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ORIGINAL PAPER

Cycle of heavy metals in the soil of livestock farms in an acidic zone of the central region of Thailand*

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Abstract

The purpose of the present study was to examine the connections between heavy metal concentrations in the soil, pasture grass, and livestock manure on farms located in an acidic soil zone of central Thailand. Samples of the soil, grass, and livestock manure were collected from three farms, and were tested for Cd, Pb, As, and Hg. Multiple indicators were employed to assess the pollution levels of the farm soils. The results showed that the amounts of heavy metals in the soil were in the order Pb > Hg > Cd > As; in grass the order was Pb > As > Cd > Hg, and in livestock manure this was Pb > As > Hg > Cd. The soil pH level influenced the quantities of Hg and Ag in the soil. Concerning individual indicators, *Igeo* and *CF* indices showed that Hg was present at high levels in farm soils, but an integrated indicator PLI was less than 1, suggesting that soil in the farms was not significantly contaminated, in contrast to the individual indicators. Heavy metal accumulation depended on the species of grass, and the element content in manure was higher than in grass used for feeding the animals, including supplements given to animals by farmers. However, the levels of Cd in the livestock farms demonstrated a relationship among soil, grass, and manure. The heavy metals in manure from animal farms were below the thresholds at which they could be utilized as a soil amendments for organic farming or for safe food production. However, the heavy metals in the farm soil could possibly be dispersed to other locations.

Keywords: acidic soil, cadmium, livestock farm, soil pollution risk assessment

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INTRODUCTION

The three main factors affecting heavy metal pollution in natural soils are as follows: (1) the origin of the soil, (2) land use activities such as proximity to industrial or transportation facilities, and (3) airborne transmission. Thailand has set standards for heavy metal contamination in soil, especially soil in residential and agricultural areas, according to the Enhancement and Conservation of the National Environmental Quality Act B.E. 2535 (1992). These standards cover arsenic (As), cadmium (Cd) and cadmium compounds, hexavalent chromium (Cr^{+6}), lead (Pb), manganese (Mn) and manganese compounds, mercury (Hg) and mercury compounds, and nickel (Ni) compounds in the form of water-soluble salts (Pollution Control, 2009).

Benthic plants and weeds have the ability to take up heavy metals (Sulaiman, Hamzah 2018, Zakaria et al. 2021, Haddad et al. 2023). These heavy metals are accumulated in the plant stems, leaves, and roots (Shu et al. 2004, Kumar et al. 2013, Wang et al. 2020). The elements can be present in fodder used as animal feed, being chewed as cud or directly eaten by ruminants. Several heavy metals are essential trace elements in livestock feeds, such as iron (Fe), copper (Cu), manganese (Mn), and zinc (Zn), which are listed as macronutrients for ruminants (Poulsen 1998, Hill, Shannon 2019, Brugger et al. 2022). Livestock that consume excessive amounts of heavy metals will excrete these in urine and manure (Morse et al. 1992, Goff 2018). The heavy metal content in livestock manure is affected by both feed and feed additives (Zhang et al. 2012, Irshad et al. 2013, Hejna et al. 2019), and thus given the cycles indicated above, it is possible that heavy metal contaminated soils have an impact on the production of animal feeds (Ajorlo et al. 2010, Diaz-Uribe et al. 2015, Kozhanova et al. 2021).

The soil acidity of Thailand, especially in the central region where there has been accumulation of Fe and Se (Kroeksakul et al. 2021), can influence the content of heavy metals in the soil. There is a relationship between microorganisms in the soil and the uptake of elements by grasses (Adamczyk-Szabela Wolf 2022, Naz et al. 2022). As a result, soil pH may impact heavy metal accumulation in livestock feed. Therefore, a relevant research question is whether the use of cow dung as manure fertilizer from locations with high concentrations of heavy metals will result in heavy metals spreading to other areas. This is an especially valid question in the context of food safety and organic agriculture. These aspects of agriculture are on the national agenda of Thailand, and the usage of manure from sources that accumulate heavy metals will have an effect on the production system. The main objective of the present study was to examine the connections between the soil, pasture grasses, and livestock manure and the heavy metal cycle. The results are significant in that they demonstrate how productivity in organic farming may be improved in the future.

MATERIAL AND METHODS

Study site and samples collection

Three farms were selected as the study sites; in Universal Transverse Mercator coordinates (UTMs) their locations were farm 1, limit Zone 47, 712872.96E 1555791.26N; farm 2, limit Zone 47, 713010.28E 1555172.85N; farm 3, limit Zone 47, 714201.10E 1555477.01N. These three farms were all dedicated to raising water buffalo, and the open-system farming meant that the animals were released onto pasture for grazing. The grasses on the farms were naturally occurring.

Soil samples were collected from pastures on the farm by gathering them from the soil surface, not exceeding a depth of 10 cm. Twelve points were selected on every farm's pasture, with approximately 200 g collected from each point. All the samples were placed in a bag to be taken to the laboratory.

Grass samples were collected from the same 12 points as the soil samples, each weighing approximately 200 g (fresh weight). These samples were placed in a bag and taken to the laboratory, where they were cleaned, and the stems and roots were separated for further analysis.

Manure was collected fresh from the cattle pen, approximately 12 kg per farm. The samples were placed in a bag and taken to the laboratory.

Soil properties

The analyses of soil pH and electrical conductivity (EC) were performed using a solution technique (Nadler, Frenkel 1980, Carmo et al. 2016). The soil samples were dissolved in water in a 1:2 ratio, with 5 g of soil in 10 ml of deionized water shaken for 30 minutes. Samples were allowed to settle for 30 minutes before the pH was measured using a Hach HQ40D portable multimeter (Loveland, CO, USA), and the EC was checked via a solution method using a Eutech CON700 electrochemistry instrument (Eatontown, NJ, USA).

Sample extraction and element analysis

Soil preparation: the soil samples were dried in a 105°C hot air oven for 72 hours and then ground in a mortar and pestle. A 10 mm sample of sifted soil was made and kept in a refrigerator at a temp. of 4°C.

Grass preparation: the grass was washed and chopped to a size of 3-5 cm before being dried in a 45°C hot air oven for 120 hours, and then ground using a mixer (Sharp, Thailand). A 10 mm sample of sifted soil was made and kept in a refrigerator at a temp. of 4°C.

Manure preparation: the manure samples were dried in a 60°C hot air oven for 120 h and then ground in a mortar and pestle. A 10 mm sample of sifted soil was made and maintained in a refrigerator at a temp. of 4°C.

As, Cd, Pb, and Hg were extracted from the samples for analysis via inductively coupled plasma – optical emission spectrometry (ICP–OES) using 2 g soil samples in concentrated hydrofluoric acid (HF), perchloric acid ($HClO_4$), and nitric acid (HNO_3) at a ratio of 1:1:1 and in a volume of 20 ml. The extractions were performed at ~500°C in a SpeedDigester K-425 (Buchi; Flawil, Switzerland) until dry. Each residue was rinsed with 1% HNO_3 and then passed through filter paper. The filtrate was transferred to a 50 ml volumetric flask, and 1% HNO_3 was added for continued inductively coupled plasma (ICP) analysis using a PlasmaQuant 9100 series ICP–OES (Analytik; Jena, Germany). The results were consistent with the quality control standards, and the recovery rates for heavy metals ranged from 70% to 125%.

Quality assurance and quality control (QA/QC) procedures ensured that all samples as well as duplicates and blanks were collected, processed, and examined in the laboratory. Samples were compared to the ICP multielement standard solutions from AccuStandard (USA). An ICP-OEM blank and a quality control sample were run after every fifteen soil samples. An additional identical sequence was run using replicated material.

Soil pollution risk assessment for the livestock farms

For the assessment of heavy metal pollution risk, the geoaccumulation index (I*geo*) originally formulated by Muller (1980) was employed; this index is a quantitative measure of pollution in sediment. The index was developed through the understanding of the lithogenic effect. The value of *Igeo* was calculated from the following formula:

$$I_{geo} = log_2[C_n / 1.5\ B_n] \tag{1}$$

where: C_n is the measured concentration of an element in the sediment, and B_n is the background value of the element. The interpretation of the values of *Igeo* is: < 0 = not polluted, 0−1 = not polluted to moderately polluted, 1−2 = moderately polluted, 2−3 = moderately to strongly polluted, 3−4 = strongly polluted, 4−5 = strongly to extremely polluted, and > 5 = extremely polluted.

The enrichment factor (*EF*) was calculated from the following formula:

$$EF = (C/RE)\ sample\ /\ (C/RE)\ background \tag{2}$$

where: (C/RE) sample is the ratio of the concentration (C) of an element to a reference element (RE) in the sample, and (C/RE) background is the ratio of the concentration (C) of an element to a reference element (RE) present in the background. Aluminum (Al) was used as the reference element, as it is a major component of clay, and the interpretation of the values of EF is: < 2 = deficiency of mineral enrichment, 2−5 = moderate enrichment, 5−20 = significant enrichment, 20−40 = very high enrichment, and > 40 = extremely high enrichment.

The concentration factor (CF) is approximated as the ratio of the observed concentration of an element in the sample (Ci) to the background level of the same element (Cb). The concentration factors were calculated as follows:

$$CF = Ci/Cb \tag{3}$$

The interpretation of the values of CF is: < 1 = low pollution level, 1–3 = moderate pollution level, 3–6 = considerable pollution level, and > 6 = very high pollution level.

The background element values for the *Igeo, EF*, and *CF* calculations were taken from standard references and were as follows: As = 26, Cd = 1.7, Pb = 55 (Land Development Department, 1995), and Hg = 0.02 (UNEP, 2002).

After calculating the concentration factors, they were used to calculate the pollution load index (PLI) that indicates the general contamination level. The formula for PLI is as follows:

$$PLI = \sqrt[n]{CF_1} \times CF_2 \times CF_3 ... \times CF_n \tag{4}$$

where: CF_i is the contamination factor of the *i*th element and n is the number of observed elements. The interpretation of the values of PLI is: 0 = perfection, < 1 = baseline level, and >1 = polluted.

Statistical analysis

The data were analyzed using one-way analysis of variance (ANOVA), and means were compared using the least significant differences (LSD) between a soil property and the soil layer of the study site. Correlations between soil property were assessed using the Spearman's rank correlation coefficient (r). All analyses were performed using the SPSS v.22 (IBM; Armonk, NY, USA) and SigmaPlot v.12.0 (Systat; Chicago, IL, USA) software. Results with $p<0.05$ were considered statistically significant.

RESULTS AND DISCUSSION

Soil properties

The soil pH averaged 4.04 (±0.02), and the EC of all farms averaged 570 (±408) μS cm^{-1} (Table 1). Farm 2 had an EC value that was significantly different ($p<0.05$) from those of the other farms. The soil moisture average was 20.11 (±3.36)%, and the soil moisture was significantly different ($p<0.05$) among farms in the order Farm 2 > Farm 1 > Farm 3. The bulk density average was 0.53(±0.08) g cm^{-3}, and the bulk densities were significantly different ($p<0.05$) among farms in the order farm 2 > farm 1 > farm 3.

Table 1

The physical properties of soil in the livestock farms

Indicator	Farms			Average
	1	2	3	
Soil pH in H_2O	4.02(±0.02)	4.05(±0.03)	4.05(±0.00)	4.04(±0.02)
Soil EC (µS cm^{-1})	394(±105)^a	1059(±314)^b	257(±59)^a	570(±408)
Soil moisture (%)	18.70(±0.18)^a	24.45(±0.75)^b	17.18(±0.25)^c	20.11(±3.36)
Bulk density (g cm^{-3})	0.49(±0.00)^a	0.65(±0.02)^b	0.45(±0.00)^c	0.53(±0.08)

The content of heavy metals in the soil

The soil content of Cd averaged 1.46 (±0.02) mg kg^{-1} and was significantly different (p<0.05) among the farms in the order farm 2 > farm 3 > farm 1 (Table 2). The Pb content of the soil averaged 3.57 (±1.08) mg kg^{-1} and was

Table 2

Heavy metal content in the soil of livestock farms in the acidic soil zone of central Thailand

Heavy metals (mg kg^{-1})	Farms			Standard*
	1	2	3	
Cd	1.43(±0.002)^a	1.49(±0.002)^b	1.47(±0.004)^c	77
Pb	3.75(±0.280)^a	4.67(±0.464)^b	2.31(±0.030)^c	400
Hg	1.49(±0.215)	1.49(±0.224)	1.89(±0.072)	23
As	0.08(±0.007)^a	2.30(±0.312)^b	0.02(±0.016)^a	3.9

* Standard from soil land use for residential and agricultural of Pollution Control Department (2009).

significantly different (p<0.05) among farms in the order farm 2 > farm 1 > farm 3. The As content averaged 0.89 (±1.27) mg kg^{-1} and was significantly different (p<0.05) among farms in the order farm 2 > farm 1 > farm 3. The Hg content averaged 1.62 (±0.27) mg kg^{-1}. However, the total heavy metal content in the soil did not exceed the standard of the Pollution Control Department (2009).

The *Igeo, EF*, and *CF* indices for the soil

The values of *Igeo* for the farm soils are listed in Table 3. The *Igeo* values for Cd, Pb, and As in all farms were below 0, meaning soil not polluted, but the *Igeo* values for Hg were all greater than 5, meaning that the soils were extremely polluted. The *EF* values for Cd, Pb, As, and Hg were below 2 for all farms, indicating a deficiency in mineral enrichment. The CF values of Cd, Pb, and As in all farms were less than 1, indicating a low pollution level. In contrast, the CF values for Hg were greater than 6, indicating a very high pollution level. However, the *PLI* index demonstrated that the

Table 3

The *Igeo, EF*, and *CF* values of heavy metals in the soil

Indicators	Farms	Heavy metals			
		Cd	Pb	As	Hg
Igeo	1	-0.825	-4.45	-8.85	5.64
	2	-0.775	-4.14	-3.92	5.64
	3	-0.789	-5.15	-10.9	5.97
	average	-0.796	-4.58	-7.90	5.754
EF	1	0.013	0.426	0.201	0.000
	2	-0.006	-0.035	-0.042	0.044
	3	0.022	0.001	0.001	1.940
	average	0.009	0.130	0.053	0.661
CF	1	0.846	0.068	0.003	74.9
	2	0.876	0.084	0.098	74.9
	3	0.867	0.042	0.001	94.5
	average	0.863	0.065	0.034	81.4
PLI = 0.004					

general contamination level was 0.004; as this is well below than 1, the soils of the livestock farms would meet the unpolluted standard.

Heavy metals in grass

The grass species fed to animals varied among the farms (Table 4). Farm 1 had Para grass (*Brachiaria mutica*), farm 2 had Bermuda grass (*Cynodon dactylon* L.), and farm 3 had Torpedo grass (*Panicum repens*). The levels of Cd and Pb in the Bermuda grass were highly significant (p<0.05) compared to the Para grass and Torpedo grass, but As and Hg were not significantly different between the species.

The heavy metal accumulation was compared between the stems and roots in the Para grass and Torpedo grass (Table 5). The Cd in the roots was

Table 4

Concentrations of heavy metals in grasses of the livestock farms

Grass species	Heavy metals (mg kg^{-1})			
	Cd	Pb	As	Hg
Para grass	1.46(±0.022)^a	3.50(±0.456)^a	1.82(±4.38)	1.12(±0.572)
Bermuda grass	1.54(±0.072)^b	22.60(±21.2)^b	2.49(±5.36)	1.16(±0.489)
Torpedo grass	1.44(±0.009)^a	2.73(±0.367)^a	2.44(±3.10)	1.52(±0.547)
Average	1.48(±0.059)	9.63(±14.9)	2.25(±4.12)	1.27(±0.537)

^{ab} The mean in row differences is significant at the 0.05 level (*LSD* test).

Table 5

The accumulation of heavy metals in grasses: comparison between stems and roots

Grass species	Organs	Heavy metals (mg kg^{-1})			
		Cd	Pb	As	Hg
Para grass	stem	1.44	3.38	3.62	1.36
	root	1.48	3.62	0.026	0.892
T-test		0.006	0.633	0.419	0.55
Bermuda grass	stem	1.6	41.6	4.46	1.48
	root	1.48	3.63	0.513	0.841
T-test		0.035	0.01	0.49	0.056
Torpedo grass	stem	1.43	2.42	2.5	1.85
	root	1.45	3.04	2.37	1.18
T-test		0.051	0.076	0.928	0.22

significantly greater (p<0.05) than in stems, whereas for Bermuda grass the Cd in the stems was significantly greater (p<0.05) than in the roots. For the Bermuda grass, Pb in the stems was highly significantly different (p<0.05) from that in the roots, but there were no significant differences in Pb content between roots and stems of Para grass or Torpedo grass. The As and Hg content between the roots and stems of grasses was not significantly different (Table 5).

The content of heavy metals in manure

The average content of heavy metals in livestock manure was 1.47 (±0.011) mg kg^{-1} for Cd, 3.60 (±0.383) mg kg^{-1} for Pb, 2.65 (±2.77) mg kg^{-1} for As, and 1.78 (±0.080) mg kg^{-1} for Hg. The Cd content in the manure of farm 2 and farm 3 was significantly greater (p<0.05) than on Farm 1, and the level of Pb in manure from farm 1 was significantly higher (p<0.05) than from farm 2 and farm 3 (Table 6).

Table 6

The content of heavy metals in livestock manure

Farm	Heavy metals (mg kg^{-1})			
	Cd	Pb	As	Hg
1	1.46 (±0.002)^{a}	4.00 (±0.300)^{a}	3.84(±4.55)	1.73(±0.075)
2	1.48 (±0.012)^{b}	3.58 (±0.104)^{b}	1.09 (±1.86)	1.78 (±0.021)
3	1.47 (±0.001)^{b}	3.21(±0.110)^{b}	2.74 (±0.937)	1.84 (±0.105)
Average	1.47 (±0.011)	3.60 (±0.383)	2.65 (±2.77)	1.78 (±0.080)

^{ab} The mean differences in rows are significant at the 0.05 level *(LSD)*.

Relationships among heavy metals in soil, grass, and manure

The correlations among soil pH, soil EC, and the heavy metals Cd, As, Pb, and Hg in soil, grass, and manure were measured (Table 7). Levels of soil pH were negatively correlated with As in soil (r=-0.768; p<0.05) and

Table 7

Correlation of heavy metals in soil, grass, and manure on livestock farm

Specification	Cd-soil	Pb-soil	As-soil	Hg-soil	Cd-grass	Pb-grass	As-grass
Cd-soil	1						
Pb-soil	0.133	1					
As-soil	0.688*	.794*	1				
Hg-soil	0.158	-.674*	-0.444	1			
Cd-grass	0.690*	0.687*	0.941**	-0.282	1		
Pb-grass	0.697*	0.721*	0.962**	-0.309	.957**	1	
As-grass	0.011	-0.051	0.010	0.198	0.247	0.292	1
Hg-grass	0.308	-0.583	-0.150	0.057	0.002	0.173	0.205
Cd-manure	0.776*	0.259	0.659	-0.074	0.603*	0.527	-0.298
Pb-manure	-0.653	0.563	0.004	-0.454	-0.021	-0.019	0.007
As-manure	-0.466	-0.051	-0.351	0.343	-0.359	-0.365	-0.256
Hg-manure	0.387	-0.264	-0.016	0.658	-0.004	-0.008	-0.113
pH-soil	0.520	-0.387	0.004	0.177	0.007	0.022	-0.012
Ec-soil	-0.079	-0.242	-0.214	0.136	-0.098	-0.147	0.489
	Hg-grass	Cd-manure	Pb-manure	As-manure	Hg-manure	pH-soil	Ec-soil
Hg-grass	1						
Cd-manure	0.285	1					
Pb-manure	-0.732*	-0.433	1				
As-manure	-0.514	-0.146	0.478	1			
Hg-manure	0.091	0.405	-0.363	0.224	1		
pH-soil	0.569	0.136	-0.768*	-0.774*	0.192	1	
Ec-soil	0.199	-0.182	0.087	-0.191	0.295	0.150	1

* Correlations significant at the 0.05 level (two-tailed test), ** Correlations significant at the 0.01 level (two-tailed test).

Hg in soil (r=-0.774; p<0.05). As and Cd in the soil were positively correlated (r=0.608; p<0.05). Pb in the soil (r=0.608; p<0.05), Cd in grass (r=0.941; p<0.01), Pb in grass (r=0.962; p<0.01), and the Cd in manure were corelated to Cd in soil (r=0.776; p<0.05). Cd in grass was corelated to Cd and Pb in grass (r=0.603; p<0.05 and r=0.957; p<0.01).

Factor analysis of heavy metal components in livestock farming in an acidic soil zone

A factor analysis of the parameters for the 14 components of the heavy metals in soil, grass, and manure was performed using principal component analysis (PCA). Four principal components had eigenvalues > 1; these explained 87.7% of the cumulative variance in the dataset (Table 8).

Table 8

The results of PCA of heavy metal components in farm soils

Component	PC1	PC2	PC3	PC4
Eigenvalue	4.79	3.86	1.96	1.66
% of variance	34.2	27.6	14.0	11.9
Cumulative (%)	34.2	61.8	75.8	87.7
Cd-soil	0.751	0.516	0.3564	-0.079
Pb-soil	0.725	-0.487	-0.419	-0.105
As-soil	0.983	-0.010	-0.143	-0.103
Hg-soil	-0.292	0.088	0.864	0.182
Cd-grass	0.964	-0.007	-0.075	0.129
Pb-grass	0.977	-0.010	-0.091	0.076
As-grass	0.112	-0.008	-0.011	0.899
Hg-grass	-0.146	0.855	0.041	-0.031
Cd-manure	0.666	0.276	0.332	-0.424
Pb-manure	-0.058	-0.869	-0.401	0.114
As-manure	-0.332	-0.770	0.418	-0.283
Hg-manure	0.106	0.077	0.902	0.008
pH-soil	0.033	0.893	0.060	0.091
Ec-soil	-0.130	0.099	0.159	0.771

Note: PC – principal component; an underlined factor loading was weighted when within 10% of the variation of the absolute value of the highest factor loading in each PC.

The percentages of the variance explained by the first four principal components were PC1 (34.2%), PC2 (27.6%), PC3(14%), and PC4 (11.9%). The As in grass was the most important contributor, for which the highest factor load was 0.983 in PC1, and PC1 included the factors As-soil > Pb-grass > Cd-grass > Cd-soil > Pb-soil > Cd-manure. For PC2, the factor loadings were pH-soil > Hg-grass, and for PC3 the factor loadings were Hg-manure > Hg-soil. For PC4 the factor loadings were As-grass > Cd-soil. The PC distributions are presented in Figure 1.

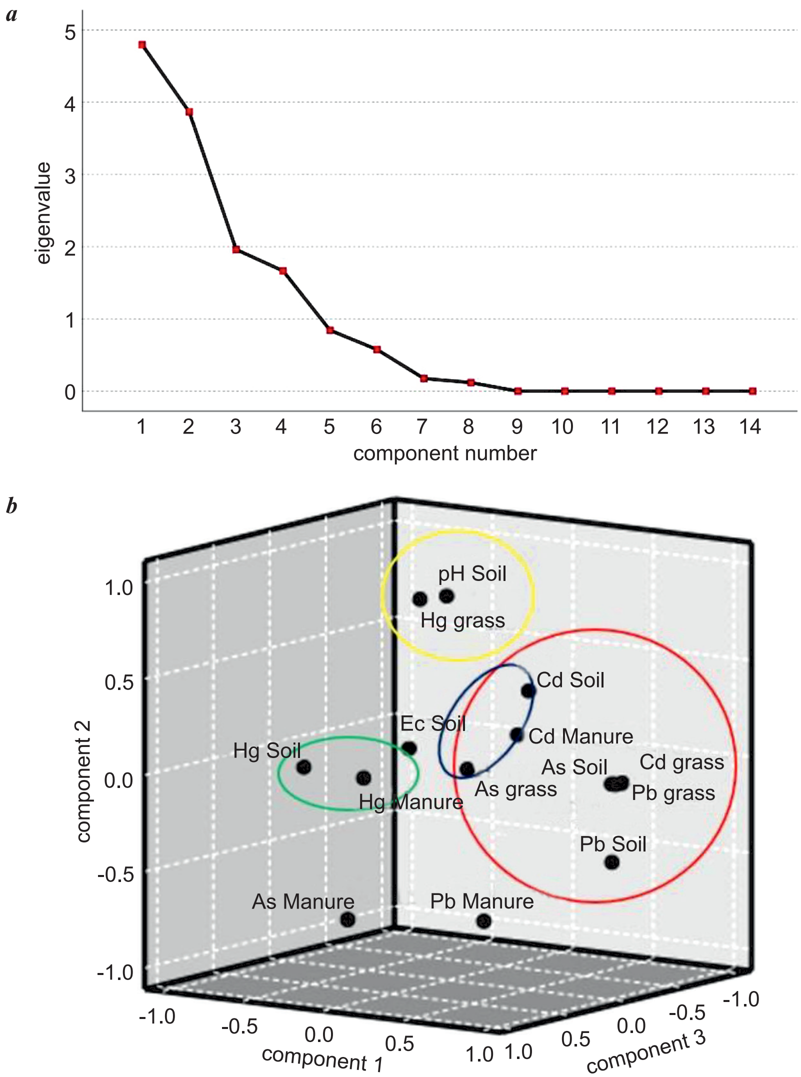

Fig. 1. Results of the PCA for heavy metal accumulation in the soil from livestock farms. *a* – the eigenvalues of components in the principal component analysis, *b* – the components of PC loadings, PC1 – the group in the red ellipse, PC2 – the group in the yellow ellipse, PC3 – the group in the green ellipse, and PC4 – the group in the blue ellipse

The relationship between soil acidity and heavy metal content

There was a negative correlation between soil pH and the quantities of As and Hg in the soil (Figure 2). The Hg content in the soil was related to adsorption, which depended on the soil pH. The Hg in the soil was in the form of Hg^{2+} (Yin et al. 1996, Yang et al. 2007, Jing et al. 2007), and thus the soil pH influenced the uptake of Hg (Yu et al. 2018). The release of arse-

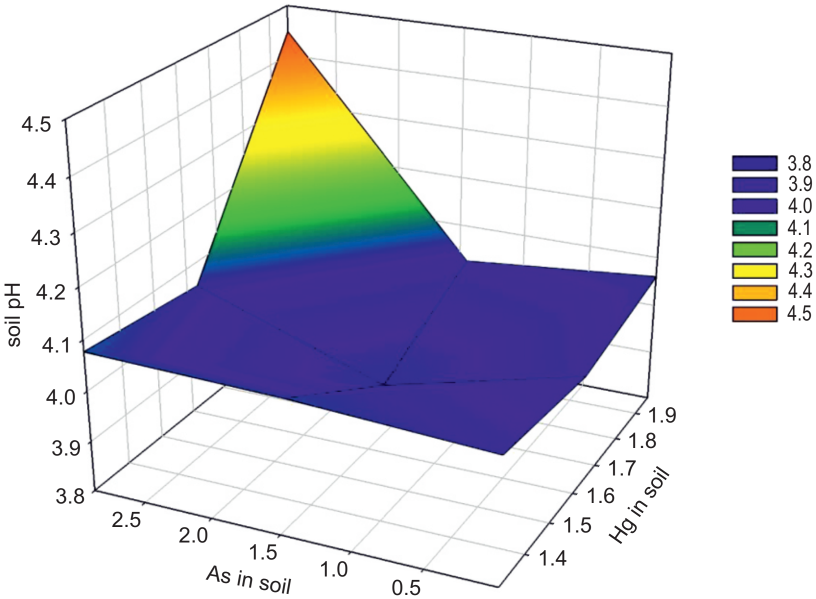

Fig. 2. The relationships between pH, As, and Hg in the soil of farms with acidic soil in central Thailand

nate compounds increases in low pH soils (Gersztyn et al. 2013), and soil pH is one of the most important factors in the uptake of As by plants (Marin et al. 1993, Anh et al. 2013).

The cycle of the Cd in soil, feed, and manure

The present study examined the cadmium levels in the soil, feed, and manure of livestock farms located in an acidic soil zone in central Thailand. The global average concentration of cadmium in the soil is 0.36 mg kg^{-1}, and it typically exists as the divalent metal Cd^{2+} that is mobilized in acidic environments (Kubier et al. 2019). Although the quantity of Cd in the soils examined herein was higher than the global average concentration (1.46:0.36 mg kg^{-1}), the quantity of Cd did not exceed the 77 mg kg^{-1} standard for residential and agricultural land use stipulated by the Pollution Control Department (2009). Despite being a common, non-essential trace element in the environment (Haider et al. 2021, Oliva et al. 2019), Cd hinders plants' ability to grow and function when present in high concentrations (Yaqun et al. 2005, Khanna et al. 2022). The Cd is transferred to the plant by interfering with the transport routes of trace elements, including the apoplastic and symplastic pathways, allowing it to enter through the roots and be disseminated to the plant's organs (Sterckeman, Thomine 2020, Lua, Zhang 2021). The quantity of Cd in livestock manure averaged 1.47 (±0.011) mg kg^{-1}, nearly identical to the levels of Cd in the soil (average 1.46 mg kg^{-1}) and grass (average 1.48 (±0.059) mg kg^{-1}). The cycle of Cd in the farm is illustra-

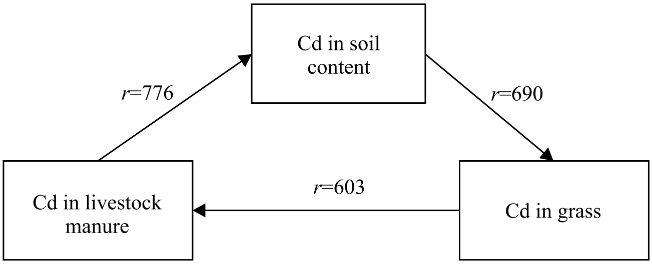

Fig. 3. The cycle of Cd in a livestock farm in central Thailand.

ted in Figure 3, which shows that cattle can excrete Cd by urination and defecation and thereby contaminate the animal feeding (van der Fels-Klerx et al. 2011; Lane et al. 2015) if the amount of Cd in the feed is too high.

CONCLUSIONS

The present study confirmed that the levels of Cd, Pb, Hg, and As in the soils of the cattle farms were not above the upper limits established by the Thailand Pollution Control Department. However, the soil pH had varied effects on the quantity of As and Hg contents of the soil. The single indicators *Igeo* and *CF* suggested that Hg in the farm soils was present at high pollution levels, but the integrated indictor *PLI* was less than 1. The heavy metal accumulation depended on the grass species; the Bermuda grass accumulated higher amounts of Pb and Cd than Para grass and Torpedo grass. The heavy metal content in manure was higher than that in the grass used as a feed by the animals; the latter depends on the mineral content in surface water and groundwater. Cd is a heavy metal present in the soil, feed, and manure of livestock farms. The heavy metals in the farm soil that could be transferred to other places occur in manure, but in this study the quantity of heavy metals in manure from the farms was below the level at which the manure could still be used as an amendment for organic farming.

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