ISSN: 1511-3701
Pertanika J. Trop. Agric. Sci. **34 (1)**: 109 - 121 (2011)

Impacts of Livestock Grazing on Selected Soil Chemical Properties in Intensively Managed Pastures of Peninsular Malaysia

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ABSTRACT

This study investigates the impacts of short-term (1.5-year) heavy (SHG) and long-term (33-year) moderate (LMG) grazing intensities on the chemical properties of soil in the tropical pasture ecosystems. Two pastures with different grazing intensities and two ungrazed pastures were sampled at the varied depths of 0-10 and 10-20 cm in the Livestock Section of Universiti Putra Malaysia (UPM), Selangor, Malaysia. The EC and pH values in both the moderately and heavily grazed pastures were higher than the ungrazed ones. Meanwhile, the total carbon (TC) in the surface soil of the grazed pastures was 63% and 57% higher than the ungrazed pastures in the LMG and SHG pastures, respectively. The concentration of total nitrogen (TN) was not affected ($P > 0.05$) by livestock grazing. The concentration of available phosphorus (AP) in the surface soil and grazed pasture was significantly greater than the sub-surface soil and ungrazed pastures in the LMG pastures. The AP concentration in the grazed pasture and surface soil was 62.2% and 68.4% less than the ungrazed pasture and subsurface soil in the SHG pasture, respectively. It was found that the concentration of exchangeable cations (Ca^{+2}, Mg^{+2}, and K^{+}) was affected by grazing. In particular, the concentration of exchangeable cations in both the moderately and heavily grazed pastures was also observed to be less than the ungrazed ones, except for Mg^{+2} in the LMG pasture. These results indicate that the impacts of livestock grazing on soil chemical properties were almost limited to the surface soil. After 33 years of moderate grazing, greater values were found for pH, EC, AP, and Mg^{+2} whereas lower values were stated for TN, TC, Ca^{+2}, and K^{+}. As compared to the ungrazed control, the concentrations of AP, TN, Ca^{+2}, Mg^{+2}, and K^{+} decreased after 1.5 years of heavy grazing.

Keywords: Long-term moderate grazing, short-term heavy grazing, exchangeable cations, total nitrogen, total carbon, available phosphorus

INTRODUCTION

In Malaysia, grazing reserves are tracts of land officially allocated by various state governments to be used by farmers to graze their animals. Grazing reserves consist of native and improved grasslands. Large areas of native grazing reserve are available in Sabah (96,479 ha), Sarawak, and Peninsular Malaysia (38,000 ha). Meanwhile, the total of the current areas of improved pastures was approximately 25,000 ha in Peninsular Malaysia, 5,000 ha in Sabah, and 20,000 ha in Sarawak (FAO, 2002). Native grasslands with low productivity and poor forage quality comprise basically a mixture of Hillo grass (*Paspalum conjugatum*), Carpet grass (*Axonopus compresus*), and Slender panic grass (*Ottochloa*

Received: 31 July 2009
Accepted: 23 June 2010
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nodosa) that are used for communal livestock ranching by smallholders. Improved grasslands, which mainly consist of Guinea grass (*Panicum maximum*), Signal grass (*Brachiaria decumbens*), and Napier grass (*Pennisetum purpureum*), are used for commercial livestock ranching by both governmental and private sectors. In Malaysia, overgrazing is a common problem in the great majority of native grasslands. Low productivity of native grasslands, coupled with overgrazing, leads to a rapid degradation of soil and vegetation in such ecosystems (Arevalo *et al*., 1998; Chin, 1998). Overgrazing leads to significant changes in vegetal cover and to a complete absence of vegetation cover in some places (Xie and Wittig, 2004). In particular, livestock grazing has been found to significantly alter almost every aspect of soil structure and function, including its physical, chemical, biological, nutrient cycle, and productivity (Roberson, 1996). It is believed that animals alter soil chemical properties through direct defecation and urination (Bilotta *et al*., 2007). Livestock wastes are often a rich source of nutrients, such as N and P because a small percentage (3–30 %) of the nutrients in the food ingested by the livestock is actually utilized by the animal body, the remainder being excreted in faeces and urine (Bilotta *et al*., 2007). For instance, Tajuddin (1984) indicated that an adult sheep could produce about 186 g dry manure, containing 2.40 % N, 0.40 % P, 2.89 % K, 1.84 % Ca, 0.54 % Mg, and 0.051 % Na, every day. If added to the soil, there would be an increase in soil fertility and the supply of nutrients for vegetation growth could therefore be expected. The nutrient content of livestock excreta may be enhanced further when the animals are fed with concentrated feeds (Tamminga, 1992). Smet and Ward (2006) believe that a more likely source of high nutrients around the watering points in the commercial cattle pastures is the supplementary feed that is given to cattle at watering points.

Recently, Malaysia has placed special emphasis on the development of agriculture, specifically in livestock production, to meet the increasing demands for ruminant products. Thus, it is important to know whether grazing affects soil properties in the tropical pastures. Although the effects of animal grazing on pasture soils have been well documented in developed countries, there is still limited understanding on the extent and intensity of the impacts of animal grazing on the chemical properties of soil in the tropical pastures in Malaysia. The objective of this study was to determine the effects of short-term (1.5-year) heavy and long-term (33-year) moderate rotational grazing intensities on the chemical properties of the soil in the tropical native and improved permanent pastures.

MATERIALS AND METHODS

Site Description

The study was carried out in the catchment at Taman Pertanian Universiti (TPU) as improved pasture with long-term moderate grazing intensity and Ladang 2 farm as native pasture with short-term heavy grazing intensity. The catchments lie between 2° 58’ 53” and 2° 59’ 57” N latitude, and 101° 43’ 38” and 101° 44’ 03” E longitude in the main campus of Universiti Putra Malaysia. The coordinates of the centre of the farm are 3° 00’ 28" N latitude and 101° 42’ 10" E longitude. The areas experience a humid tropical climate with seasonality in rainfall distribution. Meanwhile, the mean annual rainfall is about 2141 mm, whereas the mean annual temperature is 26°C (Taman Pertanian Universiti, 2008). It is important to highlight that the textures of the soil vary from sandy clay to silty clay and clayey loam. The soils are generally well drained in both the areas. The TPU catchment extends over a total area of 317 ha. With the exception of the 37% of the TPU catchment, which are directly covered by oil palm plantations, settlements, roads and paths, the rest of the catchment is devoted to improved pastures and livestock grazing. The soil type has been classified as Munchong soil series (Typic Hapludox) representing the Oxisols. The soil is generally well-drained in the catchment. Within the catchment, two field sites having similar slope, topography, soil, and vegetation were selected. These were designated as grazed and ungrazed sites. The vegetation at both sites is homogenous with a dominant cover of tropical grasses, such as Signal grass (*Brachiaria decumbens* Stapf.) and Guinea grass (*Panicum maximum* Jacq.). Meanwhile, the grazed site, with an area of 180 ha, has experienced a history of regular moderate rotational grazing by cattle in the order of 2.7 livestock unit/ha/yr under a year-round rotational grazing system since 1975. Over the past 33 years, grazing intensity has remained consistent within the low to moderate range. A fenced, ungrazed exclosure of 20 hectares with topography, soil, and vegetation that was similar to the grazed area was installed in the catchment in 1975 and it has never been grazed to date.

Ladang 2 farm with an area of 2 ha was established at the beginning of 2007. Ladang 2 is an ex-tin mining land which was abandoned a long time ago. This area is a sandy clay texture. The soil is well drained in the farm. There is an ungrazed site beside the farm, with the same area, but without any anthropogenic manipulation during the recent years. The farm, both grazed and ungrazed sites, was useless natural grassland before the establishment. Both the grazed and ungrazed sites were predominantly covered by Carpet grass (*Axonopus compressus* (Sw.) Beauv.), Hillo grass (*Paspalum conjugatum* Berg.), and Slender panicgrass (*Ottochloa nodosa* Kunth). The farm has experienced regular grazing by cattle in the order of five livestock unit/ha/yr under a year-round heavy rotational grazing system since its establishment. Management practices in the study areas were typical for a controlled rotational grazing system in intensively managed pastures, where managers carry out several activities including inputs of chemicals (fertilizers, pesticides, and herbicides), offering supplementary minerals and concentrated feed to the cattle, and reducing biodiversity to enhance the productivity of the pasture beyond the natural level. Sites that have been grazed by cattle and those that remain ungrazed constitute the actual subject matter of this research.

Apart from free grazing on pasture, cattle were supplied with concentrated feed in the form of Palm Kernel Cake (PKC), in the quantities of 1 kg/head/day in a feeding trough on the pastures. Furthermore, the cattle had free intake of mineral supplement blocks every day. The chemical constituents of the Malaysian PKC and mineral lick block are summarized in Table 1.

Pastures of the TPU catchment have been fertilized with NPK fertilizers since the year of establishment. For this purpose, urea-N has added to the grazed and ungrazed pastures over 33 years at the rates of 150-200 and 200-300 kg/ha/year, respectively. Furthermore, triple super phosphate (TSP, 200 g P/kg) has been applied in the rates of 40-60 kg P/ha/year over the same period. Grazed and ungrazed pastures received 50-100 kg and 100-150 kg of potassium (K)/ha as muriate of potash (MOP, 50% K), respectively. On the contrary, native pastures of Ladang 2 farm has never been fertilized since its establishment.

TABLE 1
Mineral contents of Malaysian Palm Kernel Cake (PKC)* and mineral lick blocks**

Contents	PKC	Mineral block
Calcium (%)	0.21 – 0.34	8.50
Magnesium (%)	0.16 – 0.33	0.50
Potassium (%)	0.76 – 0.93	-
Phosphorus (%)	0.48 – 0.71	22.8
Sulphur (%)	0.19 – 0.23	-
Total nitrogen (%)	2.32 – 3.13	40
Salt (%)	-	50

* *Source*: Alimon (2004)
** *Source*: Yeong *et al*. (1983)

Sampling Procedure

Soil sampling was carried out in June 2008. In order to facilitate the sampling in the TPU catchment, four typical areas with four sampling plots (0.5 ha) in each area were identified in both the grazed and ungrazed sites. In Ladang 2 farm, four typical areas, with two sampling plots in each area, were established as well. All the samples were taken at least 100 m away from any roads in the study catchment to minimise contamination from vehicle emissions and road dust. Meanwhile, the litter layer was removed from the surface of the soil before taking the samples. The soil samples were collected at randomly selected points, i.e. at 0-10 and 10-20 cm depths in both the grazed and ungrazed sites of the study areas. Ten samples were randomly taken from the selected points at the same depth in each sampling plot and they were then pooled together and thoroughly mixed in order to get one composite sample. The pooled samples were dried at room temperature (25 ºC) and these were gently ground in a porcelain mortar with a pestle after that. The crushed soil was passed through a 2 mm stainless steel sieve to obtain the < 2-mm fraction. Stones, litter and roots were collected from the samples, before and during the grinding. Fine roots passing through the sieve were removed with forceps as far as possible. Air-dried and 2 mm sieved soil was transferred into an airtight plastic bag and stored in an air-conditioned room for chemical analysis.

Chemical Analyses

The chemical characteristics of the soil analyzed include pH, electrical conductivity (EC), total carbon (TC), total nitrogen (TN), available phosphorus (AP), and exchangeable cations (Ca^{++}, K^{+} and Mg^{++}). Meanwhile, soil pH was measured potentiometrically in the supernatant suspension of a 1:1 (soil to distilled water ratio on a volume basis) using a meter (Orion 3-star Portable pH meter, Thermo Electron Corporation, USA), following a 30 min's equilibration period. The EC was measured in the soil-water mixture (1:1 soil/deionised water ratio on a volume basis) using a meter (Orion 3-star Portable Conductivity meter, Thermo Electron Corporation, USA). Carbon was measured by the Leco CR-412 Carbon Determinator (Leco Corporation, USA). Total nitrogen was determined using the Kjeldahl method (Bremner and Mulvaney, 1982). Extractable phosphorus was determined using Bray and Kurtz No. 2 method (Bray and Kurtz, 1945). The exchangeable cations were extracted from the soil with an extracting solution of 1.0 M NH_4OAc (buffered at pH 7.0) (Rhoades, 1982) and were determined in the filtered extract using the Atomic Absorption Spectrophotometry.

Statistical Analysis

The tests were carried out to determine the main effects of grazing intensities and the GLM Repeated Measures Analysis of Variance (ANOVA). For this purpose, soil depths were included as repeated measures to account for the potential effects of grazing at various depths. Meanwhile, an independent *t*-test was applied to compare the two management regimes (grazing versus no-grazing) and determine the differences between soil depths with regard to soil chemical elements. All the tests were run using statistical software (SPSS Inc., 2007). A $P \leq 0.05$ level for testing significance was used in this study.

These long-term and short-term grazed pastures were not replicated. For statistical purposes, each of the sampling locations per treatment was designated as replicates, as the grazing treatments were not replicated. This approach has also been reported by Bauer and Black (1981), Bauar *et al*. (1987), Frank *et al*. (1995), Liebig *et al*. (2006), and Wienhold *et al*. (2001). The use of pseudo-replications has a role in certain situations. Their uses are justified from the standpoint of "space for time" substitution, given the treatments were 33 and 1.5 years old when the study was conducted. They were also used in on-farm research, where treatments were often not replicated (Liebig, Personal Communication, 10 May 2009). Although not ideal, the justification for using this approach hinges upon the value of the long-term status of the grazing treatments (Frank *et al*., 1995;

Wienhold *et al*., 2001) and the big size of the study areas.

RESULTS AND DISCUSSION

The results derived from the multivariate analysis showed that there was a significant difference between the management regimes (namely, grazing vs. no-grazing) in relation to soil chemical nutrients altogether in the short-term heavily grazed pastures of Ladang 2 farm (Wilks' λ = 0.043, P < 0.05) and long-term moderately grazed pastures of the TPU catchment (Wilks' λ = 0.071, P < 0.05). The concentration of all the soil nutrient contents was found to have been affected by soil depth (0-10 and 10-20 cm) in Ladang 2 farm (Wilks' λ = 0.072, P < 0.05), the TPU catchment (Wilks' λ = 0.033, P < 0.05) and by the interaction between soil depth and grazing treatment in Ladang 2 farm (Wilks' λ = 0.069, P < 0.05), and the TPU catchment (Wilks' λ = 0.107, P < 0.05) (Table 2).

Soil pH and EC

Naturally, the soil types in both study areas are strongly acidic. Although soil pH value was found to be not affected (P > 0.05) by grazing, it was affected either by soil depth (P < 0.05) (Table 3a) or the interactions between grazing treatment and soil depth (P < 0.05) in the long-term moderately grazed pastures (Table 5a). The pH values varied from 4.68 to 4.53 between the management regimes (grazing versus non-grazing) (Table 3a). The average pH value (4.68) in the surface soil (0–10 cm) was higher (P < 0.05) than the value (4.53) in the subsurface soil (10–20 cm) (Table 3b).

Meanwhile, the depth-by-depth comparison between grazed and ungrazed treatment (interaction between the treatment and soil depth) showed that there was a significant effect (P < 0.05) of the long-term moderate grazing on the soil pH level with regard to the soil depths and grazing treatment. The value of soil pH (4.82) in the top soil of the grazed pasture was greater than (P < 0.05) the pH (4.54) of top soil of the ungrazed pasture in the long-term moderately grazed pasture. However, the subsoil of the grazed pasture had lower pH value than the ungrazed pasture (Table 5a). Overall, in relation to both soil depths, the two pastures were significantly differed in terms of their soil pH (P < 0.05) (Table 5a).

Soil pH was affected (P < 0.05) by short-term heavy grazing (Table 4a) and the interaction between the grazing treatment and soil depth (P < 0.05) (Table 5b). In more specific, the soil pH ranged from 4.41 to 4.93 and from 4.28 to 5.40 respectively in the grazed and ungrazed pastures of Ladang 2 farm, respectively. The mean pH value varied from 4.81 in the grazed pasture to 4.64 in the ungrazed pasture (Table 4a). At the same time, the depth-by-depth comparison between the grazed and ungrazed treatment (interaction between treatment and soil depth) showed the soil pH value (4.69) in the top soil of

TABLE 2
The effects of cattle grazing on the chemical properties of the tropical pasture soil

Study area	Effect	Wilks' l	F	P	η
Short-term heavily grazed pasture (Ladang 2 farm)	Grazing treatment	0.043	19.41	00	0.957
	Soil depth	0.072	11.23	0.002	0.928
	Treatment × depth	0.069	11.76	0.002	0.931
Long-term moderately grazed pasture (TPU catchment)	Grazing treatment	0.071	34.56	00	0.929
	Soil depth	0.033	76.92	00	0.967
	Treatment × depth	0.107	21.96	00	0.893

η: effect size

TABLE 3
Soil chemical properties in response to the long-term moderate grazing treatment in the pastures of the TPU catchment

Chemical properties	(a)				(b)			
	Treatment		SE††	F	Soil depth (cm)		SE	F
	Ungrazed	Grazed			0-10	10-20		
pH (-log[H$^+$])	4.53	4.68	0.09	2.94	4.68a	4.53b	0.03	25.09
EC (S cm^{-1})	50.21a†	69.54b	4.14	21.76	73.39a	46.35b	2.35	132.17
TC (%)	1.86	1.80	0.09	0.42	2.32a	1.42b	0.61	173.66
AP (mg kg^{-1})	2.71a	5.88b	1.08	8.65	5.63a	3.03b	0.87	8.48
TN (%)	0.30	0.22	0.04	3.36	0.25	0.27	0.06	0.141
K$^+$ (cmol(+)kg^{-1}))	0.049 a	0.037 b	0.004	12.88	0.058 a	0.028 b	0.003	154.09
Ca^{+2} (cmol(+)kg^{-1})	2.133 a	0.501 b	0.136	135.65	2.371a	0.264 b	0.133	250.79
Mg^{+2} (cmol(+)kg^{-1})	0.167a	0.275 b	0.034	14.14	0.345 a	0.097 b	0.025	105.05

†† Standard error
† Means in a row with unlike lower case letters significantly differ at $P < 0.05$

TABLE 4
The soil chemical properties in response to the short-term heavy grazing in the pastures of Ladang 2 Farm

Chemical properties	(a)				(b)			
	Treatment		SE††	F	Soil depth (cm)		SE	F
	Ungrazed	Grazed			0-10	10-20		
pH (-log[H$^+$])	4.64 a†	4.81 b	0.07	5.63	4.68	4.77	0.076	1.54
EC (S/cm)	50.72 a	70.09 b	3.51	30.32	72.55a	48.26b	4.07	35.64
TC (%)	1.43 a	2.25 b	0.18	18.94	2.25 a	1.43 b	0.18	18.90
AP (mg/kg)	54.98 a	32.08 b	14.23	13.82	28.05a	89.00 b	14.43	17.84
TN (%)	0.32	0.23	0.08	1.17	0.19	0.35	0.08	3.80
K$^+$ (cmol(+)kg^{-1})	0.030	0.029	0.003	0.071	0.034	0.025	0.005	2.82
Ca^{+2} (cmol(+)kg^{-1})	2.38 a	0.983 b	0.263	28.28	0.963	1.081	0.245	34.60
Mg^{+2}(cmol(+)kg^{-1})	0.114 a	0.045 b	0.014	25.34	0.058a	0.101 b	0.014	9.41

†† Standard error
† Means in a row with unlike lower case letters significantly differ at $P < 0.05$

the grazed pasture tended to be greater than the pH (4.67) of the top soil of the ungrazed pasture. However, the subsoil of the grazed pasture had a lower pH value than the ungrazed pasture (Table 5b). In total, the two pastures were significantly differed in terms of soil pH ($P < 0.05$) (Table 5b) with regard to both soil depths.

In Malaysia, Kamaruzaman (1988) found that in the soil was significantly less acidic for the pastures that were grazed by sheep than that of the non-grazed pastures. Meanwhile, Smet and Ward (2006) indicated that long-term grazed commercial cattle ranches had higher soil pH value than the communal livestock ranches, i.e.

by around water-point in a semi-arid savannah of South Africa. In contrast, Xie and Wittig (2004) reported that there was no correlation between soil pH value and moderate and heavy grazing intensities in the grassland steppes of Northern China. Similarly, no consistent trend was observed for the effects of livestock grazing on the soil pH value in a universal grazing comparison (Milchunas and Lauenroth, 1993). The large amount of ammonia produced from the hydrolysis of urea in animal urine and the cations deposited from the manure have been attributed by Kamaruzaman (1988) as the reasons to the high pH value in the top soil of the grazed pasture. At the same time, herbivore grazing, trampling, defecation, and urination have been reported to have increased the soil pH level (Killham, 1994). The pH increase of 0.28 units in the top soil of the long-term grazed pasture could be related to Al complexing with organic matter, and it was also possibly due to the recycling of Ca and Mg to the soil surface through livestock grazing and excretion (Arevalo *et al*., 1998). It could be concluded that cattle grazing could decrease the acidity of the tropical pasture soil in the long- and short-term. Low pH level at the non-grazed sites could be explained by two-fold annual applications of N fertilizer (urea) at the mentioned site as compared to the grazed site. Meanwhile, greater acidification of fertilized crested wheatgrass (*Agropyron desertorum*) pasture is driven by the annual application of N fertilizer (Liebig *et al*., 2006).

The results indicated that both the moderate and heavy grazing by cattle had caused the soil to become less acidic. This result was also supported by the findings of Liebig *et al*. (2006) and Kamaruzaman (1988). The variation of soil pH, with respect to soil depth and grazing treatment interaction, was similar in both Ladang 2 farm and the TPU catchment. The livestock grazing impacts on soil pH were noticeable in the top soil. In particular, the non-grazed pastures showed low pH level and greater acidification.

The soil EC was affected ($P < 0.05$) by grazing treatment and soil depth in both pastures (Tables 3ab and 4ab), and the interaction between them was found to be significant only in the long-term moderate grazing (Table 5a). The EC value in the grazed pasture was higher ($P < 0.05$) than the ungrazed pasture in both pastures. The means soil EC of the grazed pastures were 38 % greater than the ungrazed pastures in both the areas studied (Tables 3a and 4a). Meanwhile, the EC values in the top soil were higher ($P < 0.05$) than the subsoil in both the pastures. The means EC of the top soils were around 58 and 50 % higher than the subsoil in the long-term moderately and short-term heavily grazed pastures, respectively (Tables 3b and 4b).

The depth-by-depth comparison between the grazed and ungrazed treatment (i.e. the interaction between the treatment and soil depth) showed that the EC of the top and sub-soil of grazed pastures were greater ($P < 0.05$) than the adjacent ungrazed exclosure in both the study areas (Table 5ab). The grazing treatment and soil depth had significant interaction in the long-term moderately grazed pastures (Table 5a). Although the EC values of the grazed surface (81.66 S/cm) and the subsurface soil (58.52 S/cm) were significantly higher ($P < 0.05$) than the ungrazed surface (63.45 S/cm) and subsurface soil (38.00 S/cm) in the short-term heavily grazed pasture, there was no significant interaction between the grazing treatment and soil depths ($P > 0.05$) (Table 5b).

The soil EC values were lower in the ungrazed pastures of both Ladang 2 farm and the TPU catchment. This result agrees with the findings of Chaneton and Lavado (1996) who reported that the topsoil EC was significantly lower within the long-term ungrazed grasslands. Nonetheless, the finding contrasts with the lower soil EC found to have been caused by grazing in the tropical pasture of Costa Rica (Reiners *et al*., 1994). Liebig *et al*. (2006) and Li *et al*. (2008) observed that the soil EC did not vary between the grazing treatments. The low EC values in the soils indicated that the area was not under risk of salinization (Li *et al*., 2008). Continuous grazing increases salt content by reducing aerial plant and litter cover, which lead to higher soil temperatures and evaporation rates. There are some salt in cattle excreta due to unrestricted daily access to salt and mineral

TABLE 5
Soil chemical properties in response to the interaction between grazing treatment and soil depth in the studied pastures

Chemical properties	Long-term moderately grazed pastures of the TPU catchment (a)								Short-term heavily grazed pastures of the Ladang 2 farm (b)							
	Grazing treatment × soil depth						F	P	Grazing treatment × soil depth						F	P
	0-10 cm		SE††	10-20 cm		SE			0-10 cm		SE	10-20 cm		SE		
	Ungrazed	Grazed		Ungrazed	Grazed				Ungrazed	Grazed		Ungrazed	Grazed			
pH (-log[H^+])	4.54 a†	4.82 b	0.002	4.97 a	4.59 b	0.002	22.28	00	4.67	4.69	00	4.97 a	4.59 b	0.374	6.90	0.02
EC (S cm^{-1})	60.00 a	86.79 b	0.132	40.41 a	52.29b	0.108	9.36	0.004	63.45 a	81.66b	00	38.00a	58.52b	00	0.08	0.78
TC (%)	2.10 a	2.40 b	0.003	1.53 a	1.32 b	0.002	22.00	00	1.78 a	2.72 b	00	1.08 a	1.77 b	00	0.44	0.51
AP (mg kg^{-1})	7.53 a	3.60 b	0.027	4.29	1.81	0.042	0.22	0.396	19.85	36.25	00	150.00a	28.00b	00	23.07	00
TN (%)	0.25	0.24	0.001	0.19	0.36	0.002	2.15	0.153	0.16 a	0.23 b	00	0.48	0.23	00	3.61	0.07
K^+ (cmol(+)kg^{-1})	0.045 a	0.072 b	00	0.028	0.027	00	31.43	00	0.027	0.039	00	0.032 a	0.018 b	00	8.09	0.01
Ca^{+2} (cmol(+)kg^{-1})	0.719 a	4.02 b	0.006	0.284	0.245	00	161.15	00	0.640 a	1.286 b	00	1.48 a	0.681 b	00	69.81	00
Mg^{+2} (cmol(+)kg^{-1})	0.285 a	0.41 b	0.002	0.146 a	0.048 b	00	0.40	0.528	0.035 a	0.076 b	00	0.188 a	0.013 b	00	57.10	00

†† Standard error
† Means in a row with unlike lower case letters significantly differ at P < 0.05

blocks in the pastures. Salt moves upward from lower soil horizons and reaches the soil surface in the periods of high atmospheric demand (dry season). Topsoil salinization peaks are followed by salt leaching caused by rainfall and soil waterlogging events in rainy season (Chaneton and Lavado, 1996).

Soil Exchangeable Cations

The Ca^{+2}, Mg^{+2}, and K^{+} concentrations in the soil were affected ($P < 0.05$) by grazing treatment, soil depth (Table 3ab) and the interaction (except Mg^{+2}) between them (Table 5a) in the long-term moderately grazed pasture of the TPU catchment. Meanwhile, the soil Ca^{+2} and K^{+} contents varied significantly between the grazed and ungrazed pastures. In particular, the grazed pasture had about four-fold and 1.32 times lower Ca^{+2} and K^{+} contents than ungrazed pasture in the catchment. Conversely, Mg^{+2} content of the grazed pasture soil was found to be significantly higher (65 %) than the ungrazed exclosure (Table 3a). The concentrations of all the measured exchangeable cations in the top soils were significantly higher than the sub-soil in the long-term grazed pastures (Table 3b).

The depth-by-depth comparison between the grazed and ungrazed treatments (i.e. the interaction between treatment and soil depth) showed that Ca^{+2}, K^{+} and Mg^{+2} concentrations in the surface soil (0-10 cm) of the grazed pastures were greater ($P < 0.05$) than the same depth of the ungrazed pastures of the catchment. Ca^{+2} and K^{+} had relatively similar concentrations in the subsurface soils (10-20 cm) of the grazed and ungrazed pastures. Overall, the interaction between the grazing treatment and soil depth was significant for Ca^{+2} and K^{+} (Table 5a).

The concentrations of Ca^{+2} and Mg^{+2} were affected ($P < 0.05$) by heavy grazing treatment in Ladang 2 farm (Table 4a). The divalent cations (Ca^{+2} and Mg^{+2}) concentration in the short-term heavily grazed (SHG) pasture was significantly lower than the adjacent ungrazed pasture (Table 4a). The content of K^{+} was not affected ($P > 0.05$) by the grazing treatment or by the soil depth (Table 4b) in the farm. This is consistent with the results of Xie and Wittig (2004) and Liebig *et al*. (2006) who reported that K^{+} was not influenced by heavy grazing intensities.

Only the concentration of Mg^{+2} in the top soil was significantly lower than the sub-soil in the short-term heavily grazed pastures. The concentration of Ca^{+2} in the top soil of the farm seemed to be lower than the sub-soil (Table 4b). Although only the concentration of Mg^{+2} was affected ($P < 0.05$) by soil depth (Table 4b), there was a significant interaction between the grazing treatment and soil depth in pastures of Ladang 2 farm for the concentrations of all the measured cations (Table 5b). The depth-by-depth comparison between the grazed and ungrazed treatments (i.e. the interaction between grazing treatment and soil depth) showed that only the K^{+} content of surface soil (0-10 cm) did not vary significantly between the heavily grazed and ungrazed pastures of Ladang 2 farm. Overall, the Ca^{+2}, K^{+} and Mg^{+2} concentrations in the surface soil (0-10 cm) of grazed pastures were greater than at the same depth of the ungrazed pastures in the farm, with disregard to statistical significant. However, the concentrations of K^{+}, Ca^{+2}, and Mg^{+2} in the subsurface soil (10-20 cm) of the heavily grazed pasture were lower than ($P < 0.05$) the ungrazed control. On the whole, significant interactions ($P < 0.05$) between grazing and soil depth were detected for all the measured exchangeable cations in Ladang 2 farm (Table 5b).

