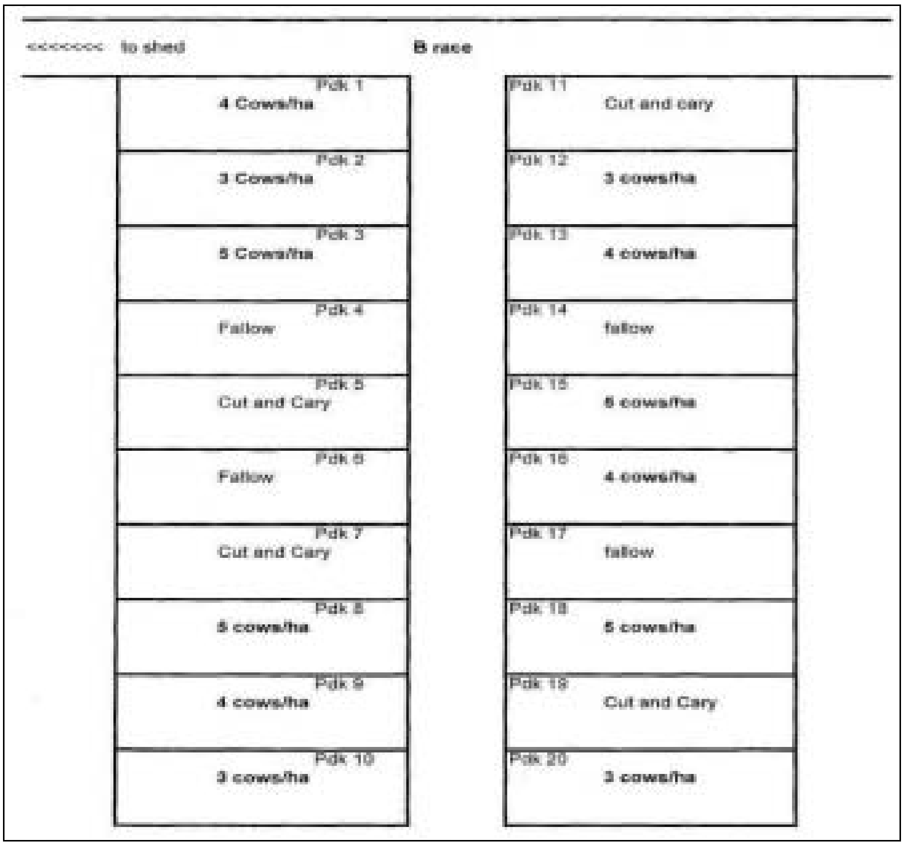

Figure 1 Map showing the layout of the 0.1 hectare grazing plots and different treatment replicates

3.2 Sampling methods

3.2.1 Abiotic measurements

3.2.1.1 Soil chemistry

In March 2007, 18 soil cores (25mm diameter) were taken to a depth of 75mm from each of the 20 grazing plots. The 18 cores from each plot were amalgamated to produce one sample per plot and these 20 samples were sent to NZLABS in Hamilton for analysis of the following (see glossary):

- pH
- Calcium content
- Olsen phosphate content
- Potassium content
- Sulphate sulphur content
- Organic sulphur content
- Magnesium content
- Sodium content
- Mineralisable nitrogen content
- Ammonium nitrogen content
- Nitrate nitrogen content
- percent organic carbon,
- percent organic matter
- soil moisture content
- percent Pseudo total nitrogen

3.2.1.2 Bulk density

Two sets of two 10 cm diameter x 7.5 cm deep soil cores (10cm in diameter) were taken from each plot (eight sets of two cores per treatment) during September 2007. Each set of cores consisted of one core from the 0-7.5cm depth range and one from the 7.5-15cm depth range. Soil cores were trimmed using a knife and wrapped in plastic wrap immediately after extraction. Soil cores were then transported back to the laboratory where the plastic wrap was removed and replaced with tin foil and the weight was recorded. The cores were then oven dried at 105 degrees Celsius. After 24 hours cores were removed from the oven and weighed. Bulk densities were then determined using the following equation: bulk density = dry weight (minus steel corer and tin foil weight)/core volume

3.2.1.3 Macroporosity

Two sets of two soil cores (10 cm diameter) were taken from each plot (eight sets of two cores per treatment) during September 2007. Each set of cores consisted of one core from the 0-7.5cm depth range and one from the 7.5-15cm depth range. Sore cores were trimmed using a knife and wrapped in plastic wrap immediately after extraction. Soil cores were then frozen until they could be analysed using the method described in Gradwell (1972)

3.2.1.4 Visual Soil Assessment

Visual Soil Assessment was conducted in each plot (four visual soil assessments per treatment) as per Shepherd 2007 during September 2007. One soil sod (about 200 x 200mm) from each plot was used for this assessment

3.2.2 Biotic measurements

3.2.2.1 Vegetation

Percent cover for each species of vegetation was estimated in $0.25m^2$ quadrats during March 2007. Eight quadrats were measured per plot (total 32 quadrats per treatment). Quadrats were located systematically at five metre intervals along a 40 metre transect which ran down the centre of each plot. Transects were located down the centre of each paddock and five metres from either end of each paddock in order to minimise impacts from neighbouring treatments and non study paddocks.

3.2.2.2 Fauna

3.2.2.2.1 Nematodes (refer glossary)

Two bulk samples, each consisting of five soil cores (7.5cm deep and approximately three cm in diameter) were collected from each 0.1 hectare paddock (eight bulk samples per treatment) during April 2007. Samples were collected down the centre of paddocks and not within five metres from each end in order to minimise impacts from neighbouring treatments/paddocks. Samples were collected so as to be representative of the environment within each paddock. Nematode extraction and identification was conducted by Gregor Yeates at Landcare Research.

3.2.2.2.2 Insects, spiders, springtails and mites

Insects, spiders, springtails and mites were sampled via suction sampler, soil cores and pitfall traps as described further below.

3.2.2.2.2.1 Suction samples (insects and spiders)

Seven suction samples were taken of $0.25m^2$ quadrats in each replicate paddock (28 samples per treatment) during March 2007. Quadrats were located at five metre intervals along a 40 metre transect which ran down the centre of each paddock. Transects were located in the centre of each paddock and five metres from the end of each paddock in order to minimise impacts from neighbouring treatments/paddocks.

Samples were placed in snap lock bags containing ethanol and sorting was conducted via two methods; samples taken on sampling occasions one to five were hand-sorted under a magnifying glass, whereas samples collected on sampling occasions six and seven were sorted by sieving samples and immersion in water. Arthropods were sorted to order level. Four orders; Hemiptera, Diptera, Coleoptera and Hymenoptera were sorted to family level and three orders; Coleoptera, Diptera and Hymenoptera were sorted to morphospecies level. Identification and sorting was conducted by Massey University.

Photo 4 Fieldworker using suction sampler to sample arthropods

3.2.2.2.2.2 Soil cores (springtails and mites)

Five soil cores (50mm diameter) were collected from each of two depths (0-75mm and 75-150mm) in each plot to give a total of 20 cores per treatment per depth during March 2007. Acari (mites) and Collembola (springtails) were extracted from these cores using a modified Berlese-Tullgren apparatus with a mesh size of 2 mm. Using this apparatus, inverted soil cores were heated to 30.8 ° C from above and cooled to 18.8 ° C from beneath for seven days, causing fauna to migrate to the bottom of the funnel and into a collecting dish containing 70% ethanol. Soil core collection, fauna extraction and identification were conducted by Nicole Schon (Massey University) as part of her PhD project.

3.2.2.2.2.3 Pitfall traps (insects and spiders)

During May 2007, eight pitfall traps consisting of a plastic cup (diameter 75mm) dug into the ground with lip flush with ground level were installed at five metre intervals along transects running down the centre of each plot (32 traps per treatment). Transects were located down the centre of each paddock and five metres from either end of each paddock in order to minimise impacts from neighbouring treatments and non study paddocks. These cups were one third filled with propylene glycol as a killing and preserving agent. Traps were covered with 15 x 15cm pieces of corflute held in place approximately 2-3cm above the ground by large galvanized flathead steel nails (photo 5). Traps were left out for seven consecutive nights before being collected.

Photo 5 Invertebrate pitfall trap

3.2.2.2.3 Earthworms (Oligochaetes)

Earthworm samples consisted of three soil cores (15.5cm deep by 15.5cm diameter) were collected from each replicate paddock during August 2007 to give a total of 12 samples per treatment. Sample locations were chosen so as to be representative of the environment within each paddock. Samples were hand sorted and individual earthworms were weighed, identified to species level and recorded as juvenile, immature and mature. Sample collection and earthworm sorting and identification were carried out by Nicole Schon (Massey University) as part of her PhD project.

3.3 Data analysis

Means and standard deviations were calculated using Microsoft Excel. The mean and standard deviation describe the statistical distribution of datasets. The mean is the sum of the dataset divided by the number of observations and describes the central location of the data.

Standard deviation is a widely used measure of the dispersion of data. It indicates the extent to which each data point in a dataset differs from the mean. A low standard deviation indicates that the data points tend to be close to the mean, whereas high standard deviations indicate that the data are spread out over a large range of values.

Excel was also used to calculate 95% confidence intervals for means. Ninety five percent confidence intervals show the range around the mean which has a 95% probability of including the true population value. They convey how precisely the sample mean is likely to reflect the true mean. A narrow confidence interval implies high precision whereas wide confidence intervals imply poor precision.

Confidence intervals can also be used to indicate whether a difference between two independent means is statistically significant. If the 95% confidence intervals on two independent means overlap by less than half, the two tailed p value is less than 0.05 and the difference is statistically significant.

Excel was also used to produce graphs displaying means and 95% confidence intervals for abiotic measurements as well as diversity and abundance of taxa, and cumulative abundance for arthropod morphospecies.

Effect sizes (mean differences) and 95% confidence intervals for effect sizes between treatments were also calculated in Excel. Whether or not effect sizes were statistically significant was determined by whether or not the 95% confidence intervals overlapped zero (if confidence intervals overlapped zero the effect size was deemed not to be statistically significant).

For arthropod morphospecies Bray–Curtis similarity matrix (used on fourth root transformed abundance data) and non-metric multidimensional ordination in the software package PRIMER v5 were used to compare composition among treatments. Non metric multidimensional ordination (nMDS) is a way to visualize the degree of similarity among data points both within and between treatments. Similarity is indicated by how close together points are. Smaller distances between points indicate greater similarity among samples. Variation among treatments was subsequently tested for statistical significance using an ANOSIM (analysis of similarities) with 5000 permutations. This analysis was conducted by Landcare Research.

4. Results

4.1 Abiotic measurements

4.1.1 Soil chemistry

Table 1 and Figures 2, 3 and 4 below show that there was only one chemical property measured for which there was any positive or negative trend with increasing or decreasing stocking rate. This property was Na (sodium) and differences between stocking rates were small and not statistically significant. Table 1 and Figures 2, 3 and 4 also show that for most properties measured the four cows per hectare treatment had a higher or lower value than did the three cows per hectare and five cows per hectare treatments and that in no case was a difference in chemical parameter between the three cow per hectare and five cow per hectare treatment statistically significant.

Table 1 Mean values for soil properties in pasture subject to different stocking rate treatments (3c/ha = three cows per hectare, 4c/ha = four cows per hectare, 5c/ha = five cows per hectare) See appendix 1 for key to symbols, tests and units of measurement

Mean	pH	Ca	P	K	S(SO4)	OS	Mg	Na	NH4N	NO3N	OC	OM	SMC	TKN	MN
3c/ha	6.08	7.5	39	16	37.5	11	55	15.25	8.5	29.5	10.83	18.7	35.25	1	198.5
4c/ha	6.03	7.75	35	15	33.75	11.3	55.5	15	8	29	10.43	17.98	36.5	0.958	203.5
5c/ha	6.15	7	37.5	19.5	37.75	10.5	53	14.5	8.5	42.25	11.43	19.63	35.5	0.995	193
fallow	5.95	7	52.5	19	30.5	12.8	49	15.25	7.5	26.25	11.35	19.63	38	0.97	218.5
c&c	5.95	7.75	39.3	4.75	35.25	10.5	42.5	13.75	10.3	10.5	8.8	15.15	35.75	0.958	186.5
Trend ?	–	–	–	–	–	–	–	↓	–	–	–	–	–	–	–

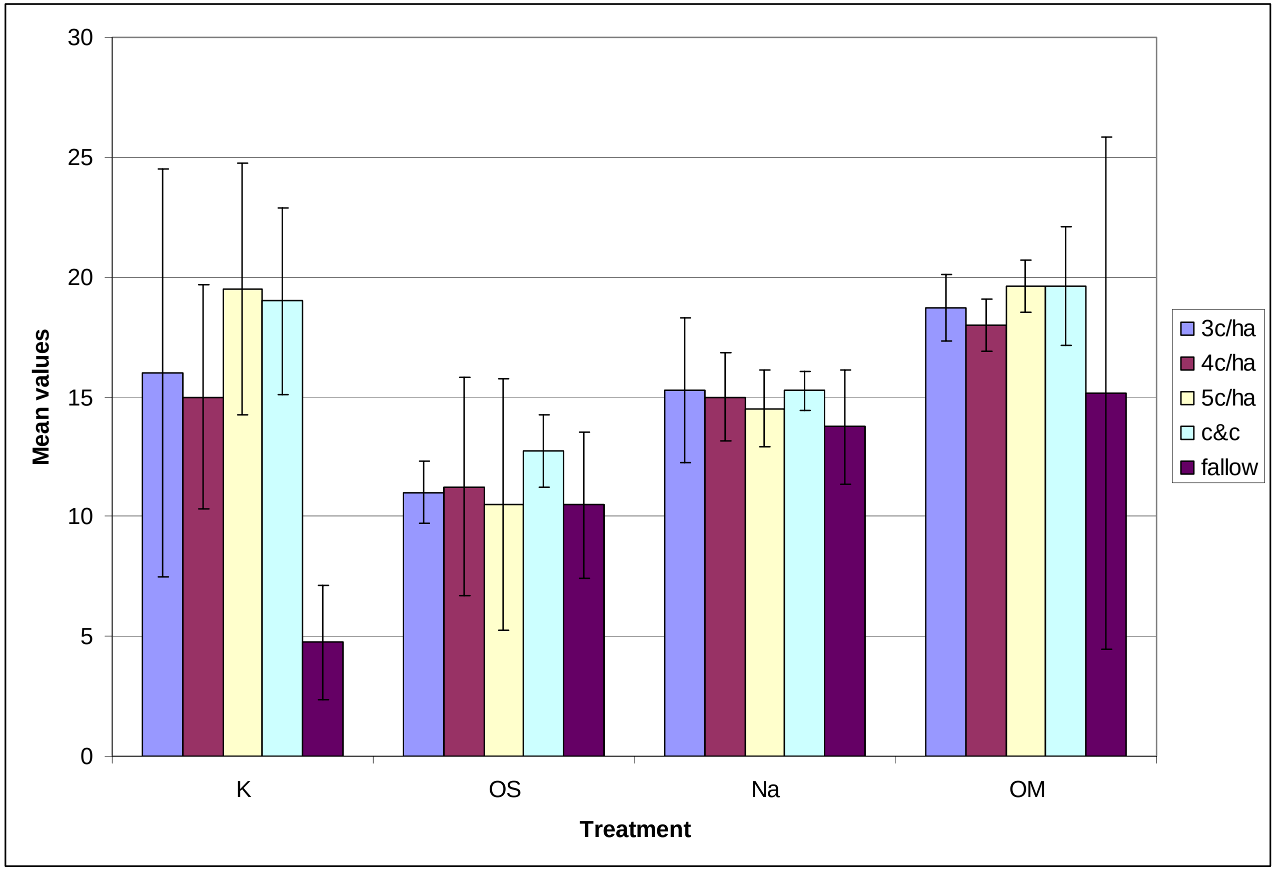

Figure 2 Bar graph showing mean values and 95% confidence intervals for tests of various chemical properties by treatment (3c/ha= three cows per hectare, 4c/ha= four cows per hectare, 5c=five cows per hectare) (Ca = calcium, K = potassium, OS = organic sulphur, Na =- sodium, NH4N = ammonium nitrogen, OC= organic carbon, OM = organic matter, TKN = pseudo total nitrogen). N=4. Please see Appendix 1 for measurement units and tests.

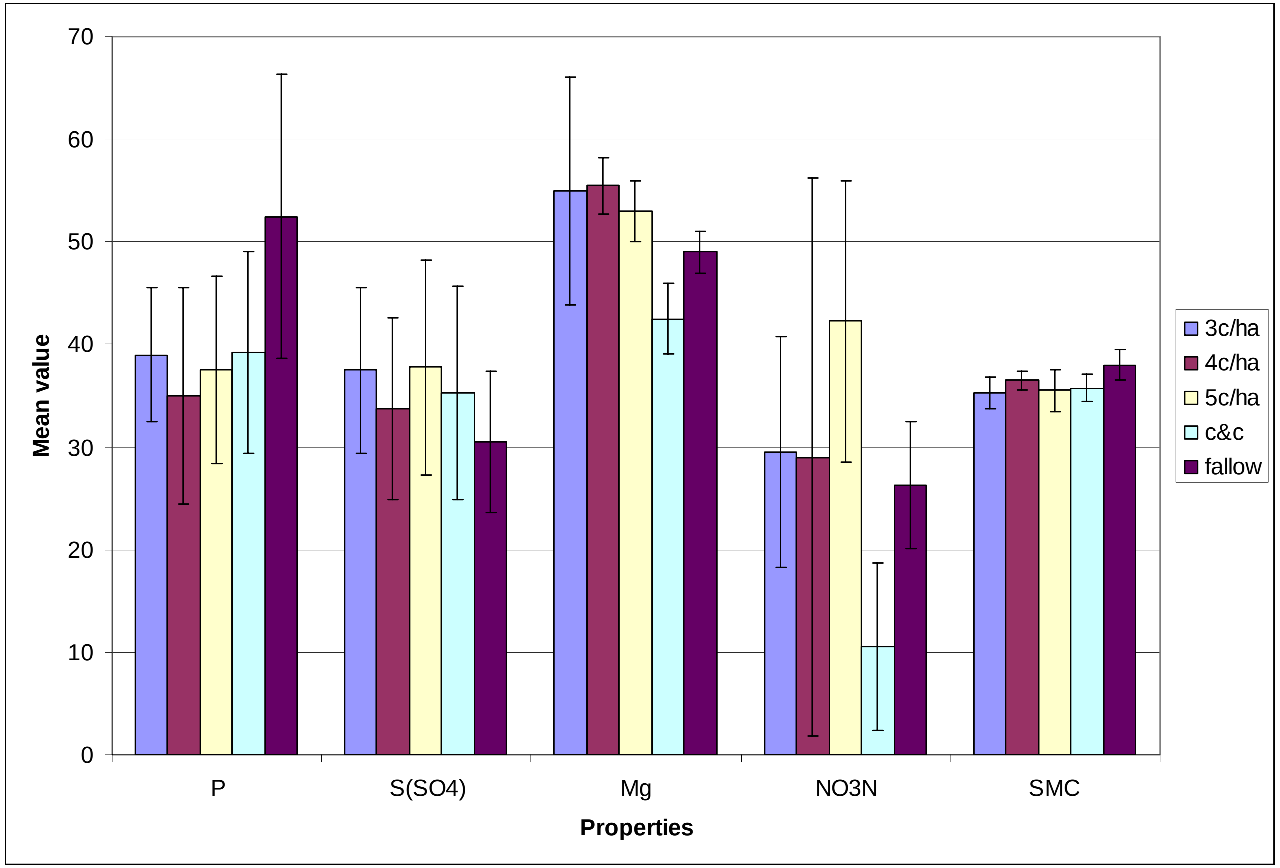

Figure 3 Bar graph showing mean values and 95% confidence intervals for tests of various chemical properties by treatment (3c/ha= three cows per hectare, 4c/ha= four cows per hectare, 5c/ha=five cows per hectare). (P=olsen phosphate, S(SO4)= sulphate sulphur, Mg=magnesium, N03N=nitrate nitrogen, SMC=soil moisture content. N=4. Please see Appendix 1 for key to symbols, tests and measurement units used.

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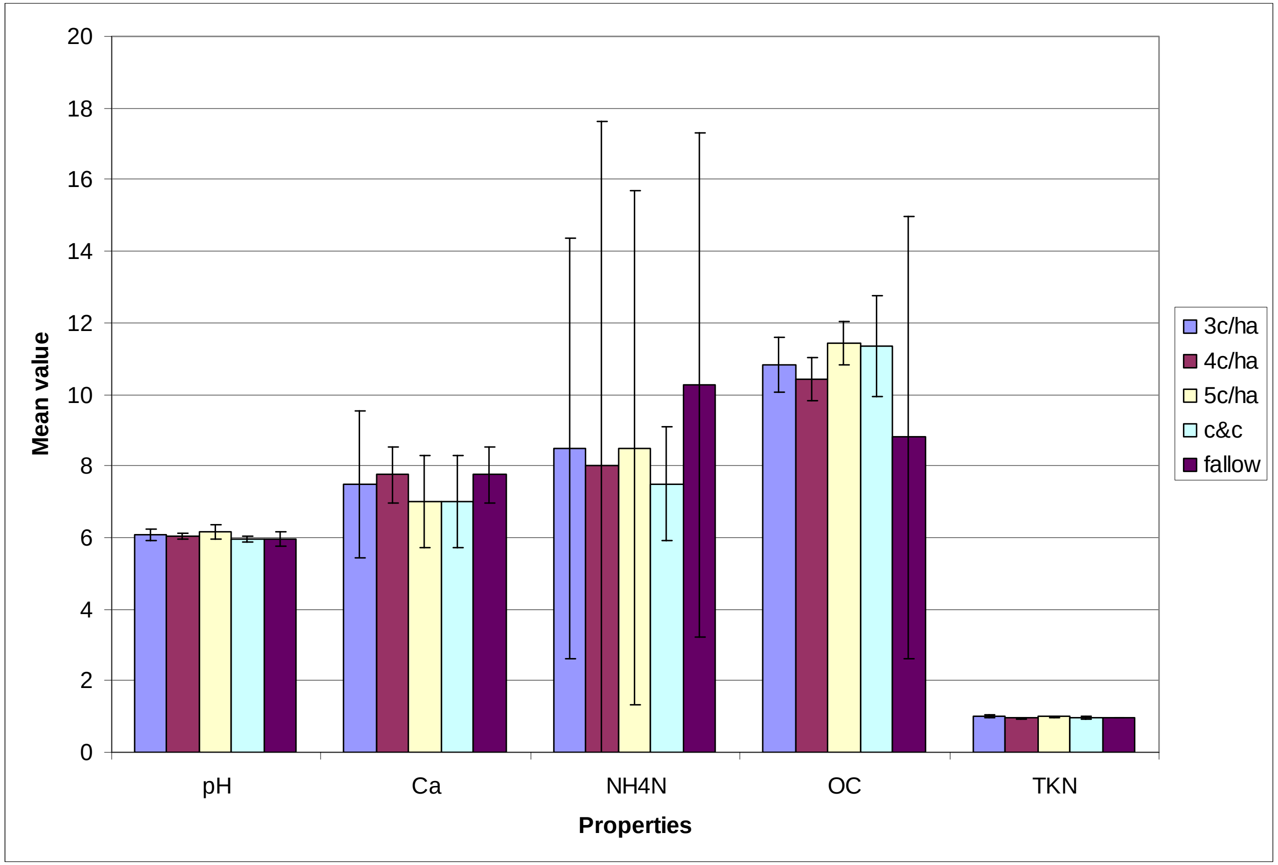

Figure 4 Bar graph showing mean values and 95% confidence intervals for tests of various chemical properties by treatment (3c/ha= three cows per hectare, 4c/ha= four cows per hectare, 5c/ha=five cows per hectare) (Ca=calcium, NH4N= ammonium nitrogen, OC=organic carbon). N=4 Please see Appendix 1 for key to symbols, tests and measurement units used.

