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Evaluation of Properties and Elements in the Surface of Acidic Soil in the Central Region of Thailand

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ABSTRACT

The study aimed to evaluate and correlate acidic soil components to understand the phenomena of this type of soil. The soil samples were collected from 64 locations in 3 provinces of central Thailand and were tested for soil pH, element content, soil organic matter (SOM), and soil organic carbon (SOC). The results show that soil acidity in central Thailand has an average pH of 4.71 ± 0.87. The soil acidity level ranges from very strongly acidic in Phatum Thani and Nakhon Nayok provinces to strongly acidic in Chachoengsao province. Soil bulk density is about 0.34 g/cm^3, and the correlation of soil pH to lead (Pb), nickel (Ni), nitrogen (N), carbon-to-nitrogen ratio (C/N ratio), and zinc (Zn) is as follows: principle component 1 (PC1) is carbon-to-nitrogen ratio > pH > zinc (C/N ratio > pH > Zn), and principle component 2 (PC2) is soil organic carbon > bulk density > soil organic matter (SOC > BD > SOM). Soil pH, SOM, and SOC are in similar groups. The soil abundance at the study site was compared with the ideal soil for plants, and heavy metal contamination in the acidic soil of the central region did not exceed the standard limit. The study found a correlation between SOM and SOM (r = 0.715; p < 0.01), indicating soil quality and microbial activity.

Keywords: Acidic soil, central region, soil component, soil property

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INTRODUCTION

Soil is the main factor for success in agricultural production (Amenyan, 1988). Highly fertile soil produces a good agricultural yield (Parikh & James, 2012), and soil with a pH below 5.5 will affect plant growth rate (Neina, 2019). Soil with a pH below 5.5 is considered acidic, so acidic soil covers about 3.95 million km^2, or 27% of the world's land surface (von Uexküll & Mutert, 1995). In Asia, acidic soil covers about 1.04 million km^2 or 26% of the total area of acidic soil in the world (Van Ranst et al., 2004). In Thailand, sulfur is present on the soil surface (depth > 5 cm) in about 8,904.5 km^2, or approximately 0.000086% of the Asian acidic soil area. It is distributed throughout the country's central region, representing 5,097.4 km^2, or 57.2% of the acidic soil in Thailand (Research and Development for Land Management Division, 2006).

The influence of soil acidity on various aspects of crop production, including growth, biomass allocation, nutrient uptake, mycorrhizal colonisation (Soti et al., 2015), and plant stress (Haling et al., 2011), is minimal. However, acidic soil may have a positive effect on the growth of some plants, such as tea and palm oil (Chien et al., 2019; Ho et al., 2019), and soil pH affects the mineralisation of organic material in the origin soil (parent soil) (Conyers et al., 1995).

Acidic soil covers the surface of the central region of Thailand in the irrigation zones and agricultural areas of Nonthaburi, Phathum Thani, Phanakhonsri Ayuthaya, Nakhon Nayok, and Chanchoengsao provinces. The water supply is essential to agricultural production in acidic soil zones because it affects the ion exchange between a liming material, such as calcium carbonate, and water, forming a hydroxyl group (OH^-) ion or the oxidation of organic sulfur (S) to sulfate ion (SO_4^{2-}) accompany by an equivalent quantity of hydrogen anion (H^+) (Freedman, 1995; Sparks, 2003). Without water, soil acidity will be a more significant factor in supporting agriculture in the area of bulk density (BD) when considering pores in the soil, soil organic matter (SOM), and soil organic carbon (SOC) along with organic fertility or soil biomass (Bautista et al., 2016) and multi-element. Therefore, it will also support agricultural production in acidic soil zones (Joris et al., 2013).

The objective of this study was to evaluate the relationship among acidic soil properties and analyse soil properties such as pH, percentage of wet material in the soil, soil electrical conductivity (EC), soil moisture, BD, SOM, and SOC in Thailand's central region. In addition, this study also looks at element compounds in acidic soil and considers the correlation of these soil components. This information is essential in understanding the physiochemical phenomena of acidic soil in this zone and the influence of elements on plant nutrients, including heavy metals (Fontes & Alleoni, 2006), so that techniques may be developed to improve future soil quality in the country.

MATERIALS AND METHODS

Study Sites

This study covers acid zones in 5 districts of 3 provinces: (1) In Nong Suea district in Pathum Thani province, 21 soil samples were collected from 7 zones; (2) in Ongkharak and Banna districts in Nakhon Nayok province, 21 samples were collected from 7 zones; and (3) in Bangnampraw and Muang districts in Chachoengsao province, 22 samples were collected from 7 zones. The study site focused on the agriculture area on the acidic soil map provided by the Land Development Department of Thailand, as presented in Figure 1 and Table 1.

