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Soil Biology

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MEASUREMENT OF BIOLOGICAL DIVERSITY OF ARTHROPODS AND RESPIRATION IN SOILS MANAGED UNDER TIME-CONTROLLED AND SET-STOCKED GRAZING PRACTICES IN CENTRAL-WEST NEW SOUTH WALES, AUSTRALIA

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Abstract. In this study we compare the effects of two contrasting grazing regimes (time-controlled grazing (TCG) vs set-stocked grazing (SSG)) on selected parameters of soil biological health**.** The purpose of the study was to evaluate these soil parameters as potential indicators of soil health and thence sustainable soil management. Two parameters, viz., arthropod biological diversity and soil respiration were chosen as reliable indicators of soil health. Samples of pasture cover, arthropod populations, and soil from varied depths were obtained in spring (September-November 2010) and autumn (March-May 2011). Results from the autumn showed a strong effect of time-controlled grazing with increased arthropod abundance and enhanced soil biological respiration while in spring the differences were not significant. It was concluded that a change to short-duration rotational grazing can be beneficial to soil biological health in the longer term and that the measurement of arthropods present in the litter and topsoil can be a simple yet effective indicator of the impact of grazing regime on soil health.

Time-controlled grazing (TCG) [high density-short duration rotational grazing] is becoming a more prevalent practice to manage livestock in key beef-exporting nations such as Australia and New Zealand [19]. Time-controlled grazing is a practice in which large numbers of livestock graze a paddock intensively over 4-7 days (short-term grazing) at stocking rates of 200-250 DSE/ha

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and are then removed allowing the pasture lengthy rest periods. This contrasts with the traditional practice of set-stocked grazing (SSG) in which smaller numbers of livestock are stocked continuously for 3-6 months (long-term grazing) at a low-stocking rate (8-9 DSE/ha) allowing little time for pastures to rest. Agricultural practices, such as grazing, impact on soil health by altering soil-biological properties [2]. However, the ratio between 'grazing duration' and 'intensity of livestock' and the 'rest-period involved' in TCG practice is likely to have varying effects on soil properties. Therefore, a need exists to characterize the impacts of TCG management practices on pasture soil enabling farm managers to choose sustainable-management efforts in the context of specific characteristics of their lands and preferred production levels. An understanding of how such grazing practices modify the biology of the soil helps in improving it by either amending some of its components or changing some of the practices. Soil as living medium [8] needs to be characterized as well; different soil microbiota are equally vital elements to be factored in the understanding and quantifying impacts of TCG on soil health.

Grazing livestock influences soil by their actions involving treading, defoliation, and excretal returns. These influence physical properties of the soil either directly; for example, treading alters soil structure; or indirectly, for instance, defoliation and excretal returns influence natural regeneration and nutrient cycling. Because soil provides habitat, space, food supply, and balanced water-oxygen supply to soil organisms, any change to the soil alters soil-faunal elements including the soil invertebrates [2, 9]. Soil-invertebrate populations (e.g., litter and topsoil-dwelling microarthropods) play a critical role in the decomposition of litter by regulating microbial populations by their trophic action and thus influencing nutrient cycling [3]. Impacts of grazing by measuring soil-faunal elements indicate substantial drops in the biodiversity of oribatid mites [15] and other invertebrates [20]. Grazing density affects the biological diversity of soil-microbial communities negatively [4], but show a positive effect on the biological diversity of Collembola [5] and nematodes [22], which were more similar to in natural prairies in North America than in the modified-prairie agroecosystems. Qi *et al*. [16] have compared microbial biomass by measuring microbial respiration and found a decrease in soil biomass with increased intensities of grazing. Fluctuations in soil and litter factors influence invertebrate communities [14]. These studies reinforce that impacts of different pasture-management techniques on soil health could be measured using diversity and abundance of soil invertebrates as a reliable index.

In general, impacts of diverse grazing practices have been thoroughly investigated, but only a few have specifically focused on comparing TCG and SSG practices. TCG practice increased soil-organic carbon and nitrogen and the ground-litter accumulation [17] and also that of productivity of annual pastures [1].

Moreover, Sanjari *et al*. [18] showed that TCG reduced losses of soil material either through sediment loss or through runoff and that the maintaining of the ground cover which was greater under TCG [19] is the main profit of the rest period characteristic of TCG. A comparison of porosity under TCG and SSG showed that three years of set-stocked and rotationally grazed fields with sheep had topsoil affected by the tested management practice: total macroporosity decreased in SSG regimes, whereas stable structural conditions prevailed in TCG regimes [7].

Trials made in the Central-western New South Wales soils comparing TCG and SSG practices show that after four years of commencement of grazing earthworm numbers remained unaffected, whereas arthropod abundance at 0-10 cm depths was directly proportional to changes followed in grazing management; arthropod abundance was greater in TCG regime, whereas microbial biomass and respiration remained unaffected in comparisons between TCG and SSG regimes [20]. In keeping with the above, the goal of the present study was to verify the previously established findings by comparing arthropod biodiversity and soil respiration in pastures that have consistently remained under SSG and TCG regimens for the past ten years and as an indicator of soil health. In this study, we tested the following hypothesis: in TCG management, compared with SSG management, greater levels of microbial activity (measured overall as soil respiration) and arthropod abundance and biological diversity occur at the soil surface (litter layer) and in the topsoil (0-20 cm depth).

MATERIALS AND METHODS

The site

A 3825 m^2 block on an easterly slope in Orange campus farm of Charles Sturt University, separated by a fence (Fig. 1), was chosen as the study site, because both TCG and SSG practices have been ongoing uninterruptedly from the year 2000. On the northern part of the field block (CSU-Orange campus farm) TCG has been the practice. On the southern part of the field block (property owned by a neighbouring grazier), on the same slope, SSG has been the practice. Broad similarities of physical and chemical features of the soil from each grazing paddock were established after analysis of randomly collected topsoil (1-10 cm) and subsoil (10-20 cm) samples by a commercial soil laboratory on 17 November 2010 (Table 1). Soils of the site were generally Brown Dermosols with loams to clay loams overlying well structured yellow-brown medium clays [14].

Because the sites were under different ownership and management, modest differences in the fertilizer regimes occurred. The TCG study site had received no synthetic amendments until 2008. In 2008, 18% single superphosphate $(CaH_2PO_4)_2$ embellished with molybdenum (Mo), was applied at the rate of 160 kg ha^{-1}.

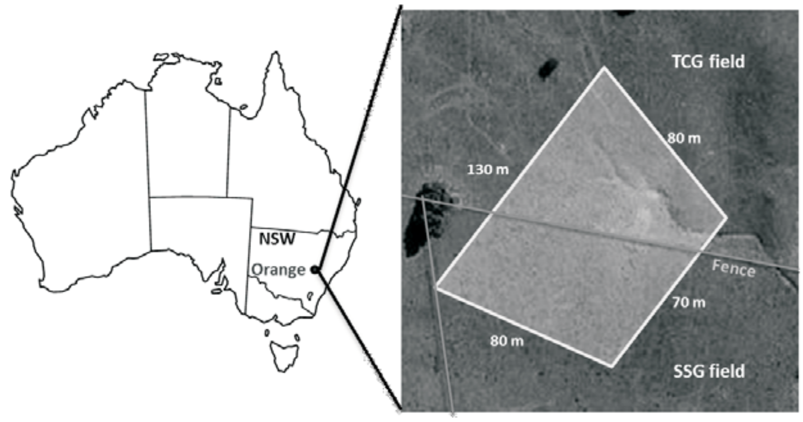

Fig. 1. Outline of the experimental site (trapezoidal) divided by a fence as marked). (Not to scale). Ten plots in each experimental block (on both sides of the fence) were randomly chosen to obtain soil samples, by throwing a 30×30 cm quadrat.

TABLE 1. SOIL-TEST REPORT (NUTRIENT ADVANTAGE ADVICE) FROM INCITEC PIVOT FERTILIZERS, WOOLONGONG, NEW SOUTH WALES, NOVEMBER 17, 2010

Analyte/Assay	SSG site (cm)		TCG site (cm)	
	0-10	10-20	0-10	10-20
pH (1:5 Water)	5.6	5.5	5.6	6
pH (1:5 $CaCl_2$)	4.8	4.5	4.8	4.8
Aluminium saturation (%)	1.6	13	1.6	3.1
Organic carbon (OC) (%)	2.6	0.56	2.8	0.59
Nitrate nitrogen (NO_3) (mg kg^{-1})	6.8	2.7	17	1.8
Phosphorus (Colwell) (mg kg^{-1})	19	8	14	6
Available potassium (mg kg^{-1})	110	61	98	40
Sulphate sulphur (MCP) (mg kg^{-1})	11	6.4	8	4.4
Electrical conductivity (dS m^{-1})	0.06	0.03	0.07	0.05
Electrical conductivity (saturated extract) (dS m^{-1})	0.5	0.2	0.6	0.4
Cation exchange capacity (meq 100 g^{-1})	6.21	2.59	6.41	3.92
Soil colour	Brown	Orange/ Yellow	Brown	Orange/ Yellow

In 2010, 160 kg ha^{-1} of Mo-$(CaH_2PO_4)_2$ was again applied. The SSG site received an application of 160 kg ha^{-1} of Mo-$(CaH_2PO_4)_2$ in 2008. Despite this variation in fertilizer application, soil analysis (Table 1) revealed only a minor difference in soluble P at 0-10 cm depth (TCG 19 mg kg^{-1} P; SCG 14 mg kg^{-1} P).

Pasture composition was assessed by 125 randomized-plant collections from each block. Because the TCG and SSG sites were on the same slope and also because similar land management practices are being followed, irrespective of different ownerships, the results show that similar pasture composition existed in both sites: *Trifolium repens* (*Fabaceae*), *Phalaris aquatica, Lolium perenne* and *Dactylis glomerata* (all *Poaceae*) were the dominant elements, whereas, *Holcus lanatus* (*Poaceae*), *Medicago polymorpha* and *Trifolium subterraneum* (both *Fabaceae*), *Echium plantagineum* (*Boraginaceae*), *Vulpia bromoides* (*Poaceae*), and a mix of *Bromus wildenowie* and *Bromus hordeaceus* (*Poaceae*) occurred in lesser frequency (Table 2). Prevalent climate data during the study period are supplied in Table 3.

Grazing treatments

Grazing at TCG site involved an average time of three days of intensive grazing by a combined mob of sheep and cattle. The animal loading was 200 DSE/ha. The chosen TCG block is a part of the 36 blocks of the farm; therefore, the rest period was between 80 and 100 d. Sampling occurred at approximately mid-time between grazing periods. At the SSG site, continuous grazing occurred at 8 DSE/ha throughout the year apart from short periods when stock was removed for shearing and other routine operations.

TABLE 2. PASTURE COMPOSITION IN BOTH SSG (SET-STOCKED GRAZING) AND TCG (TIME-CONTROLLED GRAZING) FIELDS

Species	(%)
Trifolium subterraneum	2.5
Trifolium repens	12.4
Echium plantagineum	3.3
Dactylis glomerata	10.7
Lolium perenne	17.4
Phalaris aquatica	19.8
Holcus lanatus	9.1
Medicago polymorpha	4.1
Vulpia bromoides	5.8
Bromus wildenowie	5.8
Bromus hordeaceus	9.1

TABLE 3. MEAN CLIMATE DATA DURING STUDY PERIOD

Parameters	Spring 2010	Autumn 2011
Rainfall	346.8 mm	257.2 mm
Maximum temperature	16.9°C	17.2°C
Minimum temperature	7.2°C	6.9°C
Average rainfall (last 44 years)	245.6 mm	184.0 mm
Average max. temperature (last 44 years)	17.5°C	18.4°C
Average min. temperature (last 44 years)	6.7°C	7.5°C

Grass cover

Samples of grass shoots from the 30×30 cm^2 quadrats were obtained by cutting them close to ground level with a hand-held mechanical clipper. Each of the 10 samples collected were weighed individually immediately to obtain fresh-mass data and after drying for 24 h at 50°C to obtain dry-mass data. The results were then converted into t ha^{-1}.

Arthropods

Litter and soil samples for spring 2010 were obtained on 8, 19, and 26 October 2010, and 4 November 2010. Litter and soil samples for autumn 2011 were obtained on 29 March, 8 April, 2 and 13 May 2011. Sampling included litter and soils from 0-10 cm and 10-20 depths. Two litter samples were taken from each plot with a vacuum sampler (Weed Eater®, Model GB1 30v, Poulan Co., Shreveport, Louisiana, USA). Two soil samples from each depth were taken with a 10 cm diameter auger in each plot. Each sample was placed in a Berlese-Tullgren funnel system (funnel ∅: 22 cm). After 7 days, the separated arthropods in the flask that contained 90% ethyl alcohol (100 ml), were separated on a blotting paper for identification up to Orders (following [11]), and taxa of the same order were counted; wherever necessary, taxa were determined as a 'recognizable taxonomic unit' (RTU) and numbered 1, 2, 3, and so on.

Soil respiration and soil temperature

Soil respiration and temperature were measured with a LI-COR 6400-09. Soil CO_2 Flux Chamber fitted to a LI-6400XT Portable Photosynthesis System (Lincoln, Nebraska, USA), following Zhang *et al*. [21]. Measurements were taken two times in every nominated plot in SSG and TCG blocks. All measurements were made with the flux chamber resting on collars installed at least 24 h earlier thus ensuring no seepage of gases occurred. Spring 2010 measurements were obtained on October 10 and November 20, 2010 and autumn measurements on April 15 and May 19, 2011. Measurements were obtained in both treatment sites the same day and two times in each season.

Statistics

Analysis was done using R statistical software for WINDOWS®. To obtain a normality assumption of arthropods, a square-root transformation was made. Data were analysed using a one-factor analysis of variance (ANOVA).

RESULTS AND DISCUSSION

The spring samples (n = 10 in each treatment) showed no significant differences between SSG and TCG in mean arthropod abundance, soil respiration and pasture cover (Table 4). However, at 1-10 and 10-20 cm soil depths, the mean-arthropod abundance were 1226 and 44 arthropods/m^2, respectively, under SSG, and 621 and 257 arthropods/m^2, respectively, under TCG, which indicated that there could be some grazing regime effect, which could also vary with soil depth. Species mainly found were taxa belonging to the *Thysanoptera* and *Acarina*, which together accounted for more than 68% of arthropod abundance. Taxa of the *Coleoptera*, *Hymenoptera, Araneae*, *Collembola*, and *Isoptera* constituted 30%. The 2% remaining concerns species that were found occasionally. It was observed that arthropod abundance in term of species was greater in SSG treatment litter, whereas a greater arthropod abundance at both 0-10 and 10-20 cm depths was found for TCG treatment (Fig. 2a,b,c).

On the other hand, autumn 2011 sampling revealed significant increases in mean arthropod abundance and soil CO$_2$ efflux in TCG compared with SSG (Table 5). Arthropod abundance was greater under TCG in the pasture-litter layer and at both soil depths. Although soil-physical parameters were not measured in the present study, a previous experiment comparing TCG and SSG at a different part of the Orange campus farm (but on a similar soil) found that total soil macro-porosity

TABLE 4. MEAN ARTHROPOD ABUNDANCE/m^2 IN LITTER AND TWO SOIL DEPTHS, SOIL RESPIRATION, PASTURE COVER AMONG TREATMENTS (SSG: SET-STOCKED GRAZING, TCG: TIME-CONTROLLED GRAZING, SPRING 2010)

		SSG	TCG	Results ANOVA
Mean arthropod abundance/m^2	Litter (0 cm)	1941±237	1579±538	p>0.05
	1-10 cm	1226±292	621±217	p>0.05
	10-20 cm	44±15	257±211	p>0.05
Soil CO$_2$ efflux (μmol/m^2/s)		12.33±0.50	11.39±0.47	p>0.05
Pasture cover (t ha^{-1})		4.6±0.47	4.43±0.34	p>0.05

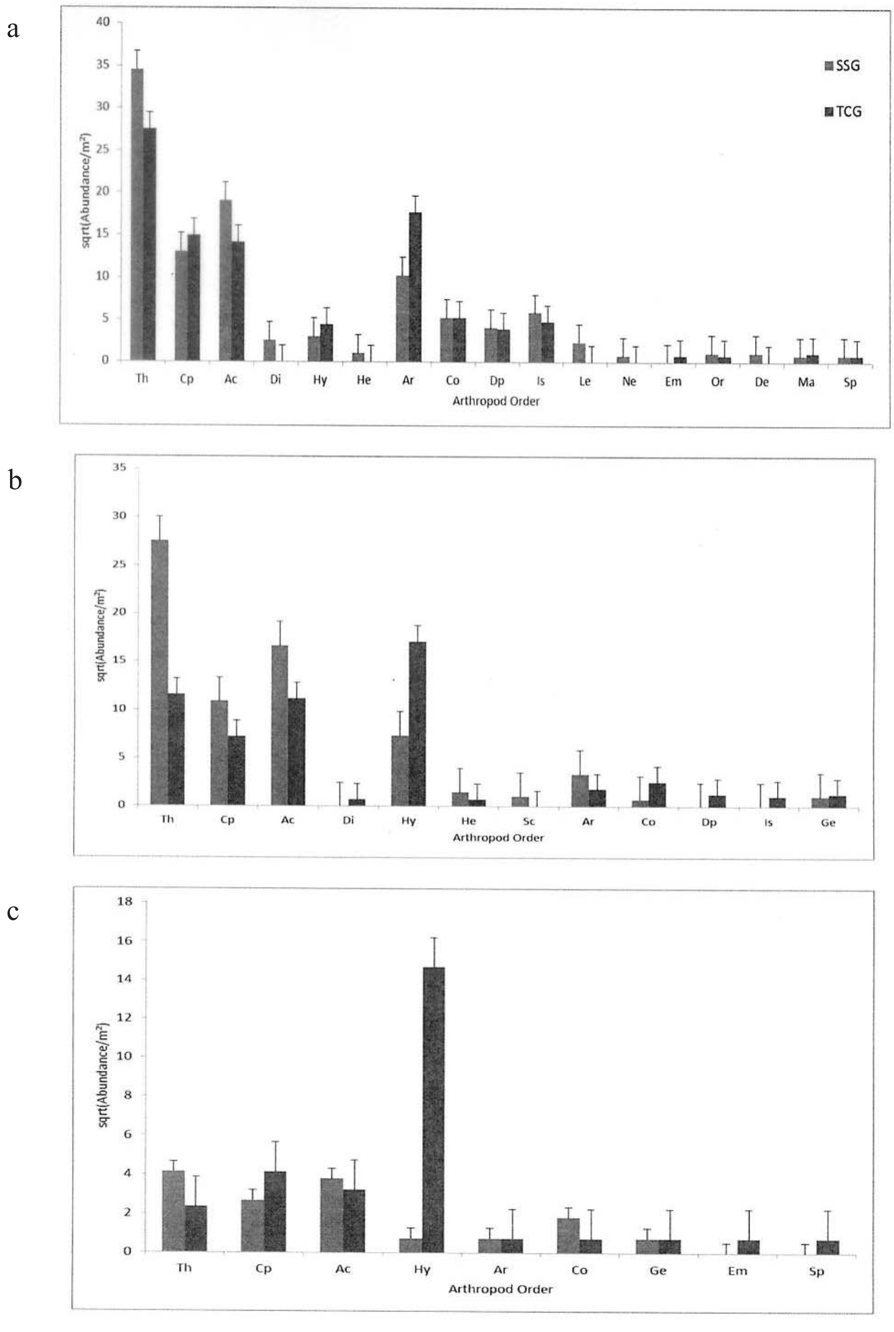

Fig. 2. Square-root mean abundance/m^2 of arthropods in SSG and TCG treatments (mean data from two replicates/treatment) in Spring 2010: a – litter – 0 cm, b – 1-10 cm, c – 10-20 cm. Ac – *Acarina*, Ar – *Araneae*, Co – *Collembola*, Cp – *Coleoptera*, Di – *Diplura*, De – *Dermaptera*, Dp – *Diptera*, Em – *Embioptera*, Ge – *Geophilomorpha* (*Geophilidae*), Hy – *Hymenoptera*, He – *Hemiptera*, Is – *Isoptera*, Le – *Lepidoptera*, Ma – *Mantodea*, Ne – *Neuroptera*, Or – *Orthoptera*, Sp – *Sphaerotheriida*, Th – *Thysanoptera*.

TABLE 5. MEAN ARTHROPOD ABUNDANCE/m^2 IN LITTER AND TWO SOIL DEPTHS, SOIL RESPIRATION, PASTURE COVER AMONG TREATMENTS (SSG: SET-STOCKED GRAZING, TCG: TIME-CONTROLLED GRAZING, AUTUMN 2011)

		SSG	TCG	Results ANOVA
Mean arthropod abundance/m^2	Litter (0 cm)	1765 (±308)	3702 (±562)	p>0.05
	1-10 cm	504 (±53)	1226 (±299)	p>0.05
	10-20 cm	37 (±7)	96 (±21)	p>0.05
Soil CO_2 efflux (μmol/m^2/s)		2.93 (±0.25)	3.65 (±0.21)	p>0.05
Pasture cover (t ha^{-1})		9.97 (±0.33)	7.33 (±0.34)	p>0.05

decreased in SSG fields, whereas stable structural conditions prevailed in TCG fields [7]. The observed reduction of arthropod numbers observed in our study could thus be attributed to a decrease in pore space for the decomposer microarthropods in SSG fields. Greater macroporosity in TCG fields allowed the development and establishment of micoarthropod populations. A decrease in arthropod abundance also occurred with depth, which matched the findings of Tom *et al*. [20].

Our observed seasonal differences contrast with those of Tom *et al*. [20], who in an earlier study located in another part of the Campus farm found no significant changes in autumn, but significant changes in spring. This could be due to an atypical high rainfall during the study period (2010-2011), which could have affected the arthropod community (e.g., intense trampling by high density stock on wet soil under TCG) and thus impacting on the build up of their populations in spring. There may however be seasonal patterns of arthropod abundance due to species adaptation. In an exhaustive study made at the Northern Tablelands of New South Wales in 1976, King *et al*. [12] showed that the arthropod population and abundance evolve with seasons; particularly populations of *Acarina* and *Collembola* occurred in greater abundance in autumn than in spring. The results of our study also reinforce that the populations of *Acarina* and *Collembola* peaked in autumn and a better total-number of arthropods occurred in TCG field. Species mainly found in autumn were *Acarina* and *Collembola* which together accounted for 93%. *Thysanoptera, Coleoptera, Hymenoptera* and *Hemiptera* constituted the remaining 7%. Numbers of *Collembola* and *Acarina* were higher in each depth for TCG management (Fig. 3). Arthropod abundance - one index of diversity – appeared better in the litter and 0-10 cm depth of the SSG paddock. It is the same between the two treatments in the 10-20 cm depth. Soil respiration in TCG paddock is higher in autumn than spring. This is despite the fact that sampled pasture biomass was less, suggesting the increase may be due to greater microbial activity rather than root respiration.

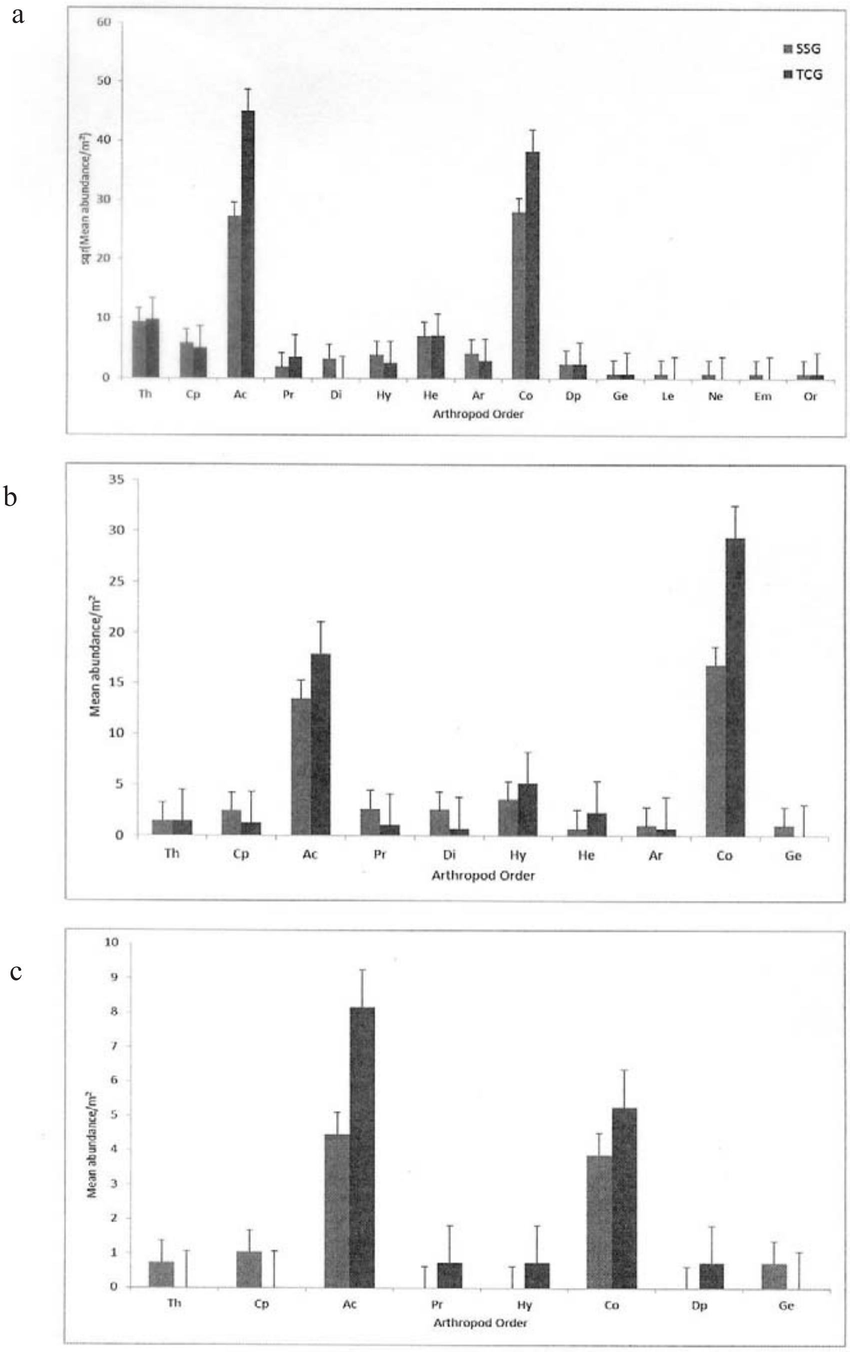

Fig. 3. Square-root mean abundance/m^2 of arthropods in SSG and TCG treatments (mean data from two replicates/treatment) in Autumn 2011: a – litter – 0 cm, b – 1-10 cm, c – 10-20 cm. Explanations as in Fig. 2.

CONCLUSIONS

Our results suggest a partial confirmation of the hypothesis. There is an indication that during autumn, the effect of TCG, when compared with SSG, is to increase arthropod abundance, diversity in the soil and surface litter and soil respiration in the topsoil. These improvements were however not consistent across both seasons which may indicate that the benefits of TCG to these soil parameters are seasonally dependent, with climatic conditions (e.g., rainfall and temperature) mediating these effects. These results, when combined with earlier studies [7] showing increased macro porosity under TCG, give increased confidence that TCG can confer improvements to soil physical and biological parameters and thus be considered as a more sustainable grazing strategy in terms of soil health. Seasonal shifts and changes in precipitation may, however, change soil cycles, suggesting that agriculture is highly vulnerable to climate changes and newer forms of grazing practice must be evaluated carefully in the context of continuing climatic variability.

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BADANIA RÓŻNORODNOŚCI BIOLOGICZNEJ STAWONOGÓW I ODDYCHANIE W GLEBACH O ODMIENNYCH SYSTEMACH WYPASANIA W CENTRALNO-ZACHODNIEJ NOWEJ POŁUDNIOWEJ WALII, AUSTRALIA

Badania dotyczyły porównania skutków oddziaływania dwóch odmiennych systemów wypasania (systemu o kontrolowanym czasie wypasu – TCG *vs* wypasu stada o określonej liczebności – SSG) na wybrane parametry biologicznej zdrowotności gleb. Celem badań była ocena tych parametrów, jako potencjalnych wskaźników zdrowotności gleby i zrównoważonego użytkowania gleb. Za wiarygodne wskaźniki zdrowotności gleby przyjęto dwa parametry, tj. zróżnicowanie biologiczne stawonogów i oddychanie gleby. Próby runi pastwiskowej, populacji stawonogów i gleby pobrano wiosną (wrzesień-listopad 2010) i jesienią (marzec-maj 2011). Wyniki z jesiennego poboru wskazują na silne oddziaływanie systemu TCG na wzrost liczebności stawonogów i zwiększoną aktywność biologiczną. Różnice w próbach z okresu wiosennego były nieistotne. Stwierdzono, że zmiana systemu w kierunku krótkotrwałego rotacyjnego wypasu może być korzystna dla zdrowotności biologicznej gleby w dłuższym okresie oraz, że pomiary stawonogów obecnych w darni i powierzchniowej warstwie gleby może być prostym, ale efektywnym wskaźnikiem wpływu systemu wypasu na zdrowotność gleby.