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4.1.2 Bulk density

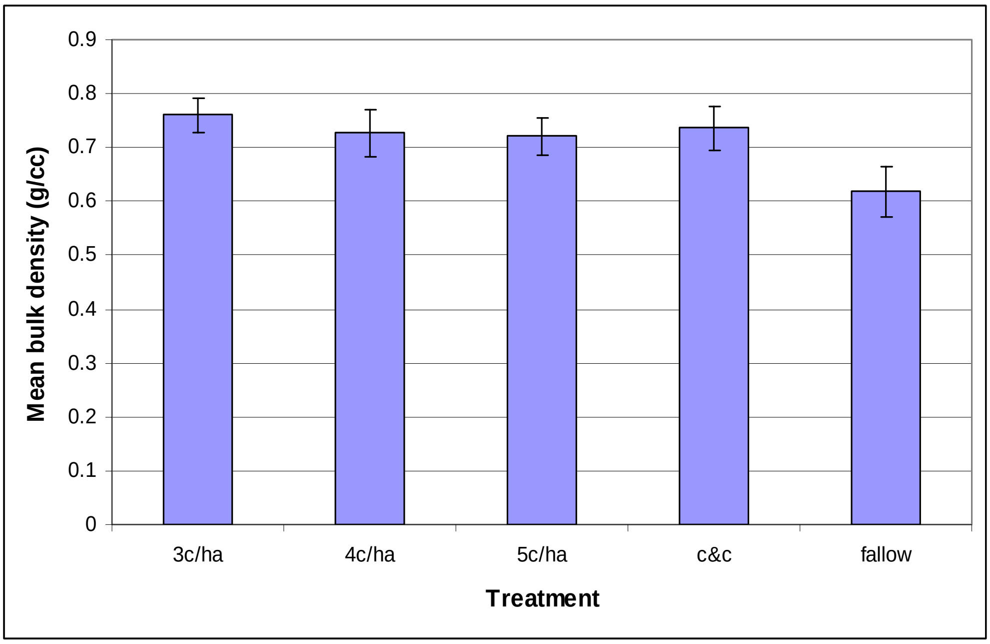

Figure 5 Bar graph showing mean bulk density (g/cc) and 95 percent confidence intervals for both depths (0-75mm and 75 -150mm) combined by treatment (3c/ha = three cows per hectare, 4c/ha = four cows per hectare, 5c/ha = five cows per hectare, c&c = cut and carry, fallow=fallow) N= 16

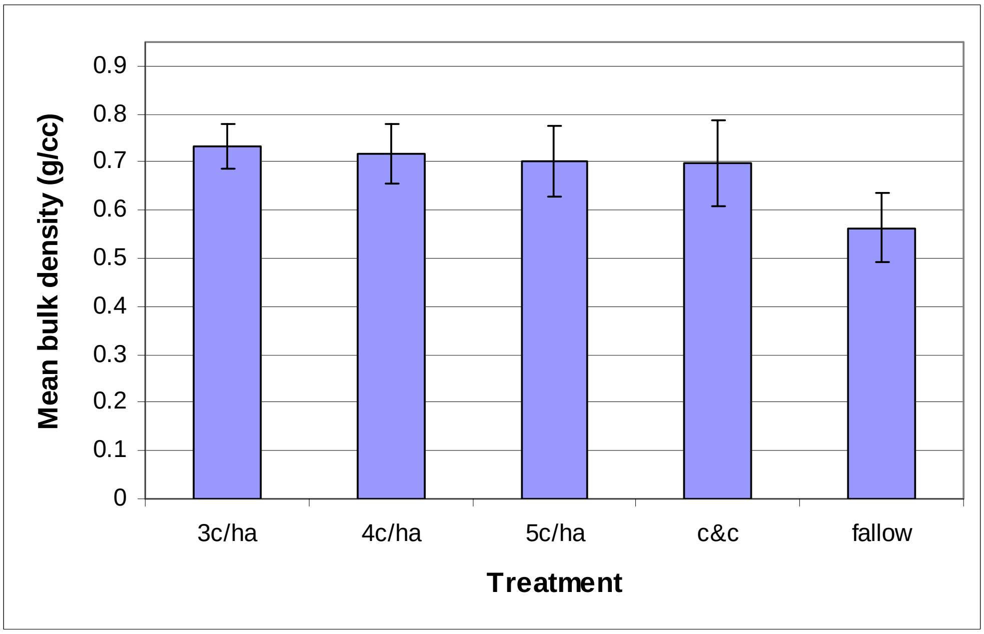

Figure 6 Bar graph showing mean bulk density (g/cc) and 95 percent confidence intervals for depth one (0-75mm) only by treatment (3c/ha = three cows per hectare, 4c/ha = four cows per hectare, 5c/ha = five cows per hectare, c&c = cut and carry, fallow=fallow) N= 8

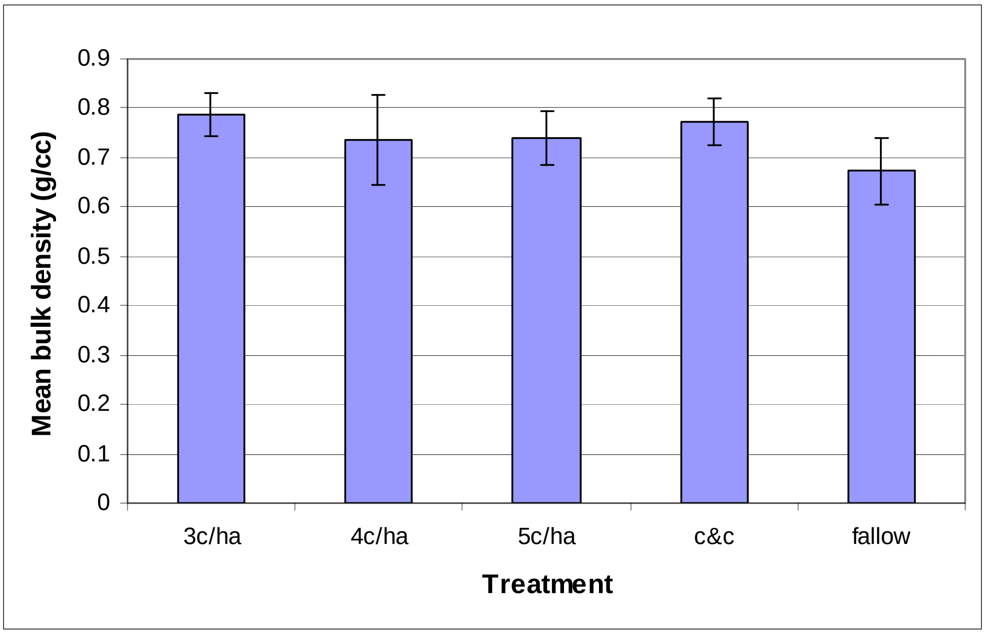

Figure 7 Bar graph showing mean bulk density (g/cc) and 95 percent for confidence intervals for depth two (75mm-150mm) only by treatment (3c/ha = three cows per hectare, 4c/ha = four cows per hectare, 5c/ha = five cows per hectare, c&c = cut and carry, fallow=fallow) N= 8

Figures 5 through 7 show that mean bulk densities differed by less than 0.1 g/cc among the grazed treatments for each depth individually and when depths were combined. Also, that the mean bulk densities for the grazed treatments differed very little (by less than 0.003 g/cc) from that of the cut and carry treatment. Figure 5 also shows that when both depths were taken together, all treatments had higher bulk densities compared to the fallow treatment, but only by a small amount (approx. $p < 0.01$).

Considering the differences between the means and judging by the overlap of the 95% confidence intervals, in no case were differences in mean bulk density among any of the grazed treatments or between the grazed treatments and the cut and carry treatment statistically significant ($p > 0.05$).

4.1.3 Macroporosity

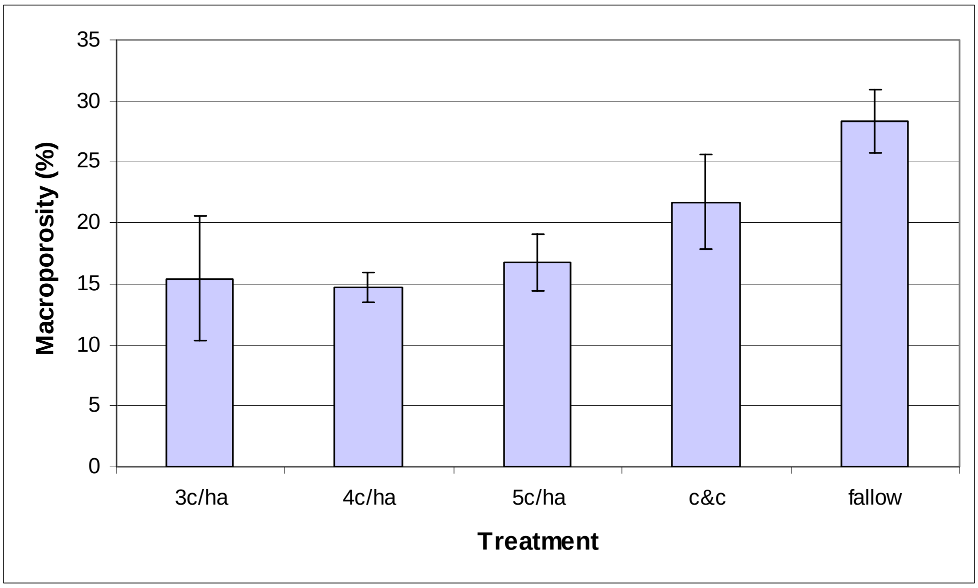

Figure 8 Bar graph showing macroporosity (proportion of pores above 60um in size) values and standard errors (SEM) intervals for the 0-7.5cm soil depth for each of five treatments (3c/ha = three cows per hectare (N=2), 4c/ha = four cows per hectare (N=4), 5c/ha = five cows per hectare (N=2), c&c = cut and carry (N=3), fallow=fallow (N=2)

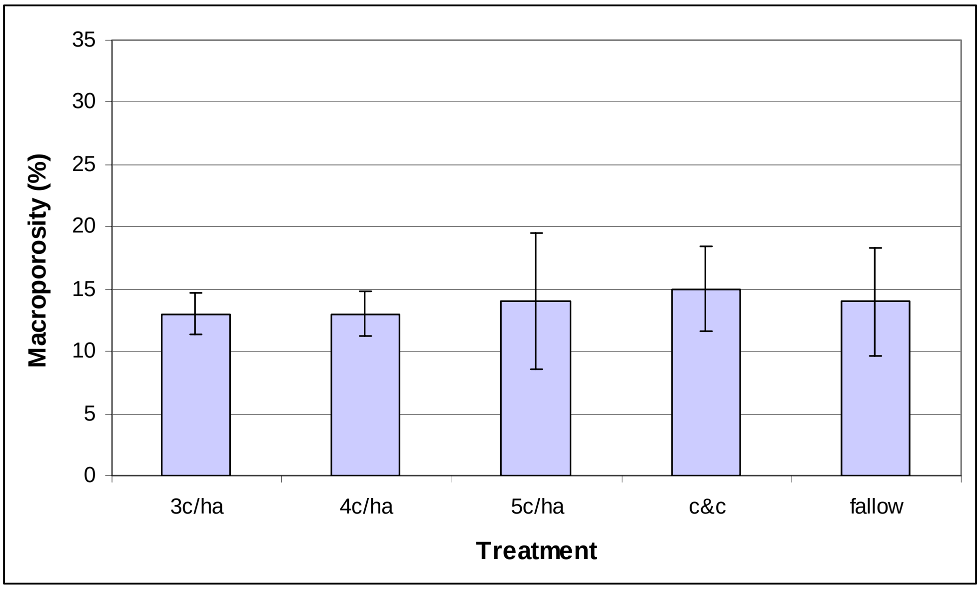

Figure 9 Bar graph showing macroporosity (proportion of pores above 60um in size) values and standard errors (SEM) for the 7.5-15cm soil depth for each of five treatments (3c/ha = three cows per hectare, 4c/ha = four cows per hectare, 5c/ha = five cows per hectare, c&c = cut and carry, fallow=fallow) N= 8

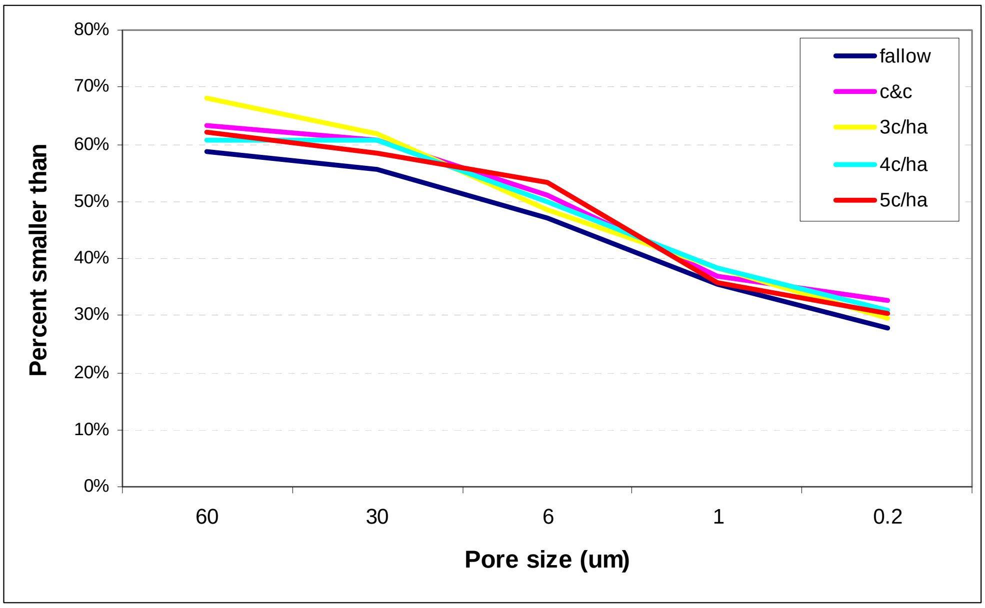

Figure 10 Shows the mean percentage of pores from soil in the 7.5-15cm range that were below 60, 30, 6 1 and 0.2 um in size for each of five treatments 3c/ha = three cows per hectare, 4c/ha = four cows per hectare, 5c/ha = five cows per hectare, c&c = cut and carry, fallow=fallow) N=3

Figures 8 to 10 show that for each depth macroporosity differed very little among treatments (by less than 14% at 0-7.5cm depth and by less than 2% at the 7.5 – 15cm depth). Figure 10 shows that the proportion of pores below each pore size (60um, 30um, 6um, 1um and 0.02um) also differed very little between treatments (by less than 9, 3, 6, 3 and 5 percent respectively).

4.1.4 Visual Soil Analysis

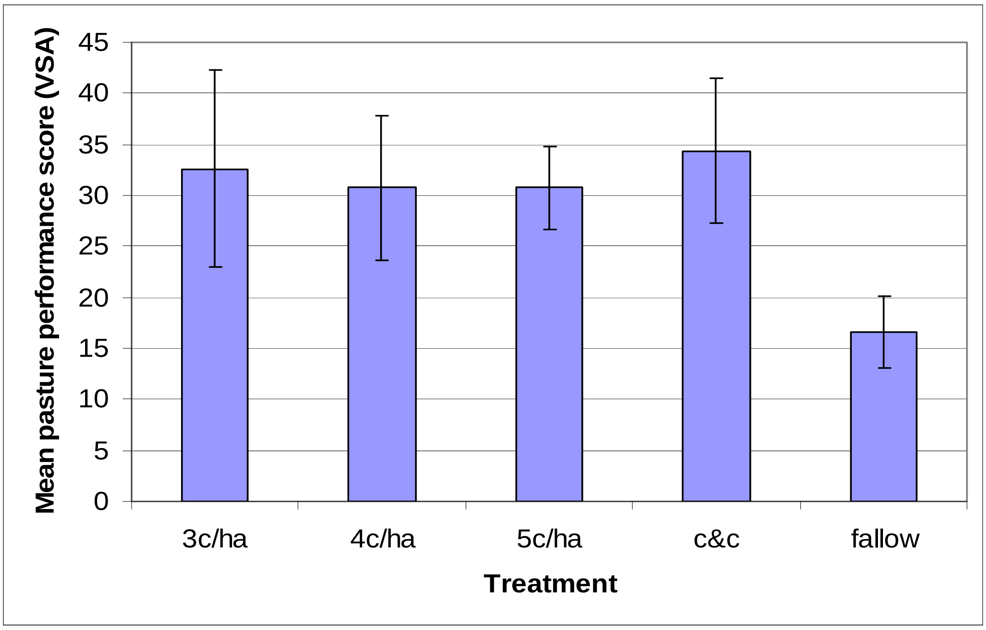

Figure 11 Bar graph showing mean pasture performance scores from Visual Soil Analysis and 95% confidence intervals by treatment (3c/ha = three cows per hectare, 4c/ha = four cows per hectare, 5c/ha = five cows per hectare, c&c = cut and carry, fallow=fallow) N= 4

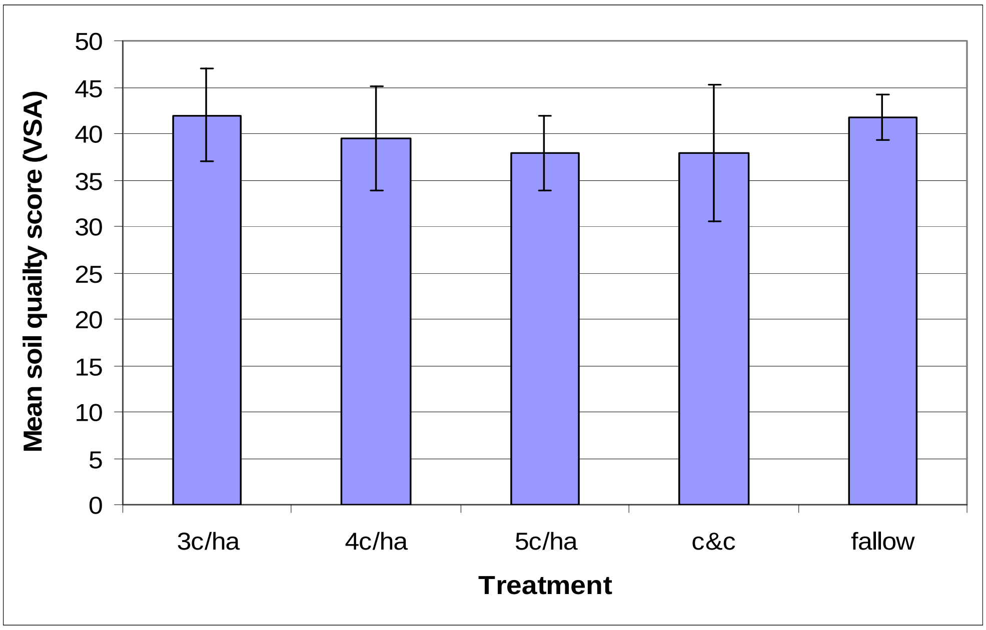

Figure 12 Bar graph showing mean soil quality scores from Visual Soil Analysis and 95% confidence intervals by treatment (3c/ha = three cows per hectare, 4c/ha = four cows per hectare, 5c/ha = five cows per hectare, c&c = cut and carry, fallow=fallow) N=4

VSA is based on the visual scoring of key bio-physical indicators of soil quality which research has shown reflect key quantitative (measurement based) indicators of soil quality. Indicators for soil quality, which are generic and largely independent of soil type, include soil structure and consistency, soil porosity, soil colour, number and colour of soil mottles, earthworm counts, tillage pan, degree of clod development and degree of soil erosion. Plant performance indicator include crop emergence, crop height at maturity, size and development of the crop root system, crop yields, root diseases, weed infestation, surface ponding, production costs.

Each indicator is given a visual score of 0 (poor), 1(moderate) or 2 (good). Scores for individual indicators are multiplied by a weighting factor according to how important the indicator is soil quality or pasture performance and summed to give an overall score. Score less than 10 indicate poor soil/pasture performance, scores between 10 and 25 indicate moderate soil quality/pasture performance while scores greater than 25 indicate good soil quality/pasture performance.

Figure 11 shows that pasture performance scores did not show an increasing or decreasing trend with increasing stocking rate and also that the three cows per hectare and five cows per hectare treatments differed in pasture performance score by less than two points.

Figure 11 also shows that mean pasture performance scores differed very little between the grazed treatments and the cut and carry treatment. As would be expected the pasture quality in the fallow treatment was significantly different from the grazed and cut and carry treatments.

Figure 12 shows that there was a negative trend in soil quality score with increasing stocking rate. However, scores differed very little among treatments and 95% confidence intervals indicate that differences between the means of grazed treatments were not statistically significant ($p>0.05$).