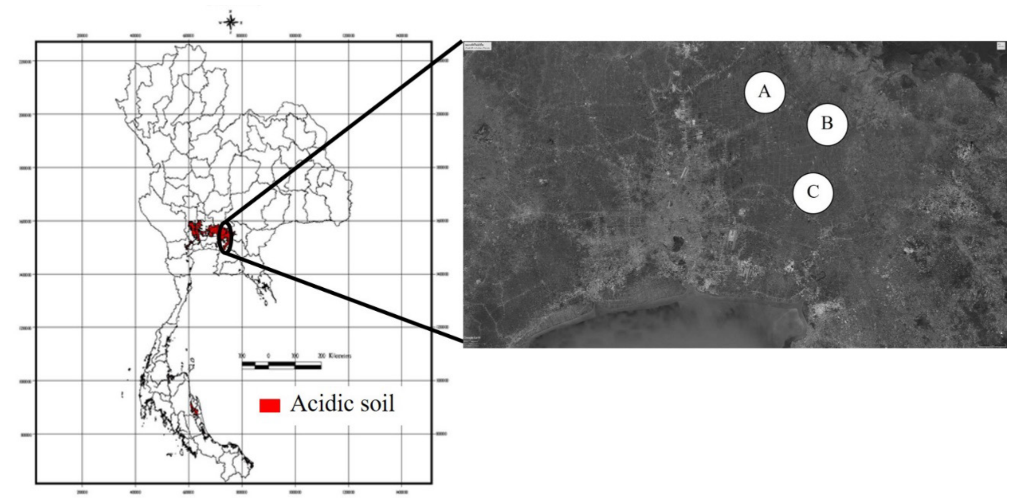


Figure 1. Study sites: (A) Nong Suea district in Pathum Thani province; (B) Ongkharak and Banna districts in Nakhon Nayok province; (C) Bangnampraw and Muang districts in Chachoengsao province

Table 1

Land use of study sites where soil samples were collected

Area	Land use							Total *N*
	1	2	3	4	5	6	7	
A	Banana farm	Lemon garden	Orchard	Papaya garden	Rubber plantation	Lemon garden	Cassava field	21
N	(3)	(3)	(3)	(3)	(3)	(3)	(3)	
B	Fallow	Paddy field	Backyard garden	Banana farm	Paddy field	Fallow	Abandoned	21
N	(3)	(3)	(3)	(3)	(3)	(3)	(3)	
C	Grass field	Lemon-grass field	Galangal field	Paddy field	Integrated farming	Paddy field	Coconut garden	22
N	(3)	(3)	(4)	(3)	(3)	(3)	(3)	
						Total samples		64

Note. *N* = sample collected from land classified as a farm zone

Soil Moisture, Soil Temperature, and Soil Electrical Conductivity

The moisture, temperature, and EC of soil collected from the surface (0–5 cm) and the data in the field survey on soil moisture—or percentage of wet soil (% Wet)—temperature, and EC were collected using series HH2 Delta-T Devices. These are automatic instruments for collecting data.

Soil pH Measurement and Validation

The soil pH meter used for collecting data in the field survey (*F*.pH, the pH value that collected from the field) was a soil tester manufactured by Takemura Electric Works LTD (Japan). The pH value of the samples was then tested using a solution technique. The soil sample from the field (soil surface 0-5 cm) was dissolved in water at a 1:1 ratio of 5 g of soil diluted in 5 mL of deionized water and then stirred for 30 min. After waiting an additional 30 min to allow for precipitation, the liquid was separated from the sample for pH checking (*L*.pH, the pH value of the laboratory test) using a series HQ40d Portable Multi Meter by Hach (United States of America). However, regarding the variation between the laboratory and the field (McKean & Brent, 1989; Neal & Thomas, 1985), Shaver (1993) reported an average pH variation of +0.132, as well as Lataysh and Gordon (2004) suggested that the pH value in the field will be greater than that in the laboratory by about 0.10 pH. In this report, the application of the soil pH value between fieldwork and laboratory analysis is derived from the following equation:

$$\text{pH} = \frac{(F.pH + 0.1) + (L.pH - 0.1)}{2}$$

The 0.1 value is applied according to Latysh and Gordon's (2004) observation ratio for balancing pH value.

Soil Organic Carbon and Total Nitrogen

In the study, total levels of carbon and nitrogen in the soil were measured using the LECO series CHN-628 CHN Analyzer (United States of America). After collection, the percentage of carbon in the soil was calculated as SOM using a formula from the Soil Lecture Team (2006):

$$\%\ \text{SOM} = 100\ (\%\ \text{C/c}) \qquad [1]$$

where % SOM = Percentage of soil organic matter, % C = Value from CHN analyzer processing, and c = % Weight of SOC use 52 for topsoil calculated (Soil Lecