Polish J. of Environ. Stud. Vol. 19, No. 6 (2010), 1369-1375

Short Communication

How Cattle Grazing Influences Heavy Metal Concentrations in Tropical Pasture Soils

Majid Ajorlo[1]*, Ramdzani Bin Abdullah[1], Ahmad Husni Mohd. Hanif[2], Ridzwan Abd. Halim[2], Mohd Kamil Yusoff[1]

[1]Faculty of Environmental Studies, University Putra Malaysia,
[2]Faculty of Agriculture, University Putra Malaysia,
43400 (UPM), Serdang, Selangor D.E., Malaysia

Received: 18 September 2009
Accepted: 15 March 2010

Abstract

This study investigates the impact of short-term (1.5-year) heavy and long-term (33-year) moderate grazing intensities on the heavy metal concentrations in soils of tropical pastures. The concentration of heavy metals (Cd, Fe, Mn, Cu, Cr, Pb, and Zn) was determined in the Livestock Section of University Putra Malaysia, Selangor, Malaysia. The heavy metal concentrations in the soil were not affected ($P>0.05$) by short-term heavy grazing intensity. The concentrations of Fe, Mn, and Zn were significantly affected ($P\leq0.05$) by long-term moderate grazing or soil depth and by the interaction between them. The Cu concentration in soil was only affected ($P<0.05$) by grazing, but not ($P>0.05$) by sampling depth or their interaction. The concentrations of Fe, Mn, Cu, and Zn in long-term moderately grazed pasture soil were 127.9, 194.8, 54.8, and 39,900% higher, respectively, than ungrazed pasture. Soil Fe, Mn, and Zn concentrations were significantly higher ($P<0.05$) in surface (0-10 cm) than subsurface (10-20 cm) soils. Results suggest that the excreta of grazing cattle can be an important source of heavy metals in intensively managed pastures in the long-term. However, metal concentrations were maintained within the normal range and were not high enough to be dangerous from the toxicological point of view.

Keywords: heavy metals, intensively managed pasture, long-term moderate grazing, short-term heavy grazing, Malaysia

Introduction

Naturally, all soils contain varying concentrations of heavy metals depending on the type of parent material from which the soil was formed. Heavy metals may be added to pasture soils through the application of mineral and organic fertilizers, direct defecation and urination by animals, pesticides, soil amendment practices (e.g. liming and gypsum applying) [1, 2], and atmospheric deposition (e.g. radionuclides, vehicle and industrial emissions) [3-5]. The heavy metal content of cattle faeces and urine vary by animal diet. Dairy and beef cattle waste contain greater heavy metal concentrations when they are fed with concentrated feed rather than forage or silage [6]. Also, the heavy metal content of cattle manure depends primarily on the concentration in the animal feed. In consideration of the potential impact of heavy metals on the pollution of pasture soils in the long-term, it is important to quantify metal concentrations in pasture soils to detect the possible long-term build-up of heavy metals, especially in tropical regions with acidic soils. The availability of metals to plants is high in acidic soils [35]. It is reported that the application of dairy sludge to grassland soils does not lead to the accumulation of heavy metals to a harmful level in the short or medium-

*e-mail: Ajorlo_m54@yahoo.com

term (1 and 4 years) [7]. The impact of heavy metals entering pasture soils is affected by the characteristics of the soil [8]. The concentration of metals in the soil varies with the type of source, presence of metals in the environment [9], and soil chemical characteristics. The distribution and localization of heavy metals within the soil profile are governed by the type of clay minerals and organic matter percent [10], leaching, erosion, and biological and microbial processes. The distribution of heavy metals is not identical throughout the soil profile [11]; however, heavy metals are normally located within the top 25 cm of the soil in cultivated soils [12].

Although most of the available literature has discussed the effects of animal manure and slurry applications on agricultural land, there are very few documents concerning the impact of animal grazing on the heavy metal contents of soil in pastures. To date, there has been very little published information on heavy metal inputs to pasture soil by grazing animals in Malaysia. The objective of this study was to evaluate the effects of long-term (33-year) moderate and short-term (1.5-year) heavy cattle grazing on the concentration of heavy metals in the soils of tropical pastures.

Materials and Methods

Site Description

The study was carried out in the TPU catchment and Ladang 2 experimentally constructed farm that lie between 101º43'38" and 101º44'03" E longitude and 2º58'53" and 2º59’57"N latitude on the University Putra Malaysia campus about 20 km south of Kuala Lumpur, Malaysia. The areas experience a humid tropical climate with seasonality in rainfall distribution. Mean annual rainfall is about 2,300 mm and mean annual temperature is 31ºC. Soil texture varies from sandy clay to silty clay and clay loam. The soils are generally well drained in both areas. The TPU catchment extends over a total area of 317 ha. Within the catchment, two field sites with similar slope, topography, soil, and vegetation were selected. These are designated as grazed and ungrazed sites. Vegetation of both sites is homogenous, with a dominant cover of tropical grasses such as signal grass (*Brachiaria decumbens* Stapf.) and guinea grass (*Panicum maximum* Jacq.). The grazed site, with an area of 180 ha, has experienced a history of regular moderate 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 similar to the grazed area was installed in the catchment in 1975 and has never been grazed to date.

Ladang 2 farm with an area of 2 ha was established in early 2007. There is an ungrazed site beside the farm with the same area without any anthropogenic manipulation during recent years. The farm, both grazed and ungrazed sites, was unused native grassland before establishment. Both 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 heavy grazing by cattle in the order of five livestock unit/ha/yr under a year-round rotational grazing system since 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, herbicides), offering supplementary minerals, and concentrated feed to cattle, and tend to reduce 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. The heavy metal concentrations of ungrazed sites were considered as background values due to minimal anthropogenic influence.

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

Pastures had been fertilized with NPK fertilizers since the year of establishment. Urea-N was added to grazed and ungrazed pastures over 33 years at the rates of 150-200 and 200-300 kg, respectively. Furthermore, triple super phosphate (TSP, 200 g P/kg) had been applied in rates of 40-60 kg P/ha/year over that period. Grazed and ungrazed sites received 50-100 kg and 100-150 kg of potassium (K)/ha as muriate of potash (MOP, 50% K), respectively.

Furthermore, pastures received grazing cattle waste over time directly through defecation and urination. It should be emphasized that cattle waste often shows high variability in its physical and chemical properties over time. Heavy metals concentration ranges in animal manure and mineral fertilizers are listed in Table 2. Herbicides, including Ken-phosate, Ken-star plus, and Tordon 101, were applied to the pastures at the rate of 4 lit/ha to exterminate invasive and thorny plants wherever and whenever needed.

Table 1. Heavy metal concentrations (mg/kg) of Malaysian palm kernel cake (PKC) [33] and mineral lick block [34].

Heavy metals	PKC	Mineral block
Fe	835-6,130	7,000
Mn	132-340	7,000
Cu	20.50-28.90	1,200
Co	-	20
Mo	0.70-0.79	-
Se	0.23-0.30	20
Zn	40.50-50.00	7,000

Table 2. Heavy metal concentrations (mg/kg) in mineral and organic fertilizers [5].

Heavy metals	Phosphate fertilizer	Nitrate fertilizer	Farmyard manure
Cd	0.1-170	0.05-8.5	0.1-0.8
Mn	40-2,000	-	30-969
Cu	1-300	-	2-172
Cr	66-245	3.2-19	1.1-55
Pb	7-225	2-27	1.1-27
Zn	50-1,450	1-42	15-566

Sampling Procedure

Soil sampling was carried out in June 2008. In order to facilitate sampling in the TPU catchment, four typical areas with four sampling plots (1 ha) in each area were identified in both grazed and ungrazed sites. In Ladang 2 farm, four typical areas with two sampling plots in each area were established as well. All samples were taken at least 100 m away from any roads in the study catchment to minimize contamination from vehicle emissions and road dust. The litter layer was removed from the surface of the soil before taking samples. Soil samples were collected at randomly selected points at 0-10 and 10-20 cm depths in both grazed and ungrazed sites of the study areas. Ten samples were taken in randomly selected points from the same depth in each sampling plot and pooled together and thoroughly mixed in order to get one composite sample. The pooled samples were dried at room temperature (25ºC) and then gently ground in a porcelain mortar with a pestle. 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 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.

Soil Chemical Analyses

The extractable form of cadmium (Cd), lead (Pb), copper (Cu), chromium (Cr), iron (Fe), zinc (Zn), and manganese (Mn) concentration in the soil was measured using dilute double acid solution (Mehlich-1 extractant) [13, 14]. Twenty-five mL of the extracting solution (0.025 mol/L H_2SO_4 + 0.050 mol/L HCl) was added to a 5 g weight of the soil (soil: extractant, 1:5) and mixed using a rotating horizontal agitator at a frequency of 180 rpm for 15 minutes. The heavy metal content of the filtrate was then measured by inductively coupled plasma (ICP) spectrophotometry (SpectroFlame Modula, Spectro Analytical Instruments, Kleve, Germany) [15]. Concentrations of heavy metals in the soil were expressed in mg/kg. Extractable forms of heavy metals are supposed to be readily available for plant uptake and/or recycling within the ecosystem [16].

Statistical Analysis

Tests for the main effects of grazing intensities and interactions between grazing treatment and soil depth were performed using the repeated measures analysis of variance (ANOVA). Soil depths were included as repeated measures to account for potential effects of grazing at various depths. Post-hoc Fisher's least significant difference test was used for pair-wise comparisons among means. All tests were run with SPSS statistical software [17]. The study used a $P\leq0.05$ level for testing significance. 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 themselves were not replicated. This approach was also reported by [18-22]. Use of pseudo-replications has a role in certain situations. We justified their use from the standpoint of "space for time" substitution, given that the treatments were greater than 30 and 1.5 years old when we conducted the study. They are also used in on-farm research, where treatments are often not replicated (Mark A. Liebig, Research Soil Scientist, USDA-ARS-NGPRL, personal communication, 10 May 2009). Though not ideal, justification for using this approach hinges upon the value of the long-term status of the grazing treatments [20, 22] and the large size of the study areas.

Results

The results of multivariate analysis showed that there was a significant difference between the management regimes (grazing vs. no-grazing) with regard to heavy metals concentration in the soil for the long-term moderately grazed TPU catchment (Wilks' λ=0.21, $P<0.05$). No significant difference was found between the management regimes in the short-term heavily grazed Ladang 2 farm (Wilks' λ=0.318, $P>0.05$). The concentration of heavy metals in the soil was affected by grazing treatments soil sampling depth (0-10 and 10-20 cm) and by interaction between soil depth and treatment in the TPU catchment (but not in Ladang 2 farm) (Table 3).

Table 3. Effects of cattle grazing on heavy metals concentration in tropical pasture soil.

Study area	Treatment	Effect	Wilks' λ	F	P
Ladang 2 farm	Short-term heavy grazing	Treatment	0.318	2.45	0.12
		Depth	0.367	1.97	0.18
		Treatment × depth	0.749	0.38	0.89
TPU catchment	Long-term moderate grazing	Treatment	0.210	11.41	0.0
		Depth	0.170	15.05	0.0
		Treatment × depth	0.290	7.70	0.0

Table 4. Effects of long-term moderate grazing by cattle on heavy metals concentrations (mg/kg) of pasture soils.

Heavy metals	Treatment		SE*	Soil depth (cm)		SE	Treatment × depth					
							0-10		SE	10-20		SE
	Non-grazed	Grazing		0-10	10-20		Grazing	Non-grazed		Grazing	Non-grazed	
Cd	0.045	0.069	0.016	0.073	0.042	0.017	0.10	0.045	0.016	0.037	0.046	0.02
Fe	399.76[a]**	911.16[b]	93.18	773.54[a]	537.37[b]	44.54	1113.16[a]	413.92[b]	91.11	689.15[a]	385.60[b]	48.63
Mn	1.95[a]	5.75[b]	2.01	5.26[a]	2.44[b]	0.54	7.76[a]	2.75[b]	1.77	3.73[a]	1.14[b]	1.09
Cu	0.31[a]	0.48[b]	0.07	0.45	0.34	0.07	0.61	0.29	0.08	0.34	0.33	0.06
Cr	0.28	0.34	0.10	0.25	0.37	0.10	0.26	0.23	0.09	0.41	0.32	0.11
Pb	0.37	0.59	0.25	0.52	0.44	0.17	0.62	0.43	0.23	0.56	0.31	0.20
Zn	0.001[a]	0.40[b]	0.09	0.28	0.13[a]	0.05	0.55[a]	0.0[b]	0.08	0.26[a]	0.0[b]	0.07

*standard error

**Means in a row with unlike lower case letters significantly differ at $P<0.05$.

The concentrations of Fe, Mn, and Zn were significantly affected ($p \leq 0.05$) by long-term (33 years) moderate grazing or soil depth and by the interactions between grazing regimes and soil depth (Table 4). The concentrations of Fe and Mn in surface (0-10 cm) soils of the grazed site were 169 and 78.7% greater, respectively, than the surface soils of the ungrazed site, and the concentrations of these metals in the grazed site were 182 and 227% greater, respectively, than the ungrazed site in subsurface (10-20 cm) soils. The Zn content in top and subsoils of the grazed site varied from 0.55 and 0.26 mg/kg, respectively, to zero in the same depth of the ungrazed site. The Fe, Mn, and Zn concentrations were higher ($P<0.05$) in surface than subsurface soils. The Cu concentration in the soil was only affected ($P<0.05$) by grazing, but not ($P>0.05$) by sampling depth or the interaction between them. The Cu concentration for the grazed site was 54.8% higher than the value for the control (Table 4). The concentrations of Fe (399.76), Mn (1.95), Cu (0.31), and Zn (0.001) in the ungrazed site were significantly lower than ($P<0.05$) their concentrations in the long-term moderately grazed site, which were 911.16, 5.75, 0.48, and 0.40 mg/kg, respectively. In other words, Fe, Mn, Cu, and Zn concentrations of the grazed site were 127.9, 194.8, 54.8, and 39,900% higher, respectively, than the ungrazed site. The concentrations of Cd, Cr, and Pb were not affected ($P>0.05$) by grazing nor by the sampling depth or their interactions in the long-term moderately grazed pasture (Table 4). The concentrations of Cd, Cu, Cr, and Pb in the top and subsoils of the grazed site were greater, but not significantly, than the top and subsoils of the ungrazed site. The concentrations of all heavy metals were higher in the long-term moderate grazed pasture than the ungrazed site, but not necessarily statistically significant. The uppermost soil layer contained higher amounts of metals compared with the lower layer [23]. The concentrations of all heavy metals decreased with an increase in soil depth, although not necessarily statistically significant (Table 4).

Heavy metal concentrations in the soil were not affected ($P>0.05$) by short-term (1.5 years) heavy grazing treatment or by soil sampling depth (except Mn and Zn) or their interactions (Table 5). In other words, there was no significant difference at the 5% level between heavy metal concentrations in the soils of the short-term heavily grazed farm and ungrazed sites. Only the concentrations of Mn and Zn in the surface soil at 159.6 and 128.7%, respectively, were greater ($P<0.05$) than the subsurface soil in this farm. However, Fe, Mn, Cr, and Zn content in the surface soil of the grazed site were greater, but not significantly, than the surface soil of the ungrazed site in this farm (Table 5).

Discussion

The Council of the European Communities presented maximum permitted concentration of heavy metals in grassland soils [24]. In Malaysia, however, there are currently no soil quality reference values for heavy metals or toxic metals [2]. Thus, it is necessary to establish maximum limits (MLs) of heavy metals found in soils commonly used for agricultural production in Malaysia [25]. The "investigation level" of heavy metals for Peninsular Malaysia was introduced in 2004 [2]. The recommended limits were established to guarantee the sustainable development of the natural environment [23]. Mean heavy metal concentrations in the soils of the grazed pastures are listed in Table 6. All values of heavy metals in the studied pastures were below European Union legislated limits and the proposed "investigation level" for Malaysia. The results offer an obvious indication that the excreta from grazing cattle are a significant source of heavy metals in the soil of pastures under long-term grazing. However, the concentrations of metals in the soil of pastures was maintained within the normal range and the level of metals in the soil was not high enough to be dangerous from the toxicological point of view in the TPU catchment, which had been grazed for

Table 5. Effects of short-term heavy grazing by cattle on the heavy metals concentrations (mg/kg) of the pasture soils.

Heavy metals	Non-grazed	Grazing	SE*	Soil depth (cm)		SE	Treatment × depth					
							0-10		SE	10-20		SE
				0-10	10-20		Grazing	Non-grazed		Grazing	Non-grazed	
Cd	0.022	0.009	0.01	0.02	0.01	0.01	0.015	0.027	0.014	0.003	0.017	0.08
Fe	235.24	222.0	29.36	257.22	200.00	39.56	272.72	241.73	40.89	171.37	228.75	27.48
Mn	3.20	2.78	0.93	4.31[a]**	1.66[b]	0.91	4.45	4.18	1.15	1.11	2.22	0.61
Cu	0.367	0.264	0.08	0.38	0.25	0.11	0.36	0.38	0.11	0.16	0.34	0.085
Cr	0.146	0.78	0.42	0.49	0.44	0.38	0.89	0.084	0.98	0.67	0.21	0.081
Pb	0.428	0.059	0.21	0.31	0.18	0.16	0.068	0.55	0.21	0.051	0.30	0.16
Zn	1.19	1.45	0.41	1.83[a]	0.80[b]	0.34	2.16	1.50	0.42	0.73	0.87	0.34

*standard error

**Means in a row with unlike lower case letters significantly differ at P<0.05.

more than 30 years. Thus, even those elevated values prove that the studied soils should be included in the group of uncontaminated soils [23]. The accumulation of heavy metals in the soil is one aspect of the sustainability of agro-ecosystems that can cause problems if certain concentration levels are exceeded [5, 26]. Therefore, prevention of the accumulation of heavy metals to a hazardous level is one of the prerequisites for sustainable agricultural production. It seems that long-term moderate grazing intensity is sustainable only in terms of the accumulation of heavy metals in the soil, but not in relation to metal bioavailability (uptake by organisms) and chemical availability (leaching and mobility) in the TPU catchment. However, the assessment of sustainability of metals accumulation and cycle in agro-ecosystems has to be carried out over time by using sustainability indices [26].

The major sources of heavy metals in intensively managed pasture soils are mineral lick blocks, supplementary feed, animal manure and slurry application, mineral fertilizers, and weathering of parent materials [27, 28]. Although quantifying the contribution of each source to the metal content in the soil was outside the scope of this study, it seems that the application of fertilizers has no significant effect on the metal content of soils compared with other sources in this study. As discussed earlier, the TPU catchment ungrazed site had received more fertilizers than the grazed site. If the application of fertilizers had a significant effect, compared with other sources, a higher metal content in the ungrazed site would be expected than in the grazed site. High concentrations of heavy metals in grazed pasture soils may be attributable to other sources, including mineral blocks and PKC consumption by cattle and discharge of some parts of mineral nutrients to soils through defecation and urination. The high content of Fe, Mn, and Zn in the soils of the grazed site may be attributable to the high concentration of these elements in mineral blocks and PKC. Regardless of grazing management, it should be noted that the high concentration of Fe in the soils of both study areas is associated with soil types in tropical regions that are higher in Fe and Al content. Therefore, a high content of this element in tropical soils is not necessarily due to anthropogenic manipulation. These findings should be used to initiate further investigation of the sources for the metals in the pastures under cattle grazing.

Table 6. Heavy metals concentrations of the pasture soils compared with European [24] and Malaysian [2] maximum limits.

Grazing treatment	Soil depth (cm)	Mean heavy metals concentration (mg/kg)						
		Cd	Cr	Cu	Fe	Mn	Pb	Zn
Long-term moderate grazing	0-10	0.10	0.26	0.61	1113.16	7.76	0.62	0.55
	10-20	0.037	0.41	0.34	689.15	3.73	0.56	0.26
Short-term heavy grazing	0-10	0.015	0.89	0.36	272.73	4.45	0.068	2.16
	10-20	0.003	0.67	0.16	171.37	1.11	0.051	0.73
'Investigation level' for Malaysia		0.300	60.00	50.00	NA	NA	65.00	95.00
EU limits (pH < 7.0)		1.00	100.00	50.00	NA	NA	50.00	150.00

NA – Not Available

As Table 4 shows, heavy metal concentrations in the surface layer of the grazed pasture soil were significantly higher than the same depth in the ungrazed pasture soil. The effect of livestock grazing on soil chemical properties tends to be confined to the upper layers of soil, within 0-10 cm of the soil surface [29, 30]. Though the rooting depth of various grass species differs, the majority of grass roots generally occur in the top 12 cm of the soil [31, 32]. Consequently, the availability of metals for grass roots is increased in surface layer [12, 35]. As a result of long-term grazing, heavy metal concentrations in grass tissues may increase [7].

The results indicate that short-term heavy grazing by cattle has no significant effect on the heavy metal contents of pasture soils. The above results do not provide clear evidence that grazing cattle waste is a significant source of heavy metals in pasture soils in the short-term. Dairy cattle sludge for 1-4 years (short and medium term) had no significant effect on the heavy metal concentrations in the soils [7].

Conclusions

It can be concluded that long-term cattle grazing has a significant effect on heavy metal concentrations in soils in intensively managed pastures. However, short-term (1.5 years) heavy grazing does not lead to a significant accumulation of heavy metals in the soil of intensively managed pastures. The effect of livestock grazing on heavy metal concentrations was almost limited to the surface layer (0-10 cm depth) of pasture soils in which metal concentrations were significantly greater than the ungrazed pasture. The study shows that all the trace elements measured are still below the maximum limit (above which the soils are likely to be contaminated). Thus, the evidence for contamination by heavy metals in the soil by livestock grazing is not clear. However, monitoring of the current environmental quality of pasture soils in terms of heavy metal accumulation should be done continuously to make sure that the levels remain low. Moreover, it is necessary to take into account that cattle manure and slurry are applied to pastures periodically, and metal accumulation occurs gradually and continuously over time; this brings about increased biotransfer to vegetation, animals and, finally, to humans. Therefore, it is important to regulate the management and application of metal-rich slurries, by both decreasing the quantity of trace metals supplied to cattle and the fertilizing application rates, which in most cases are not regulated [28]. Despite the potential impact of year-long livestock grazing on the heavy metal content of soil in intensively managed pastures, this subject has received limited attention to date and, consequently, little is known about the effects of free grazing on the metal content of soil in intensively managed pastures. This study was carried out as an attempt to answer such questions.

Acknowledgements

Funding for this project was provided by University Putra Malaysia (UPM). We express our appreciation to Mayudin Othman and Sarimah Hashim, from the Land Management Department of University Putra Malaysia for assistance with soil analysis.

Nomenclature

DM – Dry Matter
PKC – Palm Kernel Cake
MLs – Maximum Limits
NA – Not Available
SE – Standard Error
EU – European Union
TPU – Taman Pertanian Universiti

References

1. ABRAHAMS P.W., STEIGMAJER J. Soil Ingestion by Sheep Grazing in the Metal Enriched Floodplain Soils of Mid-Wales. Environ. Geochem. Hlth. **25**, 17, **2003**.
2. ZARCINAS B. A., CHE FAUZIAH I., MCLAUGHLIN M. J., COZENS G. Heavy Metals in Soils and Crops in Southeast Asia. 1. Peninsular Malaysia. Environ. Geochem. Hlth. **26**, 343, **2004**.
3. NICHOLSON F., CHAMBERS B., ALLOWAY B., HIRD A., SMITH S., CARLTON-SMITH C. An Inventory of Heavy Metal Inputs to Agricultural Soils in England and Wales. In Proc. of the 16th World Congress of Soil Science. Montpellier, France. **1998**.
4. AITKEN M.N. Short Term Leaf Surface Adhesion of Heavy Metals Following Application of Sewage Sludge to Grassland. Grass and Forage Sci. **52**, 73, **1997**.
5. ALLOWAY B.J. Heavy Metals in Soils, 2nd ed, Blackie Academic and Professional, London. **1995**.
6. NICHOLSON F.A., CHAMBERS B.J., WILLIAMS J.R., UNWIN R.J. Heavy Metal Contents of Livestock Feeds and Animal Manures in England and Wales. Bioresource Technol. **70**, 23, **1999**.
7. LO´PEZ-MOSQUERA M.E., MOIRON C., CARRAL E. Use of Dairy-Industry Sludge As Fertiliser for Grasslands in Northwest Spain: Heavy Metal Levels in the Soil and Plants. Resour. Conserv. Recy. **30**, 95, **2000**.
8. DE MATOS A. T., FONTES M. P. F., DA COSTA L. M., MARTINEZ M. A. Mobility of Heavy Metals As Related to Soil Chemical and Mineralogical Characteristics of Brazilian Soils. Environm. Pollut. **111**, 429, **2001**.
9. SOMMERS L.E. Chemical Composition of Sewage Sludges and Analysis of Their Potential Use as Fertilizers. J. Environ. Qual. **6**, 225, **1977**.
10. BLASER P., ZIMMERMANN S. Determining Inorganic Contaminants in Soil. In R. Schulin et al. (Ed.) Soil Monitoring: Early Detection and Surveying of Soil Contamination and Degradation. Birkhauser Verlag, Berlin. **201**, **1993**.
11. MARTIN M.H., COUGHTREY P.J. Biological Monitoring of Heavy Metal Pollution. Applied Science Publishers, London, **1982**.
12. WILKINSON J. M., HILL J., PHILLIPS C. J. C. The Accumulation of Potentially-Toxic Metals by Grazing Ruminants, Proc. the Nutr. Soc. **62**, 267, **2003**.
13. MEHLICH A. Determination of P, Ca, Mg, K, Na and NH_4; mimeo North Carolina Soil Test Division: Raleigh, NC, **1953**.

14. MEHLICH A. New extract for soil test evaluation of phosphorus, potassium, magnesium, calcium, sodium, manganese and zinc. Commun. Soil Sci. Plant Anal. **9**, 477, **1978**.
15. ISAAC R.A., KERBER J.D. Atomic Absorption and Flame Photometry: Techniques and Uses in Soil, Plant, and Water Analysis. In: L.M. Walsh (Ed.) Instrumental Methods for Analysis of Soils and Plant Tissue. Soil Science Society of America, Madison. 17, **1971**.
16. MAYS P.A., EDWARDS G.S. Comparison of Heavy Metal Accumulation in A Natural Wetland and Constructed Wetlands Receiving Acid Mine Drainage. Ecol. Eng. **16**, 487, **2001**.
17. KINNEAR P.R., GRAY C.D. SPSS for Windows Made Simple Release 10. Psychology Press, East Sussex, United Kingdom. **2001**.
18. BAUAR A., COLE C. I., BLACK A. L. Soil Property Comparisons in Virgin Grasslands Between Grazed And Non-Grazed Management Systems. Soil Sci. Sot. Amer. J. **51**, 176, **1987**.
19. BAUER A., BLACK A. L. Soil Carbon, Nitrogen, and Bulk Density Comparisons in Two Cropland Tillage Systems After 25 Years In Virgin Grassland. Soil Sci Sot. Amer. J. **45**, 1166, **198l**.
20. FRANK A.B., TANAKA D.L., HOFMAN L., FOLLETT R.F. Soil Carbon and Nitrogen of Northern Great Plains Grasslands as Influenced by Long Term Grazing. J. Range Manage. **48**, 470, **1995**.
21. LIEBIG M.A., GROSS J.R., KRONBERG S.L., HANSON J.D., FRANK A.B., PHILLIPS R.L. Soil Response to Long Term Grazing in The Northern Great Plains of North America. Agr. Ecosyst.Environ. **115**, 270, **2006**.
22. WIENHOLD B.J., HENDRICKSON J.R., KARN J.F. Pasture Management Influences on Soil Properties in the Northern Great Plains. J. Soil Water Conserv. **56**, 27, **2001**.
23. JANOWSKA E., CZĘPIŃSKA-KAMIŃSKA D. Trace Elements Dynamics in the Upper Soil Horizons of the Puszcza Kampinoska Biosphere Reserve. Pol. J Environ. Stud. **13**, 367, **2004**.
24. Council of the European Communities. The Protection of the Environment, and in Particular of the Soil, When Sewage Sludge Is Used in Agriculture. J. Eur. Communities. **181**, 6, **1986**.
25. KHANIF, Y.M., SALMIJAH, S. Contaminants and the soil environment in Malaysia. In R. Naidu et al. (Ed.) Contaminants and the Soil Environment in the Australasia-Pacific Region. Kluwer Academic Publishers, Dordrecht. 563, **1996**.
26. MOOLENAAR S. W., VAN DER ZEE S., LEXMOND T. M. Indicators of the Sustainability of Heavy Metal Management in Agro-Ecosystems. Sci. Total Environt. **201**, 155, **1997**.
27. FRANCO-URÍA A., LÓPEZ-MATEO C., ROCA E., FERNÁNDEZ-MARCOS M. L. Source Identification of Heavy Metals in Pastureland by Multivariate Analysis in NW Spain. Journal of Hazardous Materials. **165**, 1008, **2009**.
28. QISHLAQI A., MOORE F. Statistical Analysis of Accumulation and Sources of Heavy Metals Occurrence in Agricultural Soils of Khoshk River Banks, Shiraz, Iran. American-Eurasian J. Agric. & Environ. Sci. **2**, 565, **2007**.
29. AWETO A.O., ADEJUMOBI D.O. Impact of Grazing on Soil in the Southern Guinea Savanna Zone of Nigeria. Environmentalist. **11**, 27, **1991**.
30. KAMARUZAMAN J. Influence of Sheep Grazing on Soil Chemical Properties and Growth of Rubber (*Hevea brasiliensis*) in Malaysia. Agroforest. Syst. **7**, 115, **1988**.
31. POWER J. F. Seasonal Changes in Smooth Bromegrass Top and Root Growth and Fate of Fertilizer Nitrogen. Agron. J. **80**, 740, **1988**.
32. BEYROUTY C.A., WEST C.P., GBUR E.E. Root Development of Bermudagrass and Tall Fescue as Affected by Cutting Interval and Growth Regulators. Plant Soil. **127**, 23, **1990**.
33. YEONG S. W., MUKHERJEE T. K., HUTAGULUNG R. I. The Nutritive Value of Palm Kernel Cake as A Feedstuff for Poultry. In Proc. of the National Workshop on Oil Palm By-products Utilization. Kuala Lumpur, Malaysia. 100, **1983**.
34. CHLÁDEK G., ZAPLETAL D. A free-choice intake of mineral blocks in beef cows during the grazing season and in winter. Livestock Science. **106**, 41, **2007**.
35. MARSCHNER H. Mineral Nutrition of Plants. Academic Press, London, **1995**.