4.2 Biotic measurements

4.2.1 Vegetation

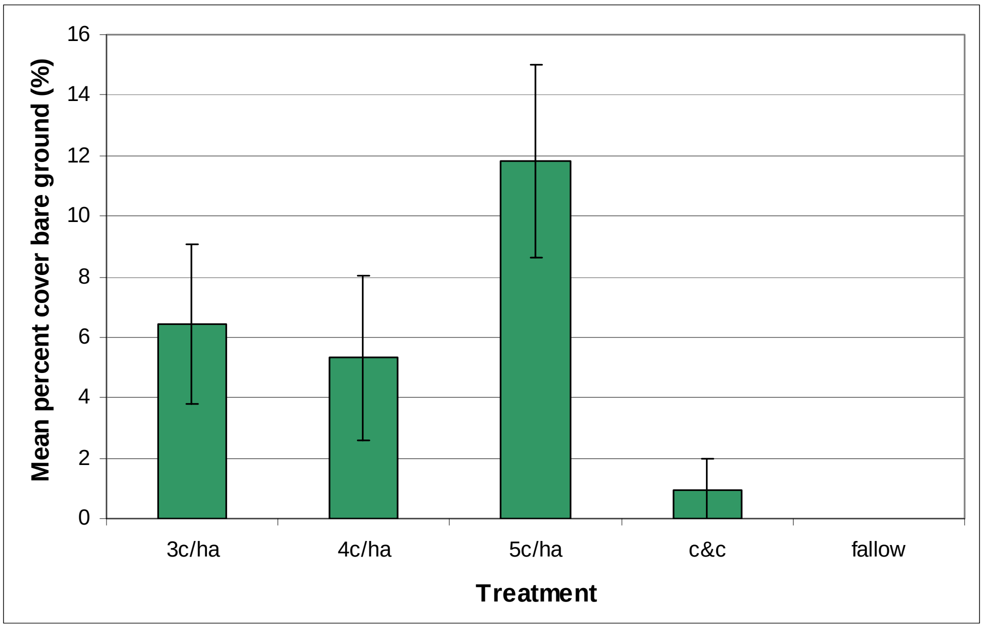

Figure 13 Bar graph showing mean percent cover of bare ground and 95% confidence intervals by treatment (3c/ha = three cows per hectare, 4c/ha = four cows per hectare, 5c/ha = five cows per hectare, c&c = cut and carry, fallow =fallow) N= 32

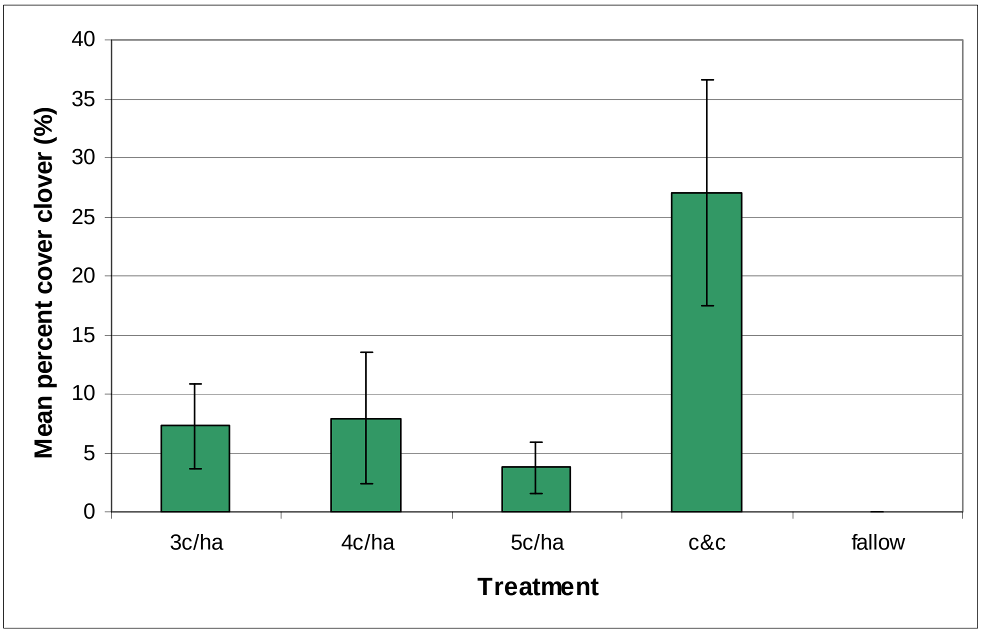

Figure 14 Bar graph showing mean percent cover and 95% confidence intervals by treatment (3c/ha = three cows per hectare, 4c/ha = four cows per hectare, 5c/ha = five cows per hectare, c&c = cut and carry, fallow =fallow) N= 32

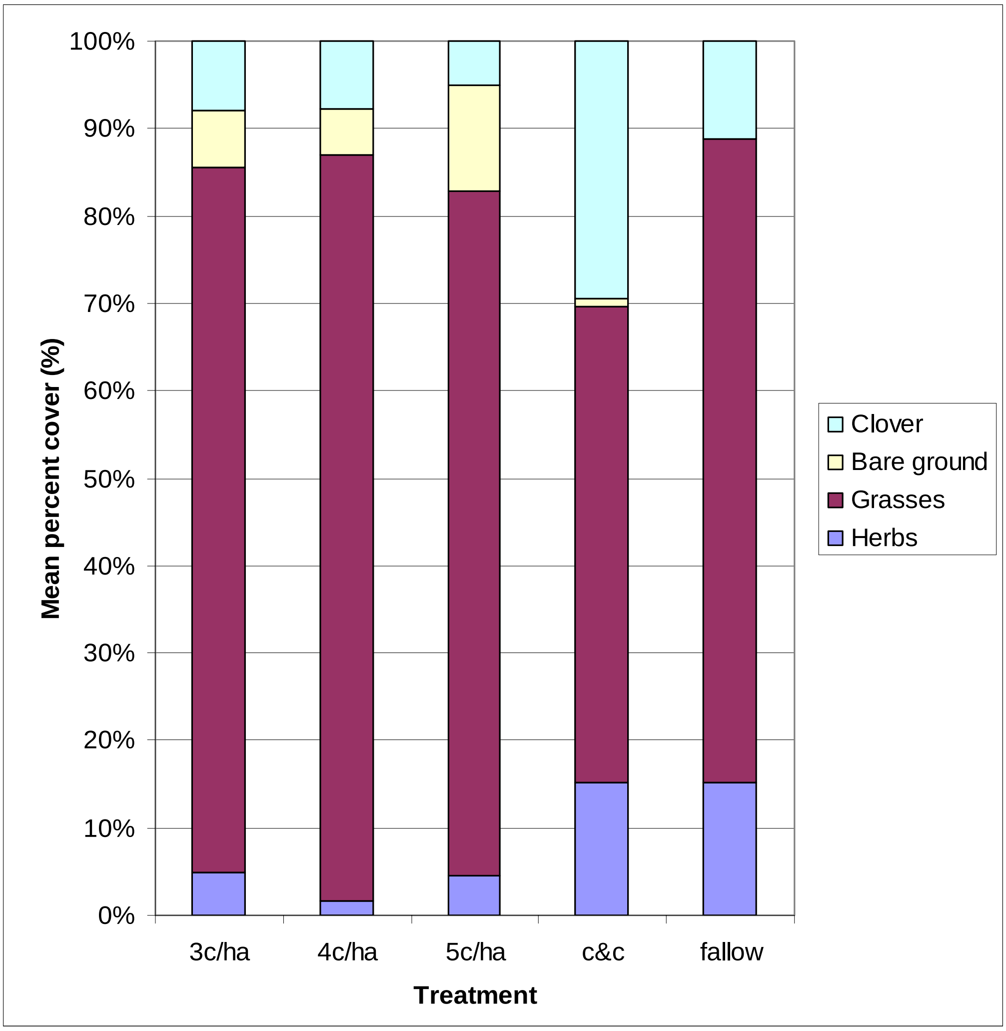

Figure 15 Bar graph showing percentage of total belonging to each cover category (clover, bare ground, grasses and herbs) in each treatment (3c/ha = three cows per hectare, 4c/ha = four cows per hectare, 5c/ha = five cows per hectare, c&c = cut and carry and fa = fallow) N=32

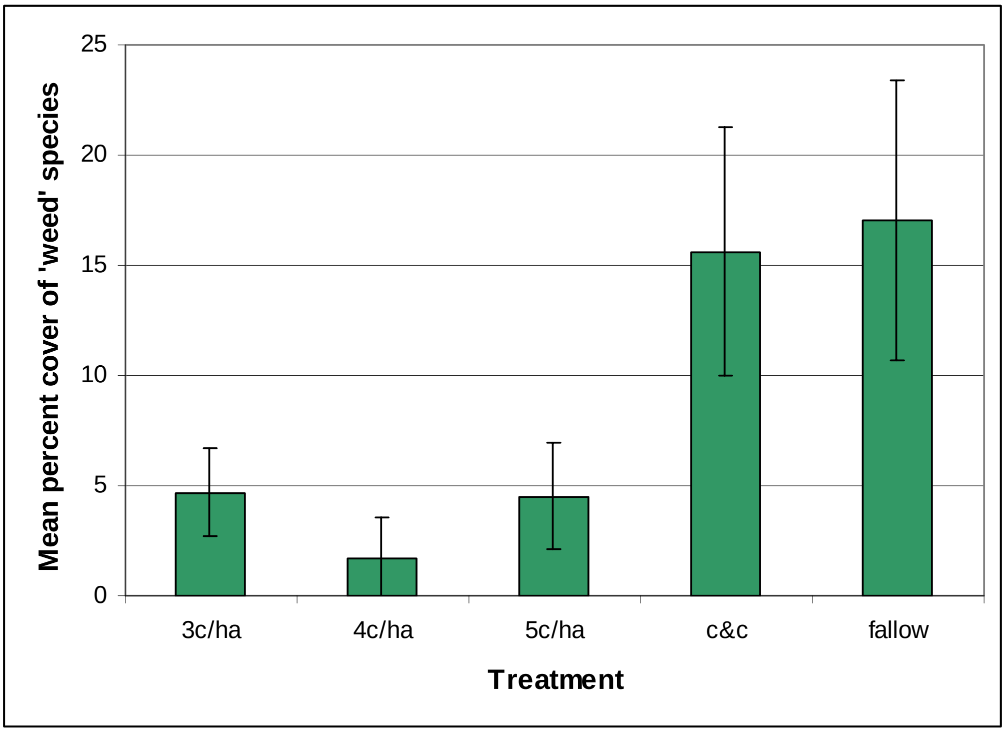

Figure 16 Bar graph showing mean per cent cover of 'weed' species for each of five treatments (3c/ha = three cows per hectare, 4c/ha = four cows per hectare, 5c/ha = five cows per hectare, c&c = cut and carry, fallow = fallow). N = 32

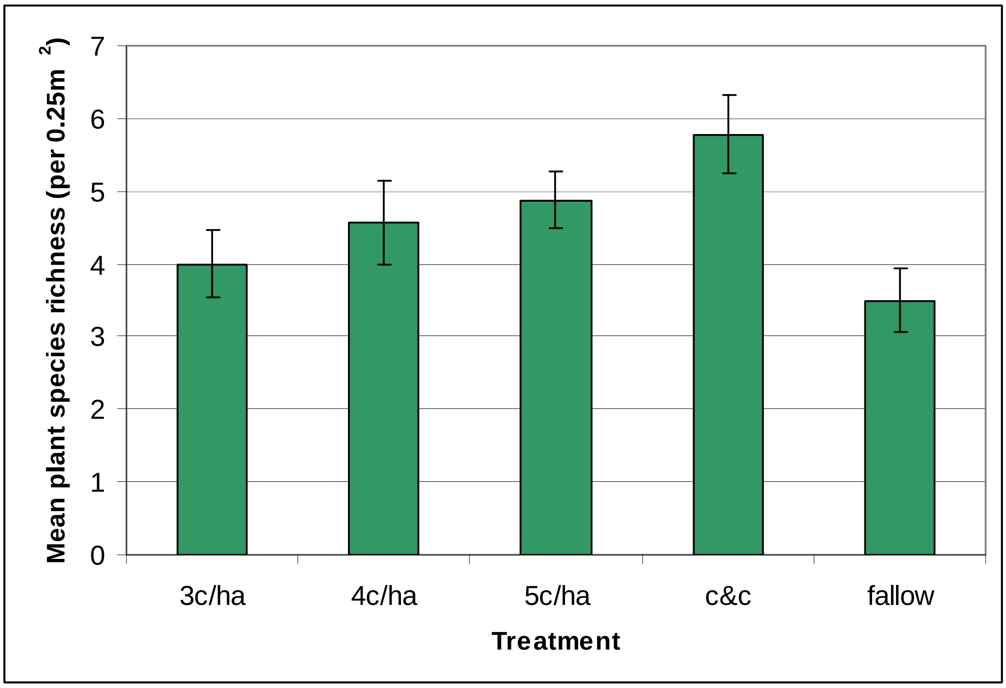

Figure 17 Bar graph showing mean plant species richness (per $0.25m^2$) and 95% confidence intervals for each of five treatments (3c/ha = three cows per hectare, 4c/ha = four cows per hectare, 5c/ha = five cows per hectare, c&c = cut and carry, fallow = fallow). N = 32

Table 2 Showing un-standardised effect sizes (m1-m2), standard deviations and confidence intervals for percent cover clover, percent cover bare ground and plant species richness for different treatment combinations. Column 8 states whether p values were less than 0.05 or not based on whether or not confidence intervals overlap zero.

Plants		m1-m2	SE(diff)	Upper CI	Lower CI	p<0.05?
Bare ground (% cover)	3c/ha*4c/ha	1.14	2.62	6.27	-3.99	No
	3c/ha*5c/ha	-5.35	2.85	0.25	-10.94	No
	5c/ha*4c/ha	-6.48	2.89	-0.82	-12.15	Yes
	5c/ha*c&c	10.86	2.09	14.95	6.77	Yes
	5c/ha*fallow	11.80	1.56	14.86	8.73	Yes
	3c/ha*c&c	5.51	1.81	9.07	1.96	Yes
	3c/ha*fallow	6.45	1.29	8.98	3.92	Yes
Clover (% cover)	3c/ha*4c/ha	-0.64	4.50	8.17	-9.46	No
	3c/ha*5c/ha	3.51	2.82	9.03	-2.01	No
	5c/ha*4c/ha	-4.15	3.79	3.27	-11.57	No
	5c/ha*c&c	-23.25	5.74	-12.00	-34.50	Yes
	5c/ha*fallow	3.75	1.05	5.81	1.69	Yes
	3c/ha*c&c	-19.74	6.45	-7.09	-32.39	Yes
	3c/ha*fallow	7.26	1.77	10.72	3.80	Yes
Species richness	3c/ha*4c/ha	-0.56	0.51	0.43	-1.55	No
	3c/ha*5c/ha	-0.87	0.42	-0.45	-1.69	Yes
	5c/ha*4c/ha	0.31	0.47	0.78	-0.62	No
	5c/ha*c&c	-0.91	0.46	-0.45	-1.81	Yes
	5c/ha*fallow	1.37	0.40	1.77	0.58	Yes
	3c/ha*c&c	-1.78	0.49	-1.29	-2.74	Yes
	3c/ha*fallow	0.50	0.44	0.94	-0.36	No

Figure 13 shows that grazed treatments had greater percent cover of bare ground than non grazed treatments. Figure 13 also shows that the five cows per hectare treatment had the highest per cent cover of bare ground, 1.8 times that of the three cows per hectare treatment.

Table 2 and 95 percent confidence intervals on Figure 13 show that the differences in percent bare ground between the means of the grazed and non grazed treatments and between the means of the three and four cows per hectare treatments and that of the five cows per hectare treatment were statistically significant (p<0.01 and p approx 0.01 respectively).

Figure 14 shows that the five cows per hectare treatment was found to have lower mean percent cover of clover compared to the three cows and four cows per hectare treatments, however, this difference was very small (only 3.75 percent). Table 2 along with the 95 percent confidence intervals on Figure 14 show that differences among grazed treatments for percent cover clover were not statistically significant (p>0.05).

Figure 14 also shows that the cut and carry treatment had mean percent clover cover 7.2 times greater than that of the five cows per hectare treatment (a 23 percent difference in clover cover) and more than 3.7 times greater than that that of the three cows per hectare treatment (a difference of 19 percent) and also that the fallow treatment had no clover cover.

Table 2 and 95 percent confidence intervals on Figure 14 show that differences between the means of the non grazed treatment and grazed treatments for percent cover clover (three or more cows per hectare) were statistically significant (p<0.01).

Figure 15 shows that the five cows per hectare treatment had a higher mean proportion of bare ground and lower mean proportion of clover and grass compared with the three cows and four cows per hectare treatments. Also that the cut and carry treatment (which was subject to no treading/grazing or dung deposition) had significantly lower mean proportions of bare ground and grass cover and greater proportions of herbs (i.e. weeds) and clover than the three, four or five cows per hectare treatments.

Thus it seems that the increase in bare ground within the five cows per hectare treatment was at the expense of clover and grass production rather than at the expense of less desirable species and thus that higher stocking rates impact negatively on pasture production by reducing clover and grass abundance while increasing abundance of bare soils.

Figure 16 shows that mean percent cover of 'weed' species (non clover, non grass species) did not differ between the three cows per hectare and the five cows per hectare treatment but was much higher for the cut and carry and fallow treatments compared to the grazed treatments. 95 percent confidence intervals on Figure 15 show that mean differences between grazed and non grazed treatments were statistically significant ($p<0.01$).

Figure 17 shows that mean plant species richness was higher in the five cows per hectare treatment than in the three cows per hectare treatment and that the four cows per hectare treatment had a mean species richness intermediate between those of the other grazed treatments. Figure 17 also shows that grazed treatments had lower mean species richness compared to the cut and carry treatment but higher mean species richness compared to the fallow treatment.

Table 2 and 95 percent confidence intervals on Figure 17 indicate that differences between the three cows per hectare treatment and the five cows per hectare treatment were statistically significant (*p* approximately 0.01) and that differences between the grazed treatments and the fallow and cut and carry treatments for plant species richness (with the exception of the three cows per hectare not differing significantly from the fallow treatment) were also statistically significant (*p* approx. 0.01).

However, no means of any treatments differed from the mean of any other treatment by more than three species and the means of grazed treatments differed from one another by less than a single species. Thus, while grazed pastures had statistically greater species richness than ungrazed pastures, and this difference became greater the more heavily the pastures were stocked, in ecological terms this difference is not remarkable.

4.2.2 Fauna

4.2.2.1 Nematodes

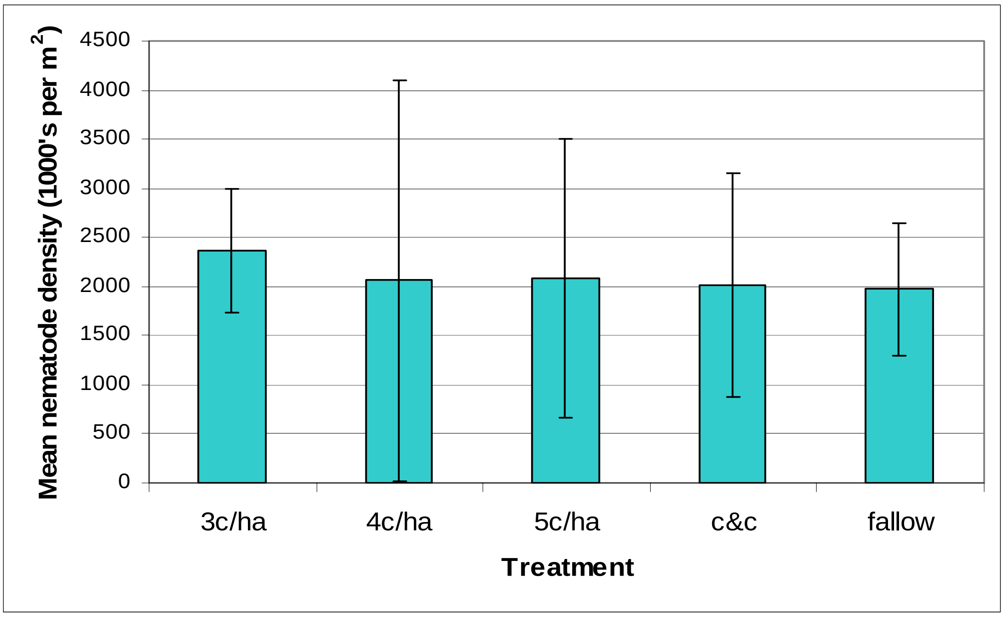

Figure 18 Bar graph showing mean nematode density (per m2) and 95% confidence intervals by treatment (3c/ha = three cows per hectare, 4c/ha = four cows per are, 5c/ha = five cows per hectare, c& = cut and carry and fallow=fallow) N=4

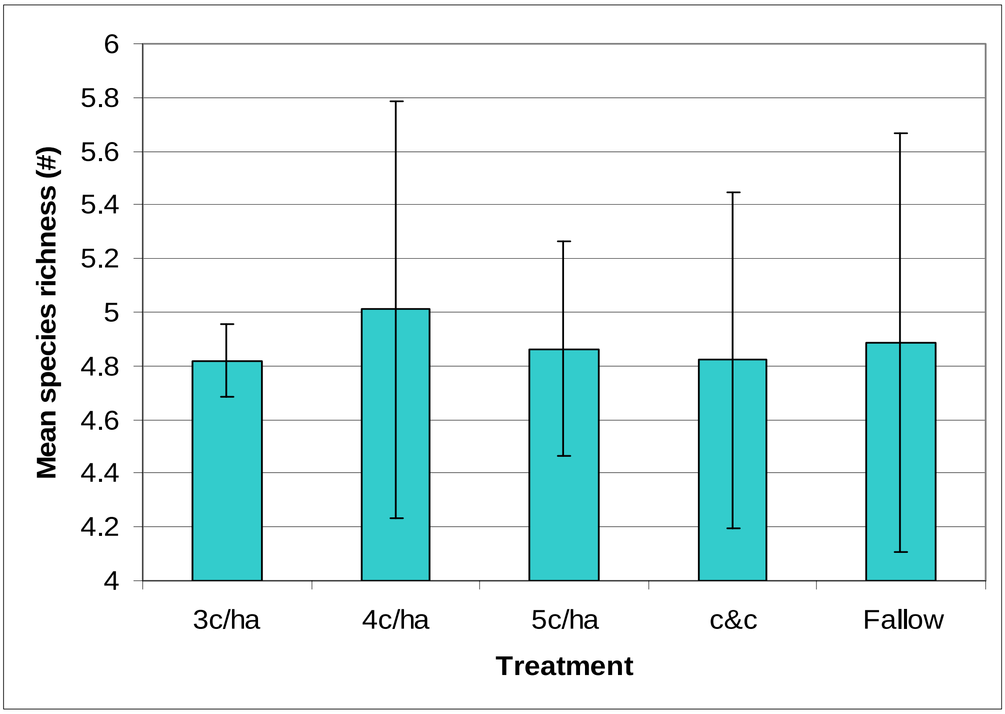

Figure 19 Bar graph showing mean nematode species richness and 95 percent confidence intervals for different stocking rate treatments (3c/ha = three cows per hectare, 4c/ha = four cows per hectare, 5c/ha = five cows per hectare, c&c = cut and carry and fallow = fallow). N= 4

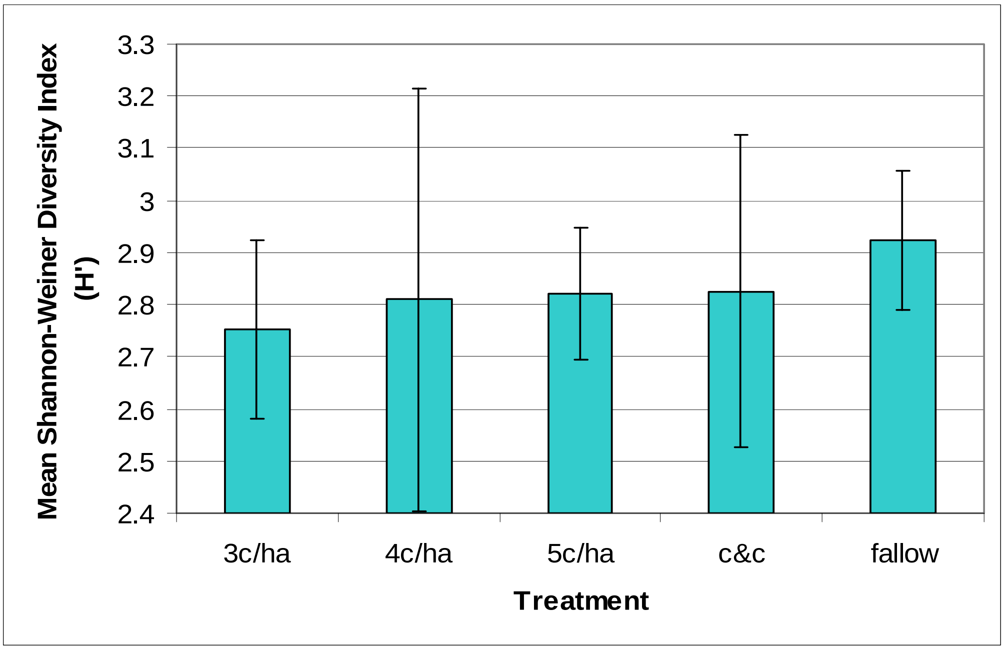

Figure 20 Bar graph showing mean Shannon Wiener Diversity Index and 95 percent confidence intervals by treatment (3c/ha = three cows per hectare, 4c/ha = four cows per hectare, 5c/ha = five cows per hectare, c& = cut and carry and fallow = fallow) N=4

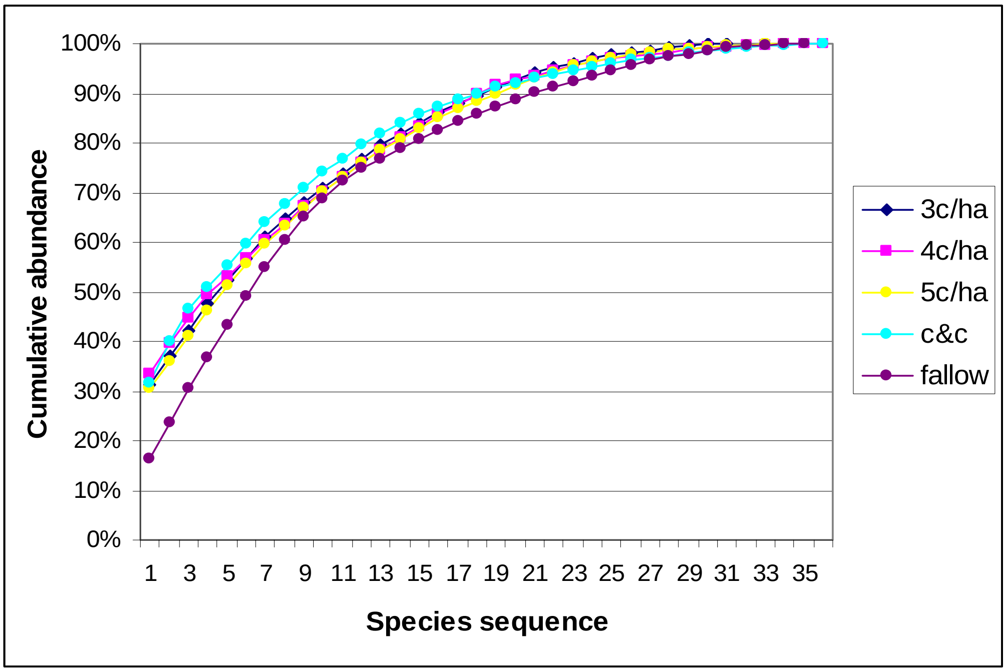

Figure 21 Line graph showing cumulative abundance curves for nematode species in each of five stocking rate treatments (3c/ha = three cows per hectare, 4c/ha = four cows per hectare, 5c/ha = five cows per hectare, c&c = cut and carry and fallow = fallow). N=4

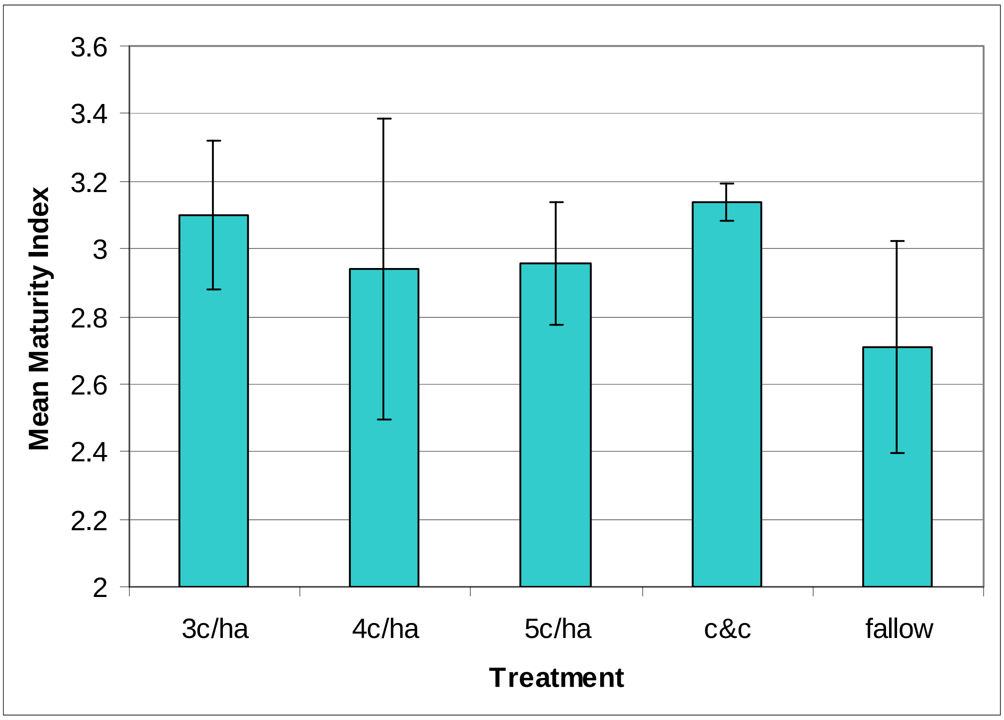

Figure 22 Bar graph showing mean Maturity Index and 95 percent confidence intervals for each of five stocking rate treatments (3c/ha = three cows per hectare, 4c/ha = four cows per hectare, 5c/ha = five cows per hectare, c&c = cut and carry and fallow = fallow). N= 4

Table 3 Number of nematode species that were found in the three cows per hectare (3c/ha) treatment that were not found in the five cows per hectare (5c/ha) treatment and vice versa

Number of nematode species found in 3c /ha treatment that were not found in the 4c/ha or 5c/ha treatments	1
Number of nematode species found in 5c/ha and 4c/ha treatments but not in the 3c/ha treatment	3
Number of species that were found in the 5c/ha hectare treatment but not in the 3c/ha or 4c/ha treatments	1

Figure 18 shows that mean nematode density for all treatments was high at between 190 thousand and 240 thousand nematodes per square metre. Figure 18 also shows that mean nematode density did not decrease or increase with increased stocking rate and that treatments differed very little in mean nematode density. Table 4 (below) and 95 percent confidence intervals on Figure 18 show that differences among treatments were not statistically significant ($p>0.05$).

Confidence intervals on Figure 18 indicate that there was much variability in nematode densities among samples within treatments.

For example one sample from the four cows per hectare pasture had the lowest nematode count of all samples collected across the management regimes, while another from the four cows per hectare pasture had the highest of all.

Figure 19 shows that mean species richness differed very little (by less than 0.2) among treatments and Table 4 (below) and 95 percent confidence intervals on Figure 19 show that there were no statistically significant differences among treatments ($p>0.05$). Confidence intervals on Figure 19 also show that there was much variability among samples within treatments.

Figure 20 shows that diversity as measured by the Shannon Weiner Index was in a range that would be considered average for all treatments and that Shannon Weiner diversity indices differed very little (by less than 0.2) among treatments (the Shannon Weiner Diversity Index is based on species richness and evenness - an index of one indicates low diversity while an index of four indicates high diversity). Table 4 (below) and 95 percent confidence intervals on Figure 20 show that there were no statistically significant differences between means among treatments ($p>0.05$). Confidence intervals on Figure 20 also show that there was a lot of variation in Shannon Weiner Indexes among samples within treatments.

Figure 21 shows that the fallow treatment had a slightly higher diversity (combination of richness and evenness) of nematode species compared to all other treatments (as it has the lowest flattest curve) but that other treatments differed very little from one another and that there is no trend in species diversity with increased stocking rate.

Figure 22 shows maturity indexes for each treatment. Maturity indexes are used to give an indication of the level of disturbance a community is experiencing. Maturity indexes are related to the ratio of *r* selected to *k* selected species in a community. Higher proportions of r selected species indicate higher levels of disturbance while higher proportions of k selected species indicate lower levels of disturbance. Species that are *r* selected species typically have short generation times, high fecundity and fast population growth rates while *k* selected species typically have longer generation times, lower fecundity and slower population growth rates (and hence are not as vulnerable to disturbance).

Figure 22 shows that all treatments had similar maturity indexes with the maturity indexes of the grazed treatments differing by less than 0.2 and the highest (cut & carry) and the lowest maturity indexes (fallow) differing from one another by less than 0.5. Furthermore, Table 4 (below) and 95% confidence intervals on Figure 22 indicate that the only statistically significant difference was between the mean of the three cows per hectare and that of the fallow treatment ($p<0.01$).

Table 3 shows that species composition differed little among grazed treatments as few species were found at higher grazing pressures but not found at lower grazing pressures and vice versa.

Table 4 Un-standardised effect sizes (m1-m2), standard deviations and confidence intervals for nematode density, nematode species richness, Shannon Weiner Index, Maturity Index and species evenness for different treatment combinations. The last column states whether p values were less than 0.05 or not based on whether or not confidence intervals overlap zero

Nematodes		m1-m2	SE(diff)	Upper CI	Lower CI	P<0.05?
Nematode density	3c/ha*4c/ha	303513.00	836385.99	1942829.53	1335803.53	No
	3c/ha*5c/ha	273976.50	642801.89	1533868.21	-985915.21	No
	5c/ha*4c/ha	-29536.50	1084095.64	2095290.95	2154363.95	No
	5c/ha*c&c	75369.00	802077.86	1647441.61	1496703.61	No
	5c/ha*fallow	115090.50	212144.04	530892.82	-300711.82	No
	3c/ha*c&c	349345.50	554368.21	1435907.19	-737216.19	No
	3c/ha*fallow	389067.00	409690.16	1192059.71	-413925.71	No
Species richness	3c/ha*4c/ha	-0.19	2.56	4.82	-5.20	No
	3c/ha*5c/ha	-0.04	2.32	4.50	-4.59	No
	5c/ha*4c/ha	-0.15	2.61	4.97	-5.27	No
	5c/ha*c&c	0.04	2.45	4.84	-4.75	No
	5c/ha*fallow	-0.02	2.50	4.87	-4.91	No
	3c/ha*c&c	-0.07	2.33	4.51	-4.64	No
	3c/ha*fallow	-0.07	2.56	4.95	-5.08	No
Shannon Weiner Index	3c/ha*4c/ha	-0.06	0.18	0.30	-0.41	No
	3c/ha*5c/ha	-0.07	0.09	0.12	-0.25	No
	5c/ha*4c/ha	0.01	0.17	0.34	-0.32	No
	5c/ha*c&c	0.00	0.13	0.27	-0.26	No
	5c/ha*fallow	-0.10	0.08	0.06	-0.26	No
	3c/ha*c&c	-0.07	0.15	0.22	-0.36	No
	3c/ha*fallow	-0.17	0.10	0.02	-0.36	No
Maturity Index	3c/ha*4c/ha	0.16	0.21	0.57	-0.25	No
	3c/ha*5c/ha	0.14	0.13	0.39	-0.11	No
	5c/ha*4c/ha	0.02	0.13	0.27	-0.23	No
	5c/ha*c&c	-0.18	0.10	0.01	-0.37	No
	5c/ha*fallow	0.25	0.16	0.55	-0.06	No
	3c/ha*c&c	-0.04	0.11	0.17	-0.25	No
	3c/ha*fallow	0.39	0.17	0.72	0.06	Yes
Species evenness	3c/ha*4c/ha	0.00	0.05	0.09	-0.09	No
	3c/ha*5c/ha	-0.02	0.04	0.05	-0.09	No
	5c/ha*4c/ha	0.02	0.05	0.12	-0.08	No
	5c/ha*c&c	0.00	0.11	0.21	-0.21	No
	5c/ha*fallow	-0.03	0.04	0.04	-0.11	No
	3c/ha*c&c	-0.02	0.10	0.18	-0.22	No
	3c/ha*fallow	-0.05	0.03	0.01	-0.12	No

4.2.2.2 Insects, spiders, springtails and mites

4.2.2.2.1 Suction sampling (surface dwelling arthropods)

Table 5 Mean densities per m2 & 95 percent confidence intervals for 16 invertebrate orders in each of five treatments (3c/ha = three cows per hectare, 4c/ha = four cows per hectare, 5c/ha = five cows per hectare, c&c = cut and carry and fa = fallow). The trend column shows which taxa demonstrated a clear stocking rates effect (increasing or decreasing abundance with increased stocking rate). These are marked with an arrow. The significance column shows whether overlap of 95 percent confidence intervals on means and 95 percent confidence intervals on mean differences indicate that differences between the three cows per hectare treatment and five cows per hectare treatment were statistically significant N= 4

Arthropod taxa		3c/ha	4c/ha	5c/ha	c&c	fallow	Trend?	Significance?
Acarina	Mean	15.00	3.00	2.86	11.00	22.00	↓	No
	CI	14.61	2.26	2.23	7.52	16.70	–	
Araneida	Mean	7.86	7.71	4.43	4.71	22.14	↓	No
	CI	9.71	8.85	4.23	5.12	19.20	–	
Chilopoda	Mean	49.86	73.00	108.14	69.29	313.86	↑	No
	CI	20.13	27.92	50.57	25.43	124.35	–	
Coleoptera	Mean	22.43	27.14	25.86	20.43	31.43	–	
	CI	8.47	8.27	9.32	7.75	19.92	–	
Collembola	Mean	25.14	26.43	26.57	19.71	30.00	↑	No
	CI	8.64	8.79	9.33	8.20	20.15	–	
Diplopoda	Mean	13.86	11.43	12.29	17.71	0.57	–	
	CI	19.43	11.58	12.98	31.85	0.70	–	
Diptera	Mean	3.14	2.43	3.43	1.86	12.86	–	
	CI	3.03	3.88	3.34	2.25	5.36	–	
Gastropoda	Mean	37.29	37.14	38.14	47.43	36.29	–	
	CI	14.91	14.76	14.06	21.72	14.47	–	
Hemiptera	Mean	9.57	2.57	1.14	6.00	53.86	↓	yes (p<0.01)
	CI	6.86	1.70	1.26	3.31	19.88	–	
Hymenoptera	Mean	81.71	162.00	210.00	61.71	66.14	↑	yes (p approx. 0.01)
	CI	167.66	332.40	430.88	126.63	135.71	–	
Isopoda	Mean	75.29	159.43	190.29	57.57	69.43	↑	No
	CI	37.26	65.82	96.31	24.31	36.83	–	
Lepidoptera	Mean	35.86	32.00	26.71	24.00	31.57	↓	No
	CI	24.63	16.59	14.49	17.52	17.59	–	
Neuroptera	Mean	0.71	0.71	5.14	1.00	19.14	↑	yes (p<0.01)
	CI	0.74	0.74	0.85	0.80	8.62	–	
Opilones	Mean	0.57	3.00	1.14	2.43	1.71	–	
	CI	0.55	2.26	0.83	2.12	1.43	–	
Psocoptera	Mean	0.71	1.57	0.43	0.29	0.57	–	
	CI	0.60	1.29	0.49	0.41	0.70	–	
Thysanoptera	Mean	0.14	0.14	0.14	0.71	0.43	–	
	CI	0.29	0.29	0.29	0.74	0.65	–	

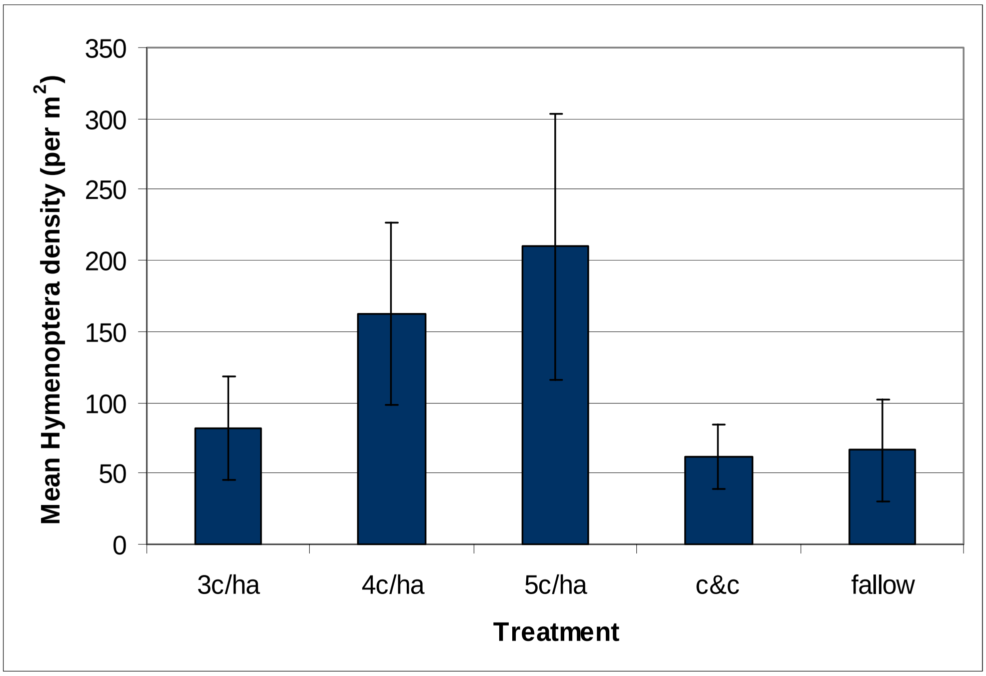

Figure 23 Mean density of Hymenoptera and 95 percent confidence intervals for each of five treatments (3c/ha = three cows per hectare, 4c/ha = four cows per hectare, 5c/ha = five cows per hectare, c&c = cut and carry and fa = fallow). N=28

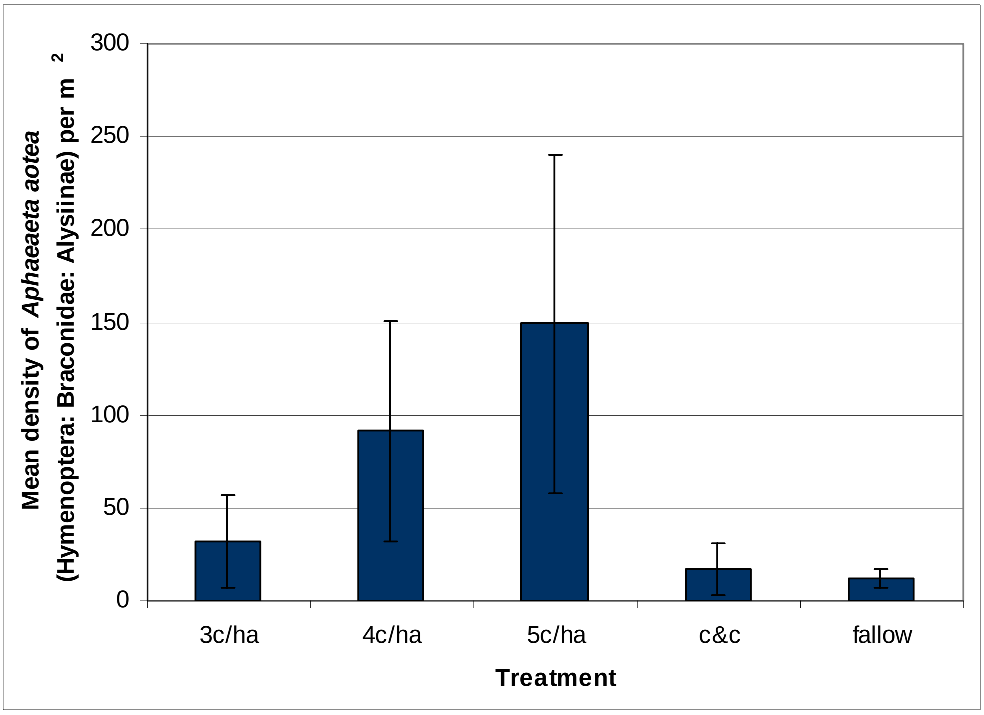

Figure 24 Mean density of Hymenoptera *Aphaeaeta aotea* (Braconidae: Alysiinae) and 95 percent confidence intervals for each of five treatments (3c/ha = three cows per hectare, 4c/ha = f our cows per hectare, 5c/ha = five cows per hectare, c&c = cut and carry and fa = fallow). N=28

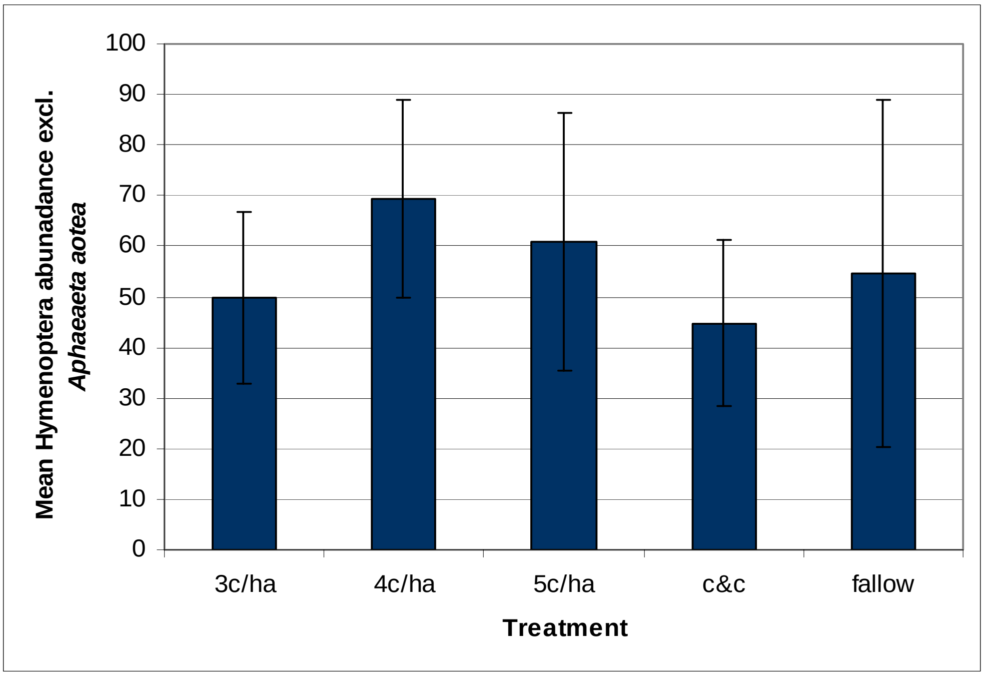

Figure 25 Mean density of Hymenoptera excluding *Aphaeaeta aotea* (Braconidae: Alysiinae) and 95 percent confidence intervals for different treatments (3c/ha = three cows per hectare, 4c/ha = four cows per hectare, 5c/ha = five cows per hectare, c&c = cut and carry and fa = fallow). N=28

Table 5 shows that nine out of sixteen invertebrate orders showed positive or negative trends in mean density with increasing stocking rates. Of nine invertebrate orders, five showed negative trends (Acarina, Araneida, Hemiptera, Lepidoptera and Neuroptera), and four showed positive trends (Chilopoda, Collembola, Hymenoptera, and Isopoda).

Table 5 also shows that of the invertebrate orders that showed negative and positive trends with increased stocking rate, only three had differences in mean densities between the three cows per hectare and five cows per hectare treatments that were statistically significant. These were Hemiptera (true bugs), Hymenoptera (wasps, bees and ants) and Nueroptera (net winged insects).

However, Figures 23 through 25 show that trends in mean Hymenoptera abundance were almost entirely the result of increased density of a single species (*Aphaeaeta aotea*), and that removing this species removed trends in Hymenoptera density with increased stocking rates.

Table 5 shows that despite being statistically significant, differences in density among grazed treatments for Hemiptera and Nueroptera were very small (less than 10 and 6 individuals respectively) and not likely to be significant ecologically.

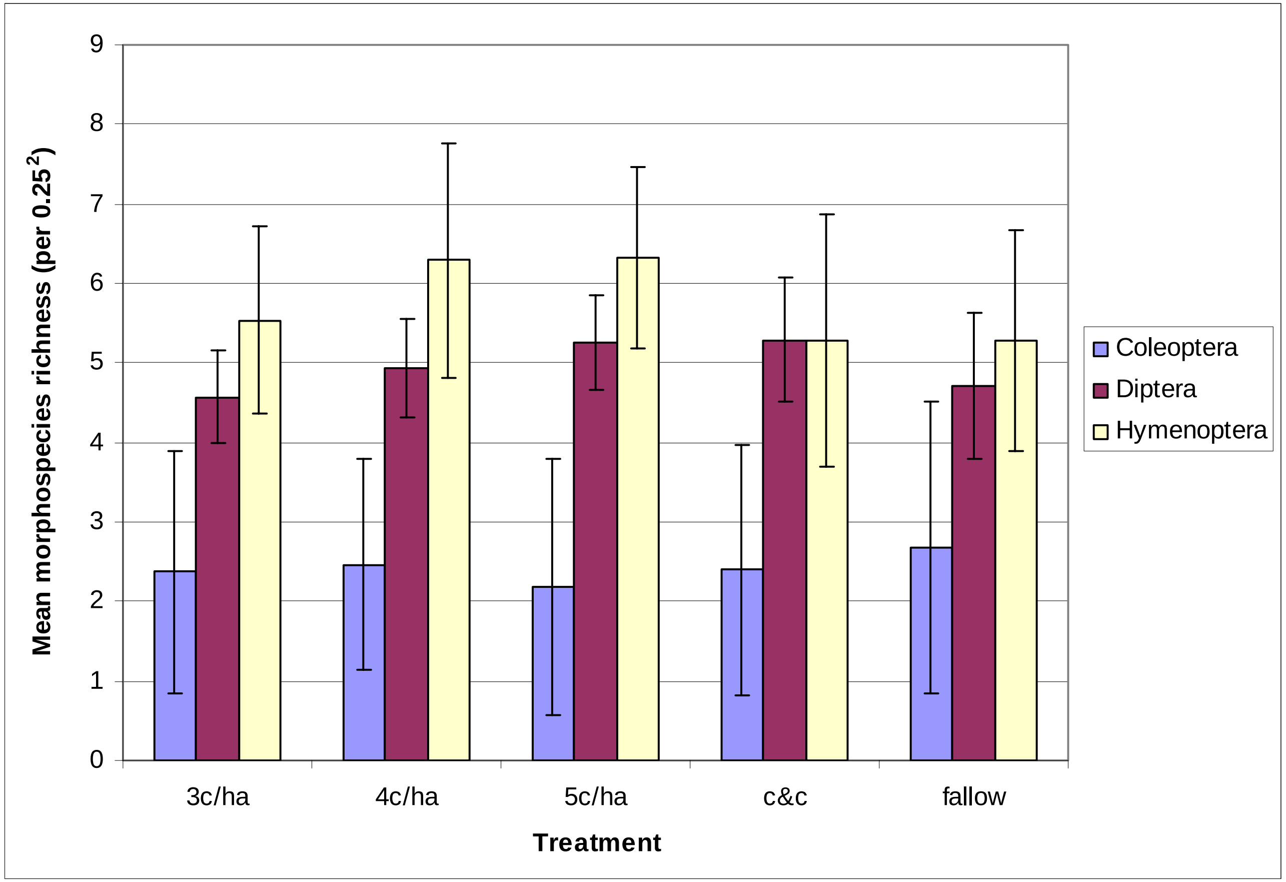

Figure 26 Mean morphospecies richness and 95% confidence intervals for Coleoptera, Diptera and Hymenoptera for each of five treatments (3c/ha = three cows per hectare, 4c/ha = four cows per hectare, 5c/ha = five cows per hectare, c&c = cut & carry, fallow = fallow). N=28

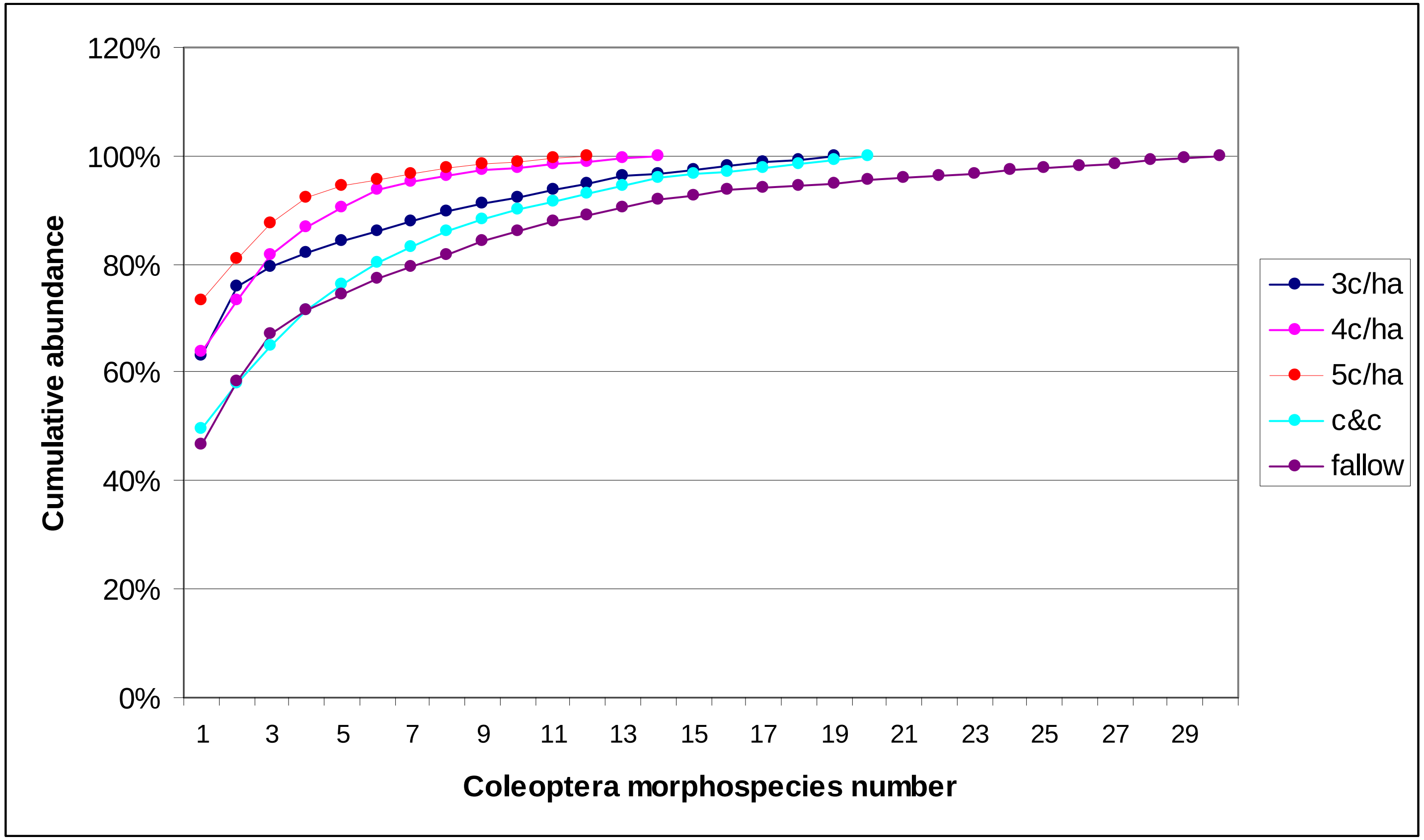

Figure 27 Line graph showing cumulative abundance curves for Coleoptera (beetles) morphospecies found in each of five treatments(3c/ha = three cows per hectare, 4c/ha = four cows per hectare, 5c/ha = five cows per hectare, c&c = cut & carry, fallow). N=28

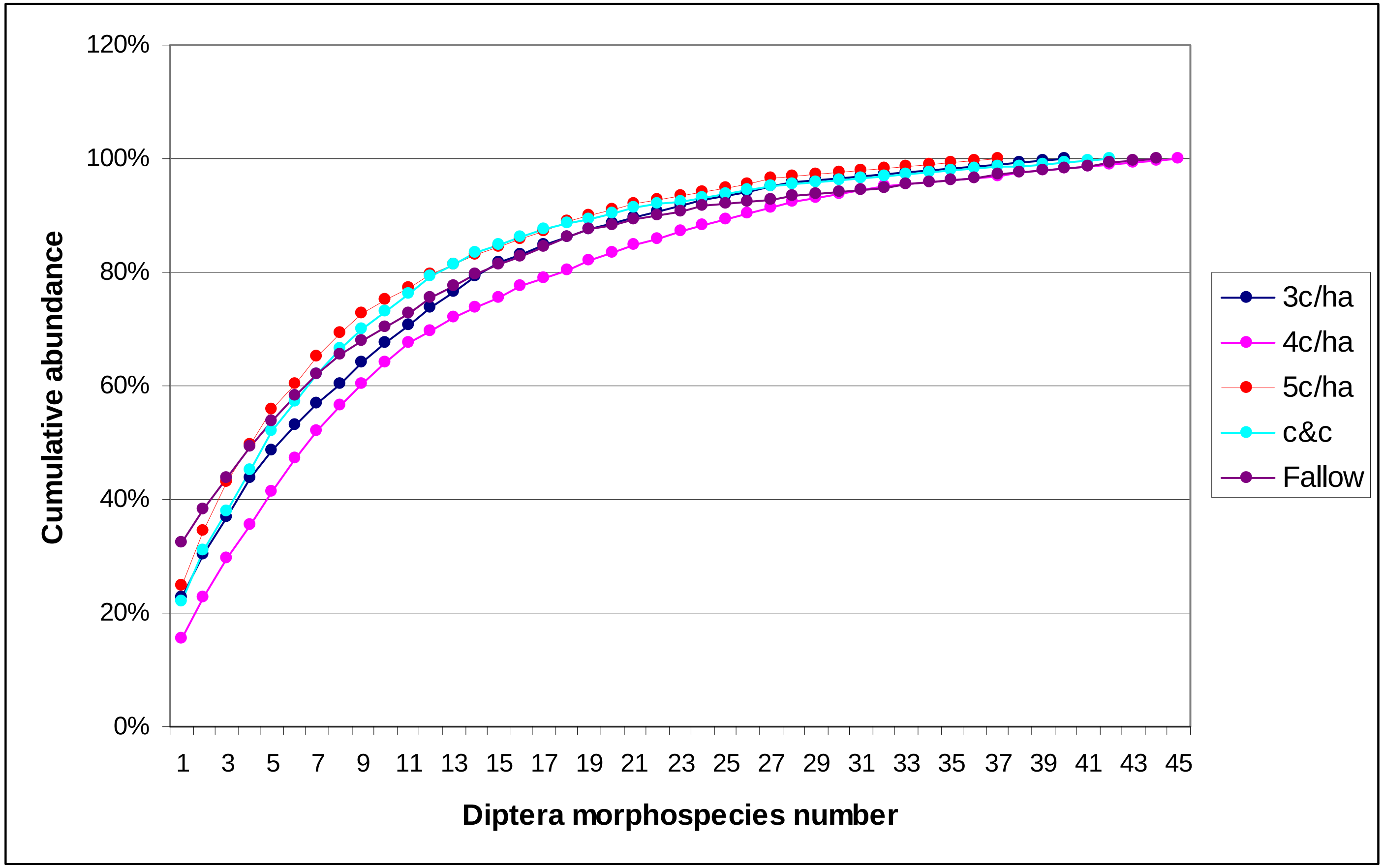

Figure 28 Line graph showing cumulative abundance curves for Diptera (flies) morphospecies found in each of five treatments(3c/ha = three cows per hectare, 4c/ha = four cows per hectare, 5c/ha = five cows per hectare, c&c = cut & carry, fallow). N=28

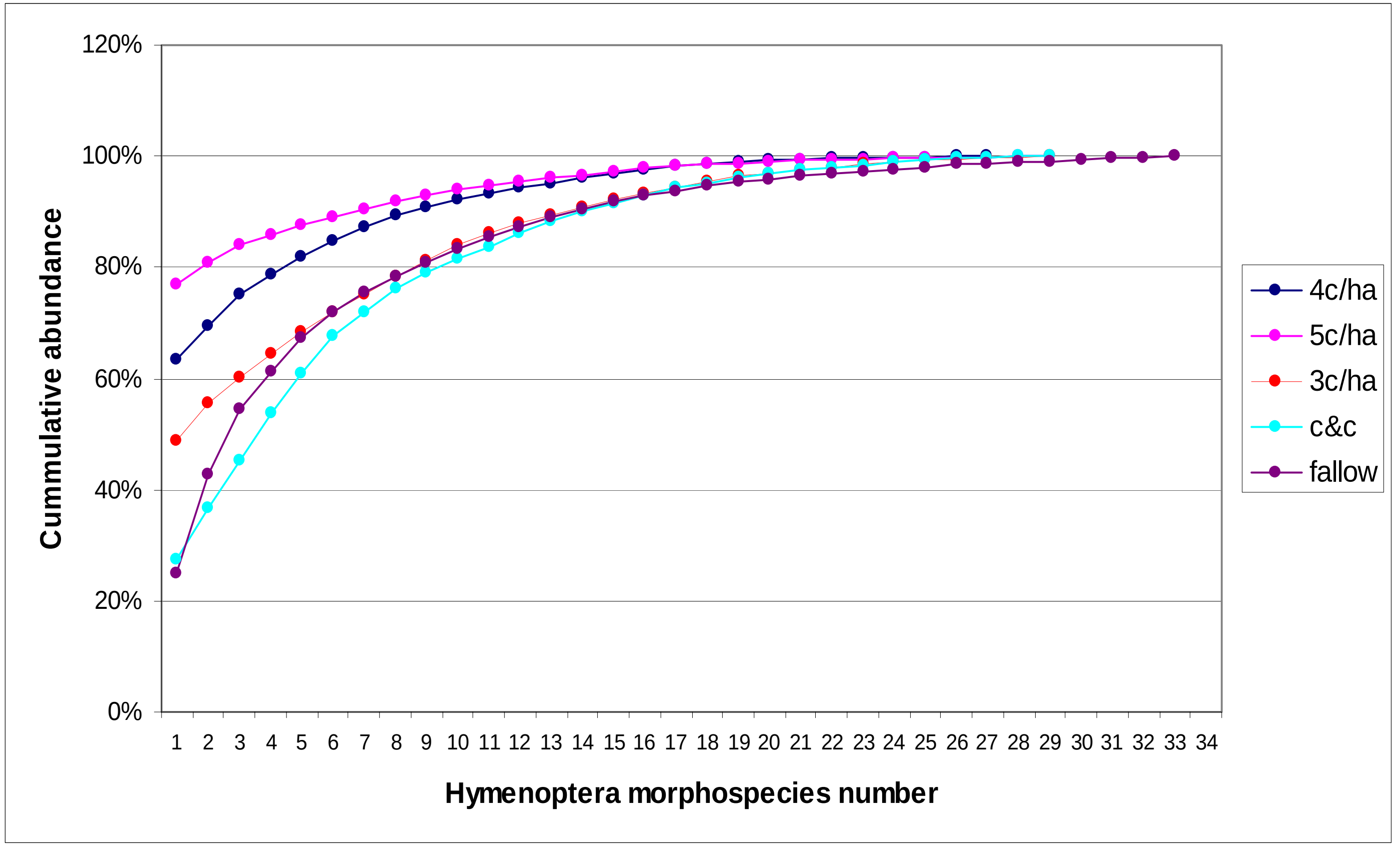

Figure 29 Line graph showing cumulative abundance curves for Hymenoptera (wasps, bees and ants) morphospecies found in each of five stocking rate treatments (3c/ha = three cows per hectare, 4c/ha = four cows per hectare, 5c/ha = five cows per hectare, c&c = cut & carry, fallow = fallow) N=28

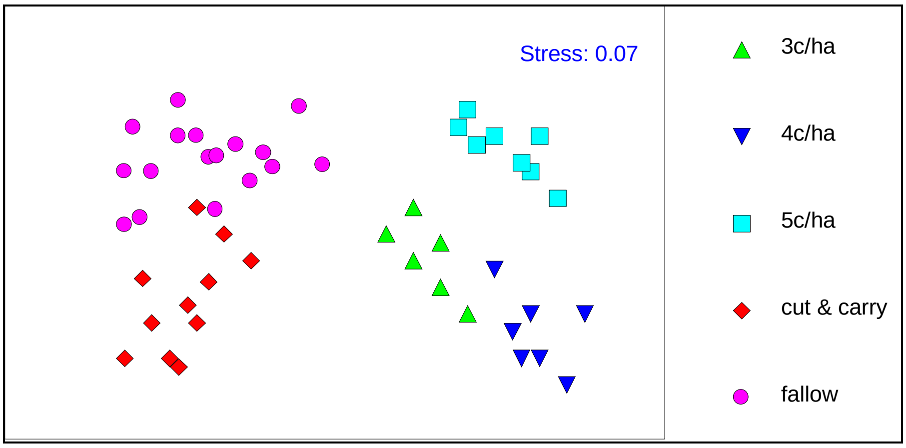

Figure 30 Example of what Figures 31 through 37 would look like if invertebrate composition differed significantly – the more separated the treatments are from one another the more different they are in terms of invertebrate composition

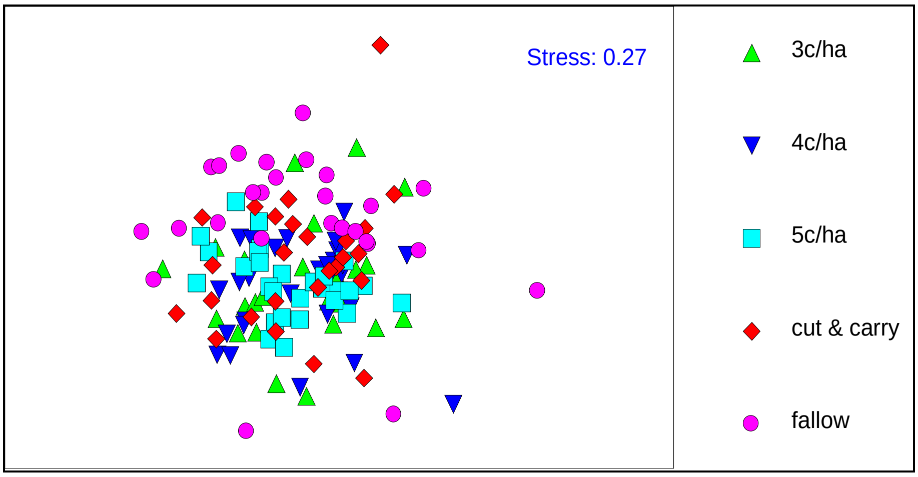

Figure 31 Shows the overlap of Coleoptera, Diptera and Hymenoptera morphospecies composition between treatments (three cows per hectare = green, four cows per hectare = dark blue, five cows per hectare = aqua, cut and carry = red, fallow = pink) based on an MDS ordination. Ordination two dimensional stress value = 0.27

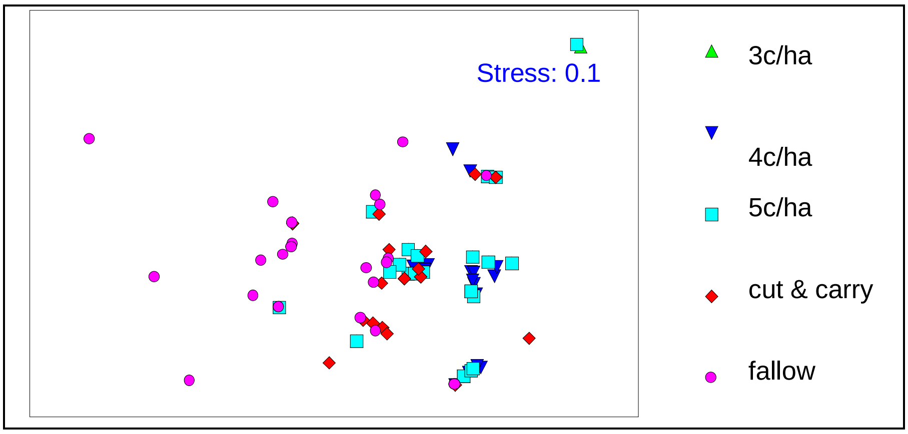

Figure 32 Shows the overlap of Coleoptera family composition between treatments (three cows per hectare = green, four cows per hectare = dark blue, five cows per hectare = aqua, cut and carry = red, fallow = pink) based on an nMDS ordination. Ordination two dimensional stress value = 0.1

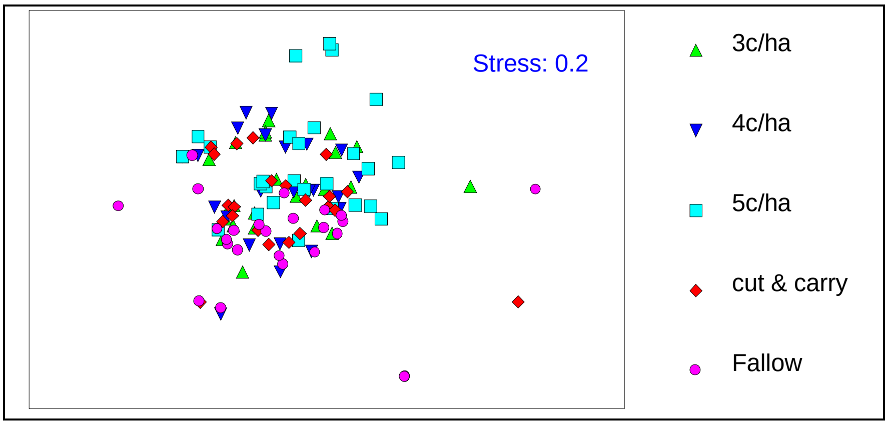

Figure 33 Shows the overlap of Diptera family composition between treatments (three cows per hectare = green, four cows per hectare = dark blue, five cows per hectare = aqua, cut and carry = red, fallow = pink) based on an nMDS ordination. Ordination two dimensional stress value = 0.2

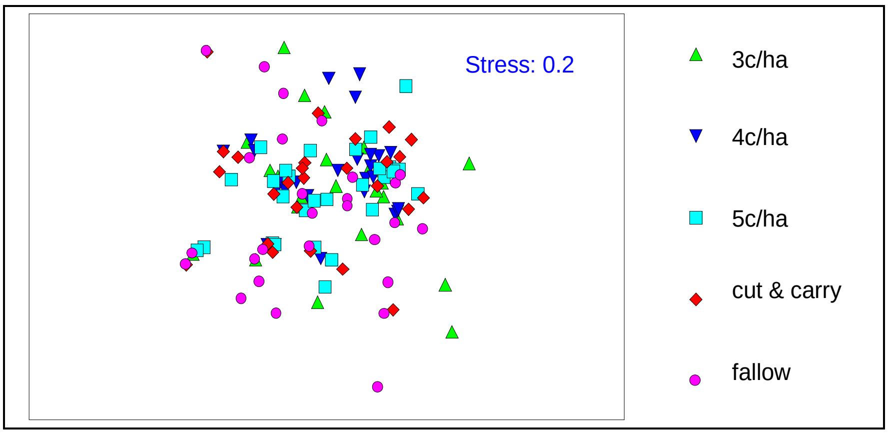

Figure 34 Shows the overlap of Hymenoptera family composition between treatments (three cows per hectare = green, four cows per hectare = dark blue, five cows per hectare = aqua, cut and carry = red, fallow = pink) based on an nMDS ordination. Ordination two dimensional stress value = 0.2

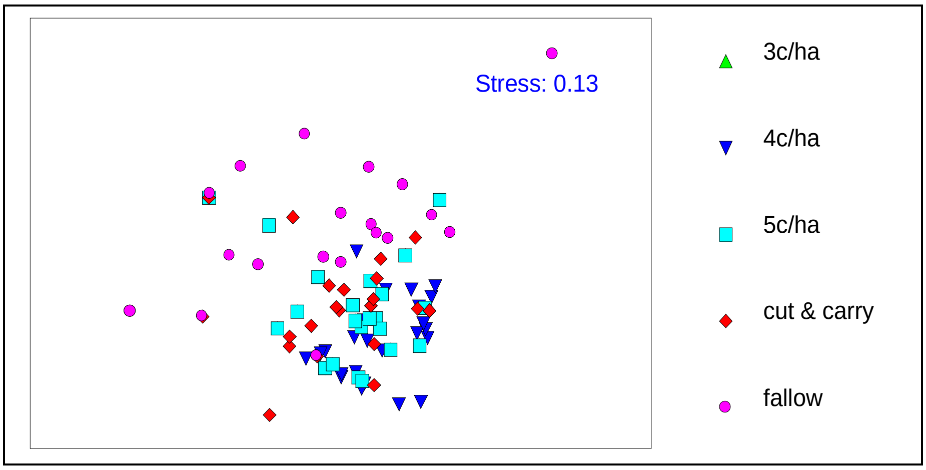

Figure 35 Shows the overlap of Coleoptera morphospecies composition between treatments (three cows per hectare = green, four cows per hectare = dark blue, five cows per hectare = aqua, cut and carry = red, fallow = pink) based on an nMDS ordination. Ordination two dimensional stress value = 0.13

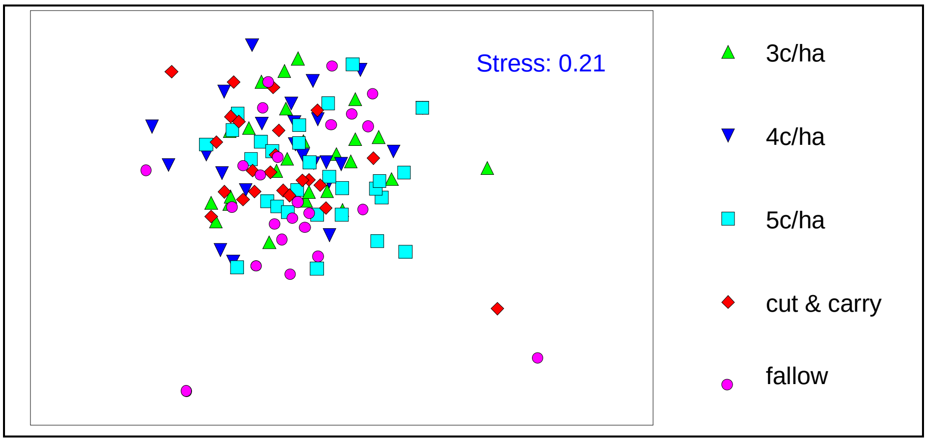

Figure 36 Shows the overlap of Diptera morphospecies composition between treatments (three cows per hectare = green, four cows per hectare = dark blue, five cows per hectare = aqua, cut and carry = red, fallow = pink) based on an nMDS ordination. Ordination two dimensional stress value = 0.21.

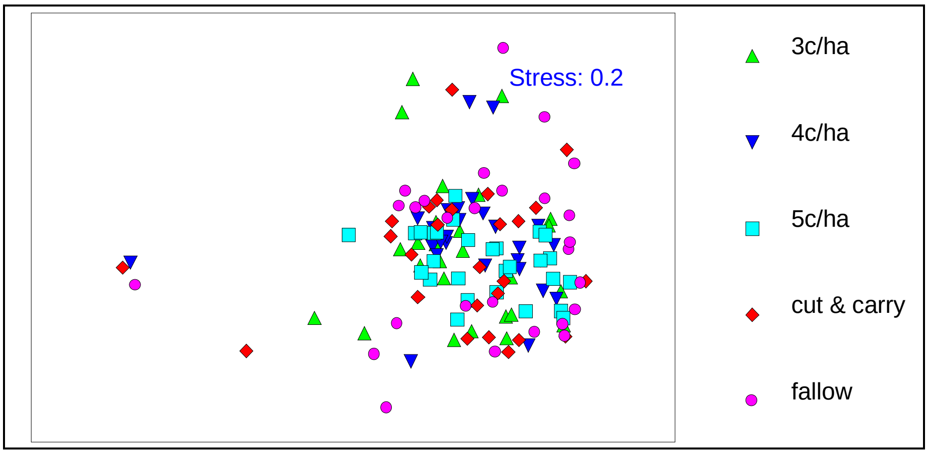

Figure 37 Showing the overlap of Hymenoptera morphospecies composition between treatments (three cows per hectare = green, four cows per hectare = dark blue, five cows per hectare = aqua, cut and carry = red, fallow = pink) based on an nMDS ordination. Ordination two dimensional stress value = 0.21

Table 6 Shows r values from one-way ANOSIM comparing similarity among treatments for all taxa combined, Coleoptera families, Diptera families, Hymenoptera families, Coleoptera morphospecies, Diptera morphospecies and Hymenoptera morphospecies.
For ANOSIM r values, Clarke and Warwick (2005) use the definitions of: well separated R > 0.75, clearly different R > 0.5, and barely separable R < 0.25].

Dataset	Global *r* value
All taxa combined	0.096
Coleoptera families	0.132
Diptera families	0.054
Hymenoptera families	0.033
Coleoptera morphospecies	0.105
Diptera morphospecies	0.057
Hymenoptera morphospecies	0.055

Figure 26 shows that mean morphospecies richness for Coleoptera, Diptera and Hymenoptera differed very little among treatments and that differences in mean species richness among treatments were not statistically significant ($p>0.05$).

Figure 27 shows that the fallow treatment had the highest mean Coleoptera morphospecies diversity (combination of species richness and evenness) compared to other treatments, followed closely by that of the cut and carry treatment (these treatments had the lowest flattest lines). Also, that while there was a trend of decreasing Coleoptera morphospecies diversity with increasing stocking rate, differences between grazed treatments were small and unlikely to be biologically significant.

Figure 28 shows that that there were no clear effects of grazing or trends with increased stocking rate for Diptera morphospecies diversity (lines are very close together and often overlap).

Figure 29 shows that the fallow treatment had the highest Hymenoptera morphospecies diversity (combination of species richness and evenness) compared to other treatments followed closely by the cut and carry treatments (these treatments had the lowest flattest lines). Also, that there was a trend of decreasing Hymenoptera morphospecies diversity with increasing stocking rate. However, differences in Hymenoptera morphospecies richness were only very small and unlikely to be biologically significant (lines are close together and overlap).

Figures 31 through 37 show that for all taxa combined, Coleoptera families, Diptera families, Hymenoptera families, Coleoptera morphospecies, Diptera morphospecies and Hymenoptera morphospecies, composition differed very little among treatments.

Stress values indicate the accuracy with which the non metric multidimensional ordination has represented the input data. Smaller stress values indicate more accurate representation. Stress values of zero represent a perfect representation while stress values above 0.3 indicate an unsatisfactory level of inaccuracy. Stress values for ordinations shown figures 32 to 37 ranged from 0.1 to 0.21. The ordination in Figure 31 had a higher stress value of 0.27.

Table 6 shows that in no case were r values large enough for compositions of arthropods to be considered even barely separated among treatments by Clark & Warwick's (2005) definition.

SIMPER analyses would have been used to examine which taxa and also which morphospecies, contributed the most to the differences between treatments. However since there was very little differences among treatments SIMPER analyses were not utilized.

4.2.2.2.2 Soil cores (springtails and mites)

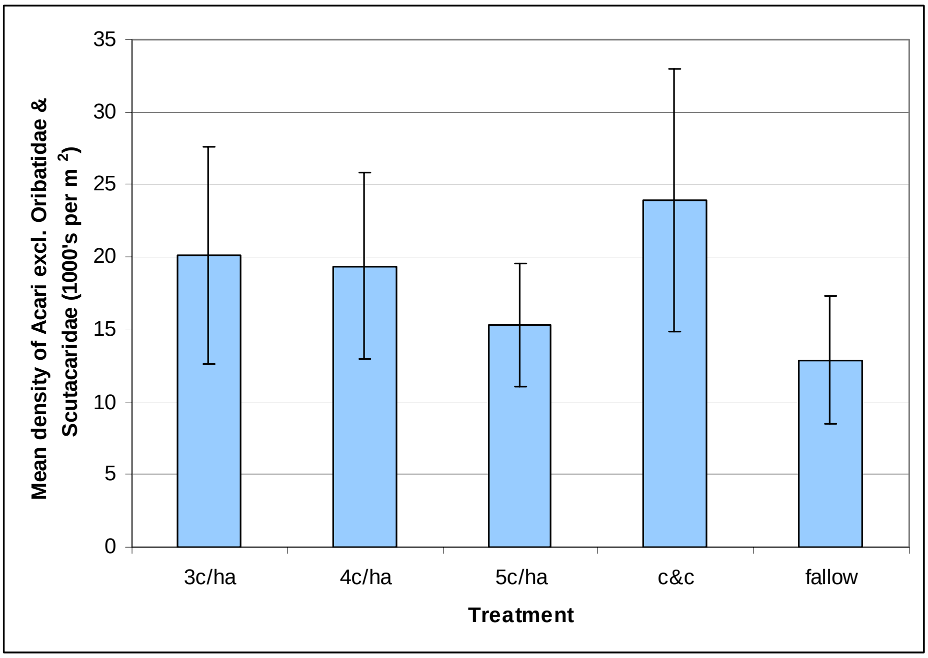

Figure 37 Bar graph showing mean density of Acari (mites) excluding Oribatidae & Scutcaridae (per m^2) at 0-7.5cm depth and 95 percent confidence intervals for each of five treatments (3c/ha=three cows per hectare, 4c/ha=four cows per hectare, 5c/ha=five cows per hectare, c&c=cut and carry, fallow=fa), N=20

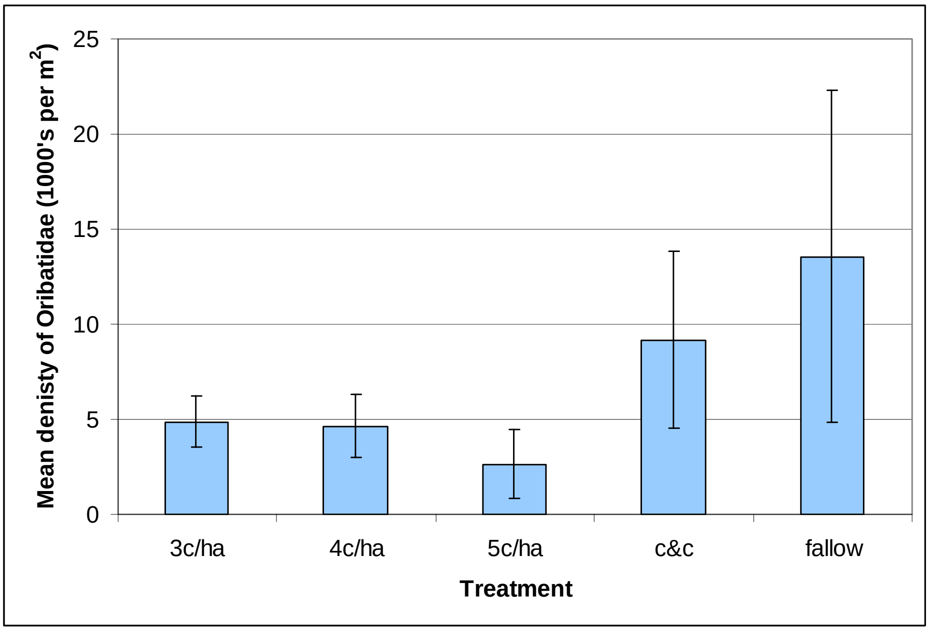

Figure 38 Bar graph showing mean density of Oribatidae (per m^2) at 0-7.5cm depth and 95 percent confidence intervals for each of five treatments (3c/ha=three cows per hectare, 4c/ha=four cows per hectare, 5c/ha=five cows per hectare, c&c =cut and carry, fallow=fallow) N=20

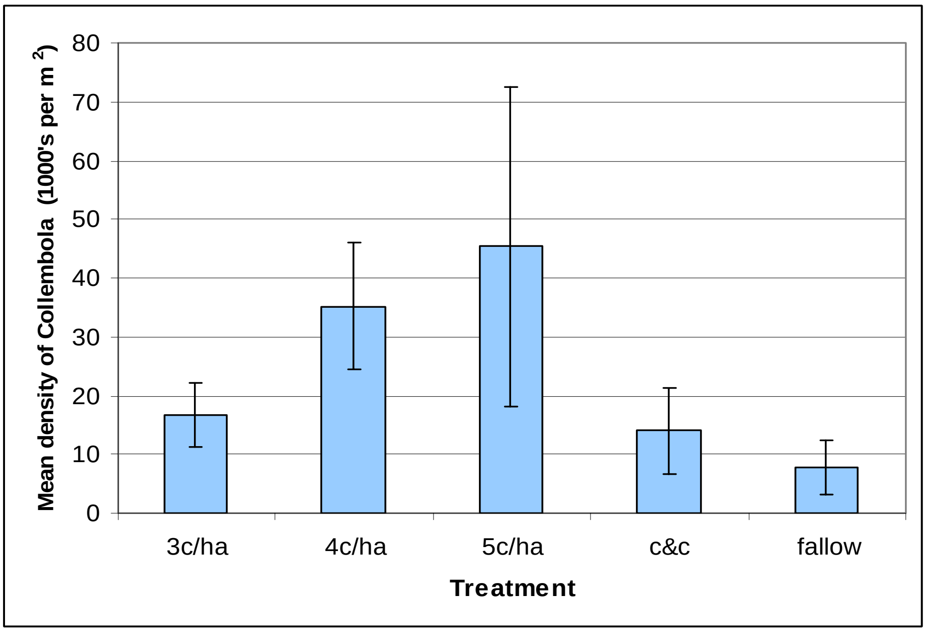

Figure 39 Bar graph showing mean densities of Collembola (per m^2) at 0-7.5cm depth and 95 percent confidence intervals for each of five treatments (3c/ha=three cows per hectare, 4c/ha=four cows per hectare, 5c/ha=five cows per hectare, c&c=cut and carry, fallow=fallow) N=20

Table 7 Un-standardised effect sizes (m1-m2), standard deviations and 95 percent confidence intervals for Acari including Oribatidae, Collembola, Acari (mites) excluding Oribatidae and Oribatidae at 0-7.5cm for different treatment combinations. Column 8 states whether p values were less than 0.05 or not based on whether or not 95 percent confidence intervals overlap zero

Micro-arthropods		m1-m2	SE(diff)	Upper CI	Lower CI	Significant?
Acari excl. Oribatidae & Scutacaridae	3c/ha*4c/ha	740	6656	13786	-12307	No
	3c/ha*5c/ha	4770	5637	15819	-6278	No
	5c/ha*4c/ha	-4031	5092	5950	-14011	No
	5c/ha*c&c	8571	6349	21016	-3873	No
	5c/ha*fallow	-2449	4167	5718	-10615	No
	3c/ha*c&c	3801	7913	19311	-11709	No
	3c/ha*fallow	7219	5731	18452	-4013	No
Oribatidae	3c/ha*4c/ha	255	1663	3515	-3005	No
	3c/ha*5c/ha	2219	1510	5178	-739	No
	5c/ha*4c/ha	-1964	1426	831	-4760	No
	5c/ha*c&c	-6531	2852	-941	-12120	Yes
	5c/ha*fallow	-10918	4800	-1510	-20327	Yes
	3c/ha*c&c	-4311	3088	1742	-10364	No
	3c/ha*fallow	-8699	5037	1173	-18571	No
Collembola	3c/ha*4c/ha	-18546	7776	-3305	-33787	Yes
	3c/ha*5c/ha	-28724	15553	1760	-59209	No
	5c/ha*4c/ha	10178	18154	45760	-25403	No
	5c/ha*c&c	37653	16465	69924	5382	No
	5c/ha*fallow	-37653	15196	-7869	-67437	Yes
	3c/ha*c&c	2577	6087	14508	-9355	No
	3c/ha*fallow	8929	4818	18372	-515	No

Figure 37 shows that mean Acari (mites excluding the Oribatidae & Scutacaridae) density did not show clear positive or negative trends with increasing stocking rate or a clear grazing effect, while Table 7 and 95 percent confidence intervals on Figure 38 indicate that differences in means among treatments were not statistically significant (p>0.05). Wide 95 percent confidence intervals around the means in Figure 37 suggest high variability in Acari (mites) density between samples within treatments.

Figure 38 shows that mean Oribatidae density decreased with increasing stocking rate (the three cows per hectare treatment having a mean density 1.8 times greater than the mean density of the five cows per hectare treatment), and all grazed treatments had lower mean Oribatidae density compared with the fallow and cut and carry treatments (the cut and carry treatment had a mean density 1.9 times greater than the three cows per hectare treatment while the fallow treatment had a mean density 2.8 times greater than that of the three cows per hectare treatment). Table 7 and 95 percent confidence intervals on Figure 39 show that mean differences between the five cows per hectare treatment and the fallow and cut and carry treatments were statistically significant (p<0.01).

Figure 39 shows that the five cows per hectare treatment was found to have the highest mean Collembola density compared to all other treatments (2.7 times greater than that of the three cows per hectare treatment and 3.1 times greater than that of the cut and carry treatment) and that the four cows per hectare treatment had the next highest mean density of Collembola (2.1 times greater than that of the three cows per hectare treatment and 2.5 times greater than that of the cut and carry treatment).

Table 7 and 95 percent confidence intervals on Figure 40 show that there were statistically significant differences (p>0.05) between the three cows per hectare treatment and the four cows per hectare treatment as well as between the five cows per hectare treatment and the fallow treatment. Wide confidence intervals suggest high variability in Collembola density between samples within some treatments.

4.2.2.2.3 Pitfall traps

Pitfall traps did not prove to be a very good method for use in this study as the number of animals trapped was very low. Hence results were not analysed. It may have been too late in the season for this method to be effective, as invertebrates will have been becoming less active as the temperatures cooled.

4.2.2.3 Earthworms (Oligochaetes)

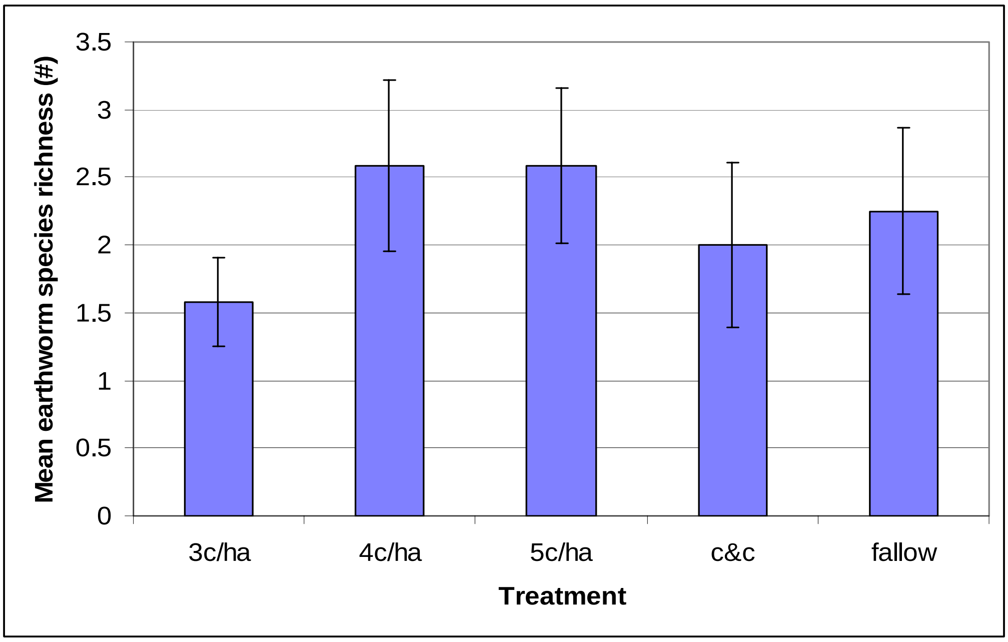

Figure 40 Bar graph showing mean earthworm species richness and 95 percent confidence intervals by treatment (3c/ha = three cows per hectare, 4c/ha = four cows per hectare, 5c/ha = five cows per hectare, c&c = cut and carry and fa = fallow). N=12

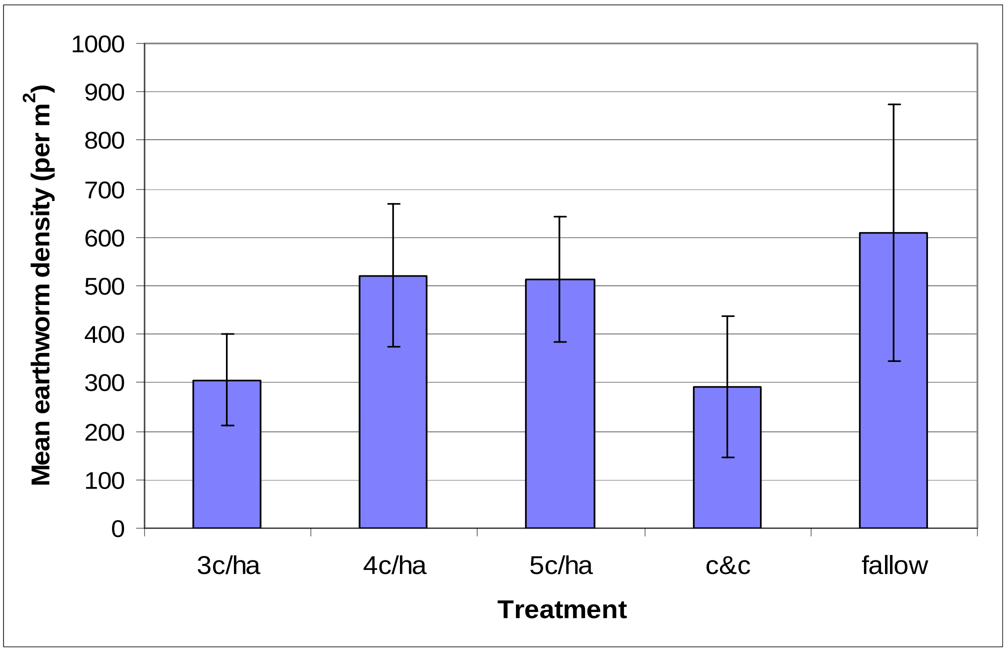

Figure 41 Bar graph showing mean earthworm density (per m^2) richness and 95 percent confidence intervals by treatment (3c/ha = three cows per hectare, 4c/ha = four cows per hectare, 5c/ha = five cows per hectare, c&c = cut and carry and fa = fallow) N=12

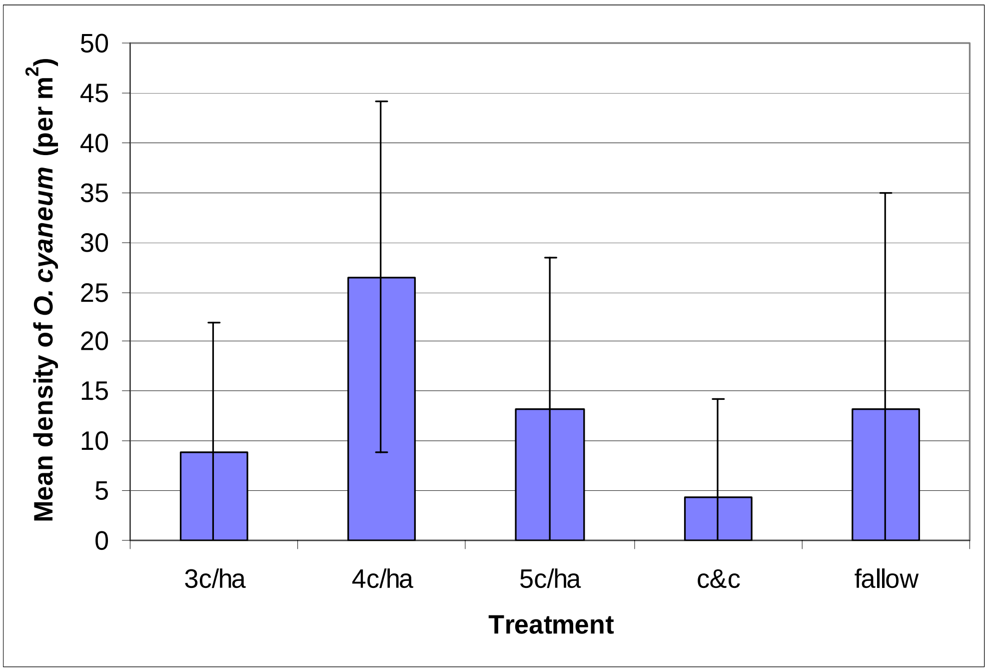

Figure 42 Bar graph showing mean density of *O. Cyaneum* and 95 percent confidence intervals for each of five treatments (3c/ha = three cows per hectare, 4c/ha = four cows per hectare, 5c/ha = five cows per hectare, c&c = cut and carry, fallow = fallow) N=12

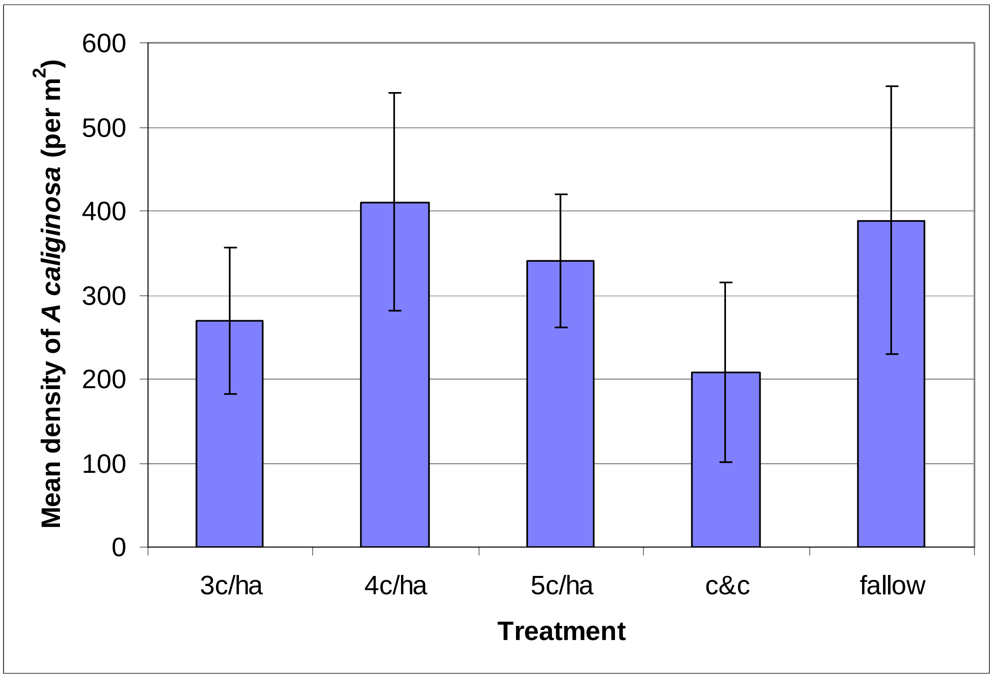

Figure 43 Bar graph showing mean density and 95 percent confidence intervals of *A. caliginosa* for each of five treatment (3c/ha = three cows per hectare, 4c/ha = four cows per hectare, 5c/ha = five cows per hectare, c&c = cut and carry, fallow = fallow) N=12

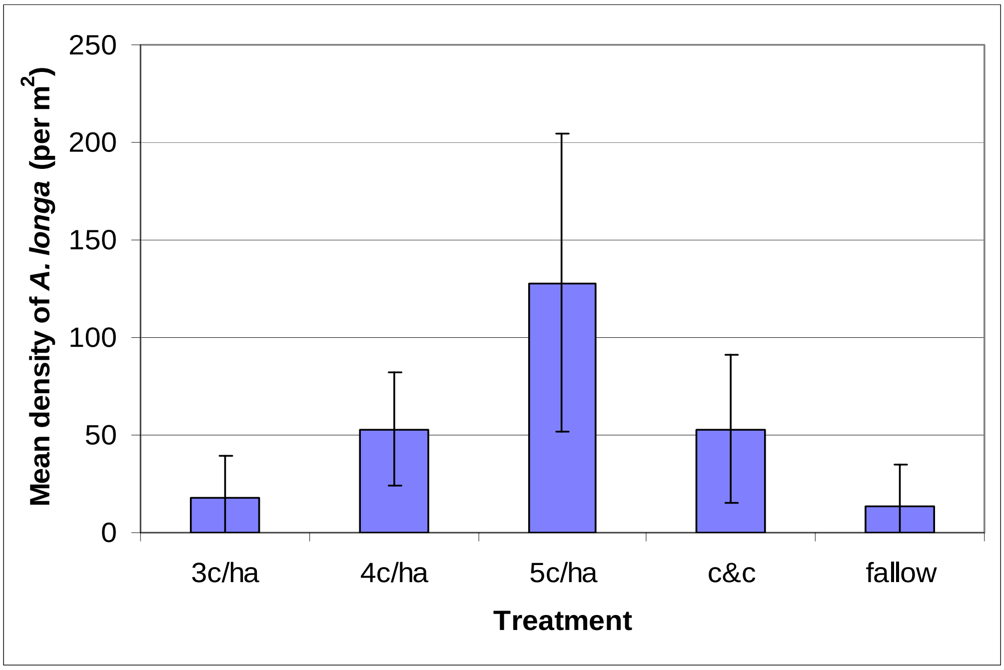

Figure 44 Bar graph showing mean density of *A. longa* and 95 percent confidence intervals for different stocking rate treatments (3c/ha = three cows per hectare, 4c/ha = four cows per hectare, 5c/ha = five cows per hectare, c&c = cut and carry, fallow = fallow) N= 12

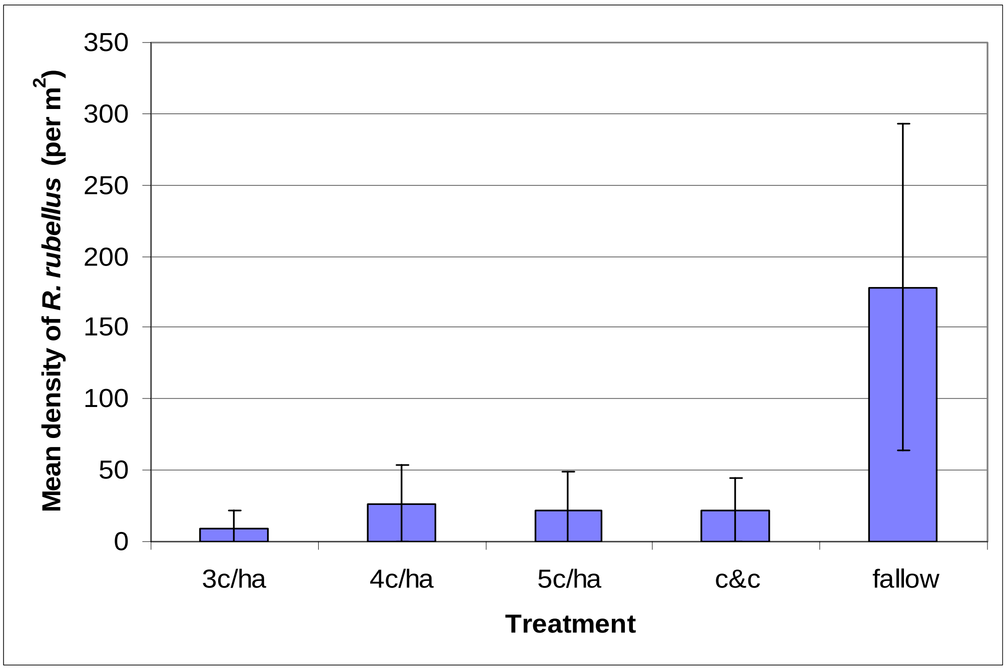

Figure 45 Bar graph showing mean density of *R. rubellus* and 95 percent confidence intervals for different stocking rate treatments (3c/ha = three cows per hectare, 4c/ha = four cows per hectare, 5c/ha = five cows per hectare, c&c = cut and carry, fallow = fallow) N=12

Table 8 Un-standardised effect sizes and 95% confidence intervals for earthworm species richness, earthworm density, *A. caliginosa* density, *L. rubellus* density, *O. cyaneum* density, *A. longa* density, *A. rosea* density and *A. Andrei* density for different treatment combinations. Column seven shows whether differences between mean were statistically significant (p<0.05)

Earthworms		Effect size	SE(diff)	Upper CI	Lower CI	p<0.05
Species richness	3c/ha*4c/ha	-1.00	0.44	-0.14	-1.86	Yes
	3c/ha*5c/ha	-1.00	0.41	-0.20	-1.80	Yes
	5c/ha*4c/ha	0.00	0.55	1.07	-1.07	No
	5c/ha*c&c	0.58	0.54	1.63	-0.47	No
	5c/ha*fallow	0.33	0.54	1.39	-0.72	No
	3c/ha*c&c	-0.42	0.42	0.41	-1.25	No
	3c/ha*fallow	-0.67	0.43	0.17	-1.50	No
Earthworm density	3c/ha*4c/ha	-216.42	109.96	-0.90	-431.93	Yes
	3c/ha*5c/ha	-207.58	101.31	-9.01	-406.16	Yes
	5c/ha*4c/ha	-8.83	125.59	237.32	-254.98	No
	5c/ha*c&c	220.83	124.52	464.90	-23.23	No
	5c/ha*fallow	-97.17	178.50	252.69	-447.03	No
	3c/ha*c&c	13.25	108.89	226.68	-200.18	No
	3c/ha*fallow	-304.75	162.87	14.48	-623.98	No
A. caliginosa	3c/ha*4c/ha	-2.67	1.86	0.98	-6.31	No
	3c/ha*5c/ha	-11.50	1.42	-8.71	-14.29	Yes
	5c/ha*4c/ha	1.33	1.79	4.85	-2.18	No
	5c/ha*c&c	2.50	1.60	5.63	-0.63	No
	5c/ha*fallow	-0.92	1.60	2.21	-4.04	No
	3c/ha*c&c	1.17	2.11	5.31	-2.97	No
	3c/ha*fallow	-2.25	2.11	1.89	-6.39	No
L. rubellus	3c/ha*4c/ha	-17.67	18.16	17.93	-53.26	No
	3c/ha*5c/ha	-30.92	18.09	4.53	-66.37	No
	5c/ha*4c/ha	-4.42	24.34	43.28	-52.12	No
	5c/ha*c&c	0.00	22.36	43.83	-43.83	No
	5c/ha*fallow	-156.19	64.27	-30.23	-282.15	Yes
	3c/ha*c&c	-13.25	16.18	18.47	-44.97	No
	3c/ha*fallow	-169.44	58.09	-55.58	-283.29	Yes
O. cyaneum	3c/ha*4c/ha	-17.67	13.95	9.67	-45.00	No
	3c/ha*5c/ha	-22.08	12.88	3.15	-47.32	No
	5c/ha*4c/ha	13.25	14.91	42.47	-15.97	No
	5c/ha*c&c	8.83	11.34	31.05	-13.39	No
	5c/ha*fallow	0.00	11.34	22.22	-22.22	No
	3c/ha*c&c	4.42	15.85	35.48	-26.65	No
	3c/ha*fallow	-4.42	15.85	26.65	-35.48	No
A. longa	3c/ha*4c/ha	-35.33	23.25	10.23	-80.90	No
	3c/ha*5c/ha	-145.75	44.77	-58.01	-233.49	Yes
	5c/ha*4c/ha	-75.08	48.08	19.16	-169.33	No
	5c/ha*c&c	75.08	52.06	177.13	-26.96	No
	5c/ha*fallow	114.83	44.70	202.44	27.23	No
	3c/ha*c&c	-35.33	19.86	3.59	-74.26	No
	3c/ha*fallow	4.42	19.86	43.34	-34.51	No
A. rosea	3c/ha*4c/ha	-4.42	4.42	4.24	-13.07	No
	3c/ha*5c/ha	-4.42	4.42	4.24	-13.07	No
	5c/ha*4c/ha	0.00	8.83	17.31	-17.31	No
	5c/ha*c&c	0.00	8.83	17.31	-17.31	No
	5c/ha*fallow	4.42	4.42	13.07	-4.24	No
	3c/ha*c&c	-4.42	4.42	4.24	-13.07	No
	3c/ha*fallow	0.00	0.00	0.00	0.00	No
A. andrei	3c/ha*4c/ha	0.00	0.00	0.00	0.00	No
	3c/ha*5c/ha	-4.42	3.58	2.59	-11.43	No
	5c/ha*4c/ha	-4.42	3.58	2.59	-11.43	No
	5c/ha*c&c	4.42	3.58	11.43	-2.59	No
	5c/ha*fallow	-26.50	20.16	13.00	-66.00	No
	3c/ha*c&c	0.00	0.00	0.00	0.00	No
	3c/ha*fallow	-30.92	16.58	1.58	-63.41	No

Figure 40 shows that the four and five cows per hectare treatments had higher mean earthworm species richness compared to that of the three cows per hectare treatment and that of the ungrazed treatments (cut and carry and fallow). However, while Table 8 and the 95% confidence intervals on Figure 41 show that differences in mean species richness between the five cows per hectare and three cows per hectare treatments was statistically significant, differences in species richness among treatments were very small (no treatments differed by more than one species).

Figure 41 shows that the four and five cows per hectare treatments had higher mean densities of earthworms compared to the three cows per hectare and cut and carry treatments (the five cows per hectare treatment had a mean earthworm density 1.7 time greater than that of the three cows per hectare treatment) and that the fallow treatment had the highest mean earthworm abundance of all treatments (1.2 times greater than that of the five cows per hectare treatment).

Table 8 and 95% confidence intervals on Figure 41 show that the differences in mean earthworm density between the three cows per hectare and other grazed treatments were statistically significant (p approximately 0.01).

Figures 42 to 45 show that *A. longa* was the only earthworm species which showed a clear trend in density with increased stocking rate. Figure 45 shows that the density of this species was greater at higher stocking rates. Mean *A. longa* density was 7.25 and 9.7 times greater in the five cows per hectare treatment than in the three cows per hectare and fallow treatments respectively. Additionally, mean *A. longa* density was three times greater in the four cows per hectare treatment than in the three cows per hectare treatment.

Table 8 and 95% confidence intervals on Figure 44 show that differences in *A. longa* mean density between the three cows per hectare and fallow treatments were significantly different (statistically) to that of the five cows per hectare treatment ($p<0.01$) but that no other treatments differed significantly from one another ($p>0.05$).

5. Discussion

5.1 Abiotic measurements

5.1.1 Soil chemistry

Higher stocking rates and overgrazing are often associated with increased rates of erosion and with depletion of soil nutrients and organic matter that are essential for pasture productivity. Soil nutrients for all treatments in this study were within levels adequate for plant growth with the exception that the fallow treatment had potassium levels below the optimum range.

All treatments had phosphorus levels above the optimum range of (20-30) with the fallow treatment having the highest phosphorus level at 52.5. This suggests that the fertiliser being applied to the paddocks in this study, in conjunction with pre-existing phosphorus levels, was in excess of what was required for optimum pasture productivity (note that phosphorus levels may have been relatively high naturally).

There were no negative or positive trends in nutrient levels with increased stocking rates with the exception of sodium. However sodium levels for all treatments were within the optimal range for pasture production and the differences among treatments in sodium levels were small and not significant.

This result suggests that increasing stocking rates from three cows per hectare to five cows per hectare has not had a detrimental effects on soil chemical health, and that the five cows per hectare treatment has not been experiencing elevated levels of erosion compared to the other grazed treatments as can sometimes occur as a result of higher stocking rates and overgrazing.

This result is in line with those of the previous study conducted at this site using the same paddocks subject to the same treatments (Roach & Morton 2005). This result also supports results of previous studies which have shown that dairy farming has not caused long-term decline in the soil nutrient status on the Taranaki ring plain, and that Taranaki ring plain soils are reasonably resistant to nutrient losses as the result of grazing (TRC Soil Plan 2001, TRC SOE 2009).

These results show that any positive or negative trends in flora and fauna abundance and diversity with increased stocking rates are unlikely to be related to differences in soil nutrient status among treatments, and changes in paddock management are unlikely to be biologically significant.

5.1.2 Bulk density

Higher bulk densities (or soil compaction) can result from increased treading at higher stocking rates. Higher bulk density and macroporosity results in reduced air permeability and hydraulic conductivity. This is a concern because it limits the rooting volume of plants, reduces the suitability and habitability of the soil for many soil organisms and can lead to increased run off and erosion (and in turn to nutrient depletion).

In this study, bulk densities for all treatments were within the range that would be considered adequate for the Taranaki ring plain and bulk density differed little among treatments. Hence, higher stocking rates have not resulted in increased bulk density. Thus any differences in species diversity and abundance found among treatments in this study are very unlikely to have resulted from differences in bulk density among treatments.

This result supports the findings of previous studies conducted in Taranaki which suggest that the allophanic soils of the Taranaki ring plain are relatively resistant to soil compaction (97% of Taranaki soils are of low to moderate vulnerability to soil structural degradation – TRC 2009) as well as Roach and Morton's (2005) study using the same site with the same paddocks subject to the same treatments.

5.1.3 Macroporosity

One effect of soil compaction is to reduce the size of air filled pores within the soil (Drewy 2008). Macroporosity is the proportion of the pores in a soil that are above a certain critical size (60μ). Macroporosity is a sensitive indicator of soil compaction and has implications for soil dwelling organisms. Reductions in soil porosity result in negative impacts on soil health, root growth and vigour as well as on populations of soil dwelling biota (Hassink *et al.* 1993).

One way in which a reduction in porosity can negatively affect soil biota is through physical exclusion. Fungal hyphae are excluded from pores below 60um in size while bacteria and micro-organism such as nematodes and bacteria are excluded from pores less than 5um in size (Brewer 1964).

The results of this study suggest that increased stocking rates have not resulted in significant decreases in macroporosity as macroporosity differed little among grazed treatments. Macroporosity was indicated to have been affected by grazing however as the grazed treatments had lower macroporosity compared to the fallow and cut and carry treatments. Negative effects of grazing on macroporosity were found at the 0-75mm soil depth only. These results correspond with those of Roach and Morton (2005) using the same study site, sampling design, treatments and replicates.

5.1.4 Visual soil assessments

Mean pasture performance scores were good for all treatments except for the fallow treatment which gained a moderate score. Soil scores were good (scores above 30) for all treatments. Pasture performance scores and soil quality scores did not differ significantly among treatments although there was a slight trend towards decreased soil quality with increased stocking rate but differences among treatments were very small.

This result indicates that the stocking rate of three cows per hectare did not result in a grazing pressure so light as to result in grass 'rankness' or over-maturation and also that the five cows per hectare treatment did not have significant detrimental effects on plant vigour and drought susceptibility. However, it is important to note that Visual Soil Analysis is qualitative and subjective rather than quantitative.

5.2 Biotic measurements

5.2.1 Vegetation

The results of this study suggest that stocking rates above three cows per hectare were responsible for slightly increasing percent cover of bare ground at the expense of clover percent cover. Increased per cent cover by bare ground and decreased per cent cover of clover at higher stocking rates may have resulted from one or more of the following;

a) increased treading causing physical damage to and death of clover which is known to be more vulnerable to treading damage compared with many grasses (Edmond 1964, Cluzeau *et al.* 1992, Menneer 2003)

b) harder grazing at higher stocking rates causing gaps between plant crowns/clumps to be exposed as well as higher radiation of clover stolons

c) increased input of dung at higher stocking rates causing increased smothering of the pasture and lower competitiveness of clover compared to grass (Ontario Ministry of Agriculture, Food and Rural Affairs website July 2009)

The finding that percent cover of bare ground increased as stocking rates increased and that percent clover cover decreased with increased stocking rate concurs with the findings of a number of previous studies (e.g. Curll & Wilkins 1981; Grant *et al.* 1985; Manley *et al.* 1997; Menneer *et al.* 2003 and Mills & Adl 2006).

Increased bare ground cover can result in increased soil erosion, negative effects on soil microclimate and reduced pasture masse. Losses of clover cover have implications for farm sustainability and the ability of paddocks to maintain adequate levels of nitrogen in the absence of nitrogenous fertilisers.

Results of this study also suggest that higher stocking rates may have resulted in slightly increased plant species diversity with increased numbers of non clover/grass species or weeds being found in pastures with higher stocking rates. Also that mowing favoured plant species richness compared to grazing.

These findings support the findings of a large number of previous studies that have found that livestock grazing and mowing increases plant species richness in productive environments (see Dyksterhuis 1958; Olff & Ritchie 1998, Proulx & Mazumder 1998, Bakker *et al.* 2004).

Trends of increased plant species diversity with increased stocking rates may result from one or both of the following;

a) the greater percent cover by bare ground in the higher stocking rate treatments being more readily colonised by weed species compared to non weed species

b) non weed species being slower to recover and more prone to mortality as a result of trampling compared to weeds (weeds often have higher root reserves and are able to grow faster and take over at higher stocking rates) (Ontario Ministry of Agriculture, Food & Rural Affairs website July 2009).

The cut and carry treatment is likely to have had higher species richness due to a lack of selective grazing and because low growing species would have remained relatively undamaged after mowing events.

Changes in percent cover of bare ground and clover and higher plant species richness at higher stocking rates could potentially impact on invertebrate diversity and abundance though alterations in resource availability, soil physical properties and microclimatic conditions (e.g. less plant cover can result in higher soil temperatures) as well as increases in microhabitat heterogeneity (Wardle *et al* 2002).

An example of below ground biota being affected by plant diversity is provided by Wasilewska (1995). In this study, nematode richness was found to be higher under mixed species grass swards compared to monocultures, and the root lesion nematode *Pratylenchus* was found to be more abundant under cocksfoot monocultures compared to mixed grass swards by Wasilewska (1995)

However, differences between grazed treatments were only very small and are unlikely to have resulted in serious effects on fauna abundances and diversity.

5.2.2 Fauna

5.2.2.1 Nematodes

Soil nematodes are very small (0.3-0.5mm long as adults) worm-like animals which are very abundant and diverse in the soils (Yeates 1979, Yeates & Bongers 1999). Nematodes are key agents in important soil processes such as decomposition, mineralization and nutrient cycling. Therefore, alterations of the nematode community structure may have a considerable influence on ecosystem functioning (Bakonyi *et al.* 2007).

Yeates and Bongers (1999) have stated that as nematodes feed on a wide range of soil organisms and their activities are largely controlled by soil biological and physical conditions, they offer great potential for use as indicators of biodiversity and for assessing the impacts of changing land use of soil conditions (Yeates & Bongers 1999).

In this study overall nematode density, species richness, diversity and maturity showed no positive or negative trends with increased stocking rate and differences among grazed treatments or between grazed and non grazed treatments (cut & carry and fallow) were very small/not significant. Therefore, this study does not provide evidence to suggest that higher stocking rates have negatively impacted on nematode diversity or abundance.

This result contrasts with results of previous studies that have found increased stocking intensity to result in reduced nematode diversity and abundance (e.g. King & Hutchinson 1983). However, lack of impacts caused by increased stocking rates on nematode abundance and diversity found in this study are not surprising as increased stocking rates were not found to have resulted in significant impacts on soil chemistry, bulk density and macroporosity.

5.2.2.2 Insects, spiders and mites

(a) Suction sampling (insects and spiders)

The results of this study provide little evidence to suggest that higher stocking rates had significant negative impacts on invertebrate abundance and diversity. Differences among grazed treatments in mean abundance of invertebrate orders as well as in the abundance, species richness and composition of Coleoptera, Diptera and Hymenoptera morphospecies were very small to non existent and are not likely to be biologically significant.

This result contrasts with the findings of previous studies which have found that increased stocking intensities have negative impacts on invertebrate diversity and abundance (e.g. Seymour & Dean 1999**;** Kruess & Tscharntke 2002; Wallis de Vries *et al.* 2007 and see East & Pottinger 1983).

(b) Soil cores (springtails and mites)

Acaridae (a taxon of arachnids that contains mites and ticks) and Collembola (springtails) are some of the most diverse and abundant organisms found in the soil and play an important role in important role in several soil processes, such as organic matter decomposition, material and energy cycles and soil formation (Nguyen 2000).

In this study higher stocking rates were not found to have negatively affected Acari (excluding Oribatidae & Scutacaridae) or Collembola densities. Grazing and increased stocking rates seem in fact to have resulted in higher densities of Collembola, probably as a result of greater availability of food resources in the form of dung and dead plant material at higher stocking rates, as Collembola feed primarily on detritus and microbes (Gregor Yeates *pers comm.)*

This result supports the results of other studies which have found increased grazing intensity increases Collembola density (i.e. Clapperton et al 2002).

Oribatid mite density decreased with increasing stocking rate and was found to be lower in the grazed treatments compared to the cut and carry and fallow treatments. Differences in Oribatid densities between the five cows per hectare treatment and the cut and carry and fallow treatments were statistically significant. Hence, it seems that Oribatid density was negatively affected by grazing and higher stocking rates.

This result corresponds with those of a number of studies that have found that increased grazing intensity results in decreased abundances and diversity of Oribatidae (e.g. Clapperton *et al.* 2002 and Schon *et al* 2008).

Oribatidae are likely to be particularly vulnerable to disturbance as they generally have low metabolic rates, slow development and low fecundity. In the absence of significant effects of increased stocking rates on soil chemistry, bulk density and macroporosity, decreases in densities of Oribatids may have resulted from increases in abundance of *Aporrectodea longa* under grazed treatments compared to mown and fallow treatments and with increased stocking rates. There is strong evidence to suggest that anecic earthworm burrowing decreases Oribatid densities by destroying Oribatid habitats (Vreeken-Buijs *et al.* 1998; Maraun *et al.* 2003).

It may also be possible that Orbiatid density was affected by differing food resource availability among treatments. Most Oribatid species present in this study were herbofungivorous (Schon *et al*. *submitted*) and heavier grazing may result in faster nutrient cycles (with fast returns of nutrients through dung) which favour bacteria over fungi (Clapperton *et al* 2002).

5.2.2.3 Earthworms (Oligochaetes)

Oligochaetes or earthworms are “ecosystem engineers” which maintain soil structure, function and fertility through organic matter decomposition, soil aeration and nitrogen cycling (Foribes & Kure 1997, Smith *et al.* 2006). Earthworm absence is an indication of poor soil quality (Shakir Hanna & Weaver 2002). Soils without earthworms or with fewer earthworm species are usually less productive than equivalent soils with higher earthworm abundances and a greater number of species (Hasselberg 1984).

The results of this study do not suggest that grazing and increased stocking rates negatively impacted upon the abundance and diversity of earthworm species. Although *Lumbricus rubellus* was found to be present in much greater densities within the fallow treatment compared to the grazed treatments, the fact that this species was also found in low densities in the cut and carry treatment suggests that changes to plant community composition and structure and hence food availability for this epigeic (see glossary) species was the factor responsible for decreased abundances in grazed treatments rather than treading by stock.

The earthworm species *Aporrectodea longa* was in fact found to be positively affected by increased stocking rate, probably as a result of increased availability of food resources for this anecic species (which feeds on the soil surface at night) in the form of animal dung at higher stocking rates. Increased abundances of this species may have helped to offset effects of increased stock treading on soil bulk density and macroporousity.

The lack of negative impacts of grazing and increased stocking rates on earthworm populations in this study are not surprising given that higher stocking rates and grazing failed to have significant effects on soil chemistry, bulk density and macroporosity. The findings of this study also support the results of previous studies which have looked at the effect of grazing and stocking intensity of earthworm populations and which suggest that adverse effects of trampling at higher stocking rates are more than compensated for by increased food supply in the form of dung and plant litter (e.g. Schon *et al.* 2008; Curry *et al.* 2008 and Mikola *et al.* 2009).

6. Conclusions and recommendations

Results of this study suggest that in the short term at least, the soil chemical and physical properties of soils in Taranaki dairy pastures are not at risk from higher stocking rates up to five cows per hectare. No significant difference was found in soil chemistry, bulk density or macroporosity among grazed treatments. This result supports the findings of previous studies that have suggested that Taranaki allophanic soils are relatively resistant to negative impacts associated with grazing elsewhere, such as increased soil bulk density and depletion of essential plant nutrients.

The plant component of this study suggest that over a period of five years, increased stocking rates may cause slightly increased percent cover of bare ground at the expense of clover cover and thus that stocking rates of five cows per hectare may have small negative impacts on pasture productivity and habitat /resource availability for some invertebrates.

Grazing and increased stocking rate were not found to have had any significant negative effects on diversity or abundance of nematodes (Nematoda), mites *(*excluding Oribatidae*)* springtails *(*Collembola*)* , earthworms or surface dwelling insects including Colleoptera, Hymenoptera and Diptera.

However, grazing and increased stocking rates were found to have resulted in decreased abundance of Oribatid mites, possibly as a result of increases in earthworm abundance or changes in resource availability.

The diversity and abundance of some taxa was found to have responded positively to increased stocking rate *(e.g.* Collembola and *A. longa*). Positive responses were probably the result of increased food availability at higher stocking rates as a consequence of increased dung input.

Overall, the results of this study suggest that in the short term at least higher stocking rates of five cows per hectare do not pose a serious threat to agricultural biodiversity in Taranaki dairy pastures.

However it is worth noting that the extent to which treatments affected some organisms in this study (especially the more mobile surface dwelling species) may have been diminished by the small size of replicate paddocks and their close proximity to one another. This is because organisms would not have had to travel far in order to cross boundaries between management regimes. Many studies have shown that habitat heterogeneity and presence of undisturbed habitat patches can increase species diversity in agricultural landscapes (see Benton *et al.* 2003).

Additionally, the robustness of this study would have been improved by larger sample sizes, and negative impacts may be more obvious at other times of the year or over longer timeframes.

Further studies examining the impacts of increased stocking rates on the biodiversity of soil and surface dwelling invertebrates should be carried out in dairy pastures throughout New Zealand. Apart from looking at the effects of increased stocking rates on species diversity, abundance and composition, such studies could look at the comparative effect of increased stocking rates on proportions of native versus exotic species, on proportions of different functional or feeding groups, or on invertebrate morphology (i.e. size).

Glossary

Ammonium nitrogen	nitrogen that is available to plants and soil organisms in the form of ammonium through fixation of atmospheric nitrogen and decomposition of organic matter by bacteria. Unlike nitrates, ammonium is sorbed to clay and organic matter particles and is not easily leached. Nitrogen is an essential plant nutrient that is an essential component of DNA and proteins, but can cause toxicity in excess quantities.
Anecic	Earthworms that construct permanent deep burrows through which they visit the surface to obtain plant material for food, such as leaves.
Annelid	any worm in the phylum *Annelida,* in which the body is divided into segments both internally and externally. Includes earthworms, ragworms, lugworms and leeches.
Arachnid	terrestrial chelicerate arthropods of the class *Arachnida*, characterised by simple eyes and four pairs of legs. Includes spiders, scorpions, ticks, mites and harvestmen.
Arthropod	any invertebrate of the phylum *Arthropoda,* having jointed limbs, a segmented body, and an exoskeleton made of chitin. Include the crustaceans, arachnids, insects and centipedes.
Calcium	an essential nutrient for plants and animals. Regulates transport of other nutrients into the plant and is also involved in the activation of certain plant enzymes. Can cause toxicity in excess quantities.
Collembola	an order of insects comprising the springtails.
Coleoptera	an order comprising of insects whose forewings are modified to form a shell like protective elytra, include the beetles and weevils.
Diptera	an order comprising of insects with a single pair of wings and sucking or piercing mouthparts. Includes flies, mosquitoes, crane flies and midges.
Earthworm	any of numerous oligocheate worms belonging to the genera *Lumbricus, Eisenia, Allolobophora* etc. which burrow in the soil and help aerate or break up the ground.
Epigeic	Leaf litter/compost dwelling earthworms.
Insect	any small air breathing arthropod of the class *Insecta,* having a body divided into head, thorax and abdomen, three pairs of legs and (in most species) two pairs of wings.
Magnesium	an essential plant and animal nutrient which has many biological roles including being an important part of chlorophyll (a critical plant

	pigment important in photosynthesis). Can cause toxicity in excess quantities.
Mineralisable nitrogen	the amount of nitrogen that can be supplied to plants in the form of ammonium through the decomposition of organic matter by microbial activity. Nitrogen is an essential plant nutrient that is an essential component of DNA and proteins, but can cause toxicity in excess quantities.
Mite	any small free living or parasitic arachnids of the order *Acarina* (or Acari) that can occur in terrestrial or aquatic environments.
Nitrate nitrogen	a form of nitrogen (an essential plant nutrient) produced by conversion of ammonium by bacteria in a process called nitrification. Whereas ammonium is sorbed to clay and organic matter particles, nitrate is leached from soils resulting in decreased soil fertility and nitrate enrichment of downstream surface and ground waters.
Nematode	any un-segmented worm of the order *Nematoda*, having a tough outer cuticle. This group includes free living forms and disease causing parasites, such as hookworm and filarial.
Oligocheate	annelid worms in the order *Oligocheata*, having bristles (chaetae) born singly along the length of the body. Includes the earthworms
Olsen phosphate	form of phosphorus that is available for uptake by plants. Phosphorus is an essential plant and animal nutrient, but can cause toxicity in excess quantities.
Organic carbon	the carbon occurring in the soil in organic matter
Organic matter	tissues from dead plants and animals, products produced as these decompose and the soil microbial biomass.
Organic sulphur	the form in which sulphur accumulates in the soil through precipitation. The sulphur in organic sulphur cannot be absorbed by plants and microorganisms until it has been mineralised to sulphate sulphur. Sulphur is an essential nutrient for plants and animals, but can cause toxicity in excess quantities.
pH	the pH scale measures the acidity or alkalinity of a substance. Levels of acidity depend on the number of H+ ions in solution. Most plants and animals have an optimum pH range for growth.
Potassium	an essential nutrient for plants and animals. Important for reducing water loss from plant leaves and increasing drought tolerance. Excess quantities may cause deficiencies in magnesium and calcium.
Pseudo total nitrogen	combination of organic nitrogen and inorganic nitrogen. Inorganic compounds are of mineral origin, whereas organic compounds are of biological origin. Inorganic nitrogen can be converted to organic

	nitrogen and vice versa by soil microorganisms. Nitrogen is an essential plant nutrient, but can cause toxicity in excess quantities.
Sodium	an essential plant macronutrient. Can cause toxicity in excess quantities.
Spider	any silk producing predatory *arachnid* of the order *Araneae*
Soil moisture	water content of soil
Springtail	primitive wingless insects of the order Collembola, having a forked spinning organ with which they project themselves forward
Sulphate sulphur	form of sulphur that can be absorbed by root and microorganisms. Sulphur is an essential macronutrient for plants and animals, but can cause toxicity in excess quantities.
Hymenoptera	an order comprising of insects that have two pairs of membranous wings and an ovipositor specialised for stinging, sawing or piercing. Includes ants, wasps and bees and sawflies

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Appendix I

Laboratory tests used for each chemical property

Symbol	Chemical property	Units	Test
pH	pH		1:2.1 V/V water slurry
Ca	Calcium content		Ammonium Acetate Extraction: AA Determination
P	Olsen phosphate content		Olsen Extraction: Colorimetry
K	Potassium content		Ammonium Acetate Extraction: AA Determination
S(So4)	Sulphate sulphur content		- Potassium Phosphate Extraction: Ion Chromatography
OS	Organic sulphur		- Calculated by difference
Mg	Magnesium content		- Ammonium Acetate Extraction: AA Determination
Na	Sodium content		Ammonium Acetate Extraction: AA Determination
MN	Mineralisable nitrogen content		NH4_N after Anaerobic Incubation less initial Min_N
NH^4_N	Ammonium nitrogen content		KCL Extraction: Colorimetry
NO^3_N	Nitrate nitrogen content		KCL Extraction: Colorimetry
OC	Percent organic carbon		Soild Sample Combusted, CO2 produced measured
SMC	Soil moisture content		Oven dried at 105degreesC
TKN	Percent Pseudo total nitrogen		Kjeldahl determination: Colorimetry

Appendix II

Mean pasture heights & residual pasture masses pre & post grazing

Treatment cover	Pre height	Pre cover	Post height	Post
3cows/ha	19.0	3638	11.0	2479
4cows/ha	17.6	3445	9.5	2263
5cows/ha	17.2	3391	8.4	2123