In general, the exchangeable K^{+}, Ca^{+2}, and Mg^{+2} concentrations were affected ($P < 0.05$) in the surface soil by grazing treatment in both the short-term and long-term grazed pastures. The soluble cation concentrations in the grazed surface soil (0-10 cm) were greater than ($p < 0.0$) the ungrazed surface soils in both the pastures, except for K^{+} in the heavily grazed pasture (Table 5ab). The results showed that grazing treatment seemed to affect soluble cations at 0-10 cm soil depth.

Meanwhile, the grazing treatments, which included both long-term moderate and heavy grazing, tended to affect divalent cations (Ca^{+2} and Mg^{+2}) at 0–10 cm, whereas grazing was found to affect monovalent cations (K^{+}) below

30 cm in Missouri Plateau, USA (Liebig *et al*., 2006). In Peru, Arevalo *et al*. (1998) reported that the concentration of K^+ remained constant until 42 months after grazing began in the tropical pastures. The same result was also observed in the short-term (18-month) grazed pasture in this study. Meanwhile, elevated levels of exchangeable cations in the surface soils (0-10 cm) might be caused by a stocking effect, resulting in a greater deposition of waste through faeces and urine, followed by subsequent decomposition and distribution throughout the soil profile. A low concentration of potassium in the short-term heavily grazed pasture might be related to the reduction in the water-soluble K due to high salinity as a result of the addition of animal manure to the soil. It is also likely that K, being highly mobile, is lost by leaching, since heavy rain is usually experienced in Malaysia (Kamaruzaman, 1988). The increase of potassium amount in the surface soil of long-term grazed pastures might be related to the recycling of nutrients in plant dead material and litter, root biomass turnover, and through the recycling of cattle excreta in long-term (Arevalo *et al*., 1998).

Total carbon, total nitrogen and available phosphorus

Nonetheless, total carbon (TC) did not differ ($P > 0.05$) between the grazing treatments (Table 3a) but it was significantly affected ($P < 0.05$) by soil depth (Table 3b) and the interaction between them (Table 5a) in the LMG pasture. The TC in the surface soil layer was 63% higher than the subsurface soil in this pasture (Table 3b). The depth-by-depth comparison of the grazing treatments (grazing treatment and soil depth interaction) showed that the TC of the surface soil (0-10 cm) of the grazed pasture was greater ($P < 0.05$) than the ungrazed pasture. However, this was reverse in the subsurface soil (Table 5a). Overall, a significant interaction was found between grazing treatments and soil depth.

There was a significant difference ($P < 0.05$) between the grazing treatments (Table 4a) and soil depth (Table 4b) but not by the interaction between them ($P > 0.05$) (Table 5b) in the SHG pasture in relation to soil carbon. Meanwhile, the TC percentage in soil in heavy grazing treatment and surface soil was 57 % greater than the ungrazed pasture and subsoil. Xie and Wittig (2004) found a significant difference between heavily grazed and ungrazed grassland communities with regard to soil organic substances. The total carbon percentages in the upper and lower soil layers in ungrazed pasture of SHG pasture were significantly lower than the adjacent grazed pasture (Table 5b).

The mean soil total C in heavily grazed pasture (2.25) was greater for the pasture than the moderately grazed pasture (1.80). This result is in agreement with the findings of Liebig *et al*. (2006) and Frank *et al*. (1995). Greater TC in the SHG pasture might be caused by the dominance of mat-forming grasses, including *Axonopus compresus* and *Ottochloa nodosa* in this pasture, which transfer most of their photosynthetic products belowground to root mass. Furthermore, root death in the pastures under heavy grazing was also found to be high. The limited increase in the soil total carbon under long-term moderate grazing could be attributable to a decrease in the amount of plant litter and an increase in soil compaction due to cattle treading, which apparently causes unfavourable living conditions for those organisms that are vital for decomposition of organic matter and incorporation of the humus into the soil (Xie and Wittig, 2004).

Nonetheless, the influence of long-term moderate grazing on the content of soil TC was limited to topsoil (0-10 cm). The effect of short-term heavy grazing on the content of soil TC in the subsoil was lower than the top soil. Xie and Wittig (2004) indicated that with the increasing depth of soil, the influence of grazing intensity on soil organic substances was found to significantly reduce. These results indicate that grazing cattle increases soil total carbon in the short-term, but there is no a consistent trend in the increase of soil total carbon over time, as the effect of long-term grazing on soil TC amount was not statistically difference in the grazed areas versus adjacent ungrazed areas.

The higher concentrations of the total carbon in the upper soil layer of the grazed pastures could be explained by deposition of organic matter by cattle faeces, greater detrital inputs of grass litter into the soils and concentration of grass roots in surface soil at 0-10 cm. Based on the results of dead material and litter measurements in these pastures (unpublished data), detrital input of grass litter into soil in grazed area is therefore greater than the ungrazed area. The higher the concentration of the total C in the subsoil of the ungrazed pasture in long-term grazed pasture might be attributable to the high grass root turnover rate in this layer. According to Dahlgren *et al*. (1997), another source of organic matter in soil B horizon is from the retention of dissolved organic matter (DOC) leaching from the litter decomposing at the soil surface and to lower soil layers.

The concentration of soil TN was not affected ($P > 0.05$) by the grazing treatments, soil depth (Tables 3 and 4) and the interaction between them (Table 5ab). Meanwhile, the concentration of TN ranged from 0.22 to 0.30 and 23 to 0.32 in the grazed and ungrazed sites of the LMG and SHG pastures, respectively.

The concentration of AP was affected ($P < 0.05$) by the grazing treatments (Table 3a) and soil depth (Table 3b), but not ($P > 0.05$) by the interaction between them in the LMG pasture (Table 5a). The mean soil AP in the pasture under the long-term moderate grazing treatment was about two-fold greater than the ungrazed control pasture. The soil AP content of the surface soil was about 46% greater than the subsurface soil in the TPU catchment.

Soil AP content was affected ($P < 0.05$) by the grazing treatments (Table 4a) and soil depth (Table 4b), but not ($P > 0.05$) by the interaction between them in the SHG pasture (Table 5b). The concentration of soil AP in the grazed pasture and surface soil (0-10 cm) was significantly ($P < 0.05$) lower than ungrazed pasture and subsurface soil (10-20) in SHG pasture. The AP concentrations in the grazed pasture and surface soil were 62.2% and 68.4% lower than the ungrazed pasture and subsurface soil in this pasture. Xie and Wittig (2004) stated that the concentration of TN and AP in grasslands, under moderate and heavy grazing, was less than the non-grazed areas. Dahlgren *et al*. (1997) observed no significant difference in the soil N concentration between the grazed and ungrazed treatments. Meanwhile, Tiedemann *et al*. (1986) reported a net loss of 3.2 kg N/acre under a moderate grazing compared to the ungrazed area in the Pacific Northwest. The depth-by-depth comparison of the grazing treatments (grazing treatment and soil depth interaction) showed that the surface soil AP and TN contents in the SHG pasture were higher than the ungrazed exclosure, but not were significant for the AP. However, this was reverse in the subsurface soils (Table 5b).

The Available Phosphorus (AP) concentration in soil was not increased after 33 years of moderate grazing (Chaneton and Lavado, 1996; Smet and Ward, 2006). Meanwhile, the total N in the surface soil of heavily grazed pasture was greater than the moderately grazed pasture (Liebig *et al*., 2006). Similar to the results retrieved from the tropical pastures in Malaysia (Kamaruzaman, 1988), the increases in the total N and the available P were observed in the surface soils of the short-term grazed pasture. The effects of grazing management on the total N were however limited to the surface soil, i.e. at 5 cm depth (Liebig *et al*., 2006). The increased N in the surface soil of the short-term grazed pasture is probably due to the increased input of organic matter from cattle manure. The increase of plant available P could be attributed to the organic part of manure retarding P fixation by mechanically separating soluble P from the mineral part of the soil (Kamaruzaman, 1988). The nutrient content of cattle excreta might be increased when the cattle have been fed with concentrated feeds like PKC (Biolotta *et al*., 2007). Since carbon, nitrogen, and phosphorus are major components of organic matter, it is assumed that the strong relationship between these components is associated with organic matter concentrations (Dahlgren *et al.*, 1997). Nutrients are lost through increased erosion in the grazed pastures, leaching and consuming of plants by animals in the pasture ecosystems.

Grazing animals profoundly affect the horizontal distribution of nutrients in pasture soil. Grazing animals remove plant biomass and redeposit it in other areas like bedding ground, under shade, around feeding trough and watering points in the forms of urine and faeces.

CONCLUSIONS

The long-term moderate and short-term heavy grazing have been found to have effects on the soil chemical properties in improved and native intensively managed pastures. After 33 years of moderate grazing by cattle, greater soil pH, EC, AP and Mg^{+2} and lower TN, TC, Ca^{+2} and K^{+} concentrations were found at the improved pastures of the TPU catchment. For the native pastures of Ladang 2 farm, higher pH, EC, TC and lower AP, TN, Ca^{+2}, Mg^{+2} concentrations were observed after 1.5-year of heavy grazing by cattle. Exchangeable cation concentrations in heavily and moderately grazed pastures were lower than the ungrazed pastures, except for Mg^{+2} in moderately grazed pastures. The heavily grazed pasture had a greater total C than the moderately grazed pasture. Heavy grazing by cattle led to a decrease in the TN and AP contents of soil. Variations of the topsoil chemical properties were noticeable as a consequence of cattle grazing. Knowledge of soil nutrient properties provides quick and useful clues to help pasture managers to make accurate decision about fertilizers application practice. Based on the findings of this study, it can be recommended that the intensity of grazing should not exceed a moderate (30-50%) grazing in order to avoid damages to pastures, such as vegetation degradation, soil compaction, and erosion. Stocking rate should ensure sustainability of the pasture ecosystem to support livestock production in the long-term.

ACKNOWLEDGEMENTS

The funding of this project was provided by Universiti Putra Malaysia (UPM). The authors are grateful to the Department of Environmental Science of Universiti Putra Malaysia for facilitating them in the fieldwork. The authors would like to express their appreciation to Mayudin Othman and Sarimah Hashim from the Land Management Department of Universiti Putra Malaysia, for their technical support in the laboratory work of this study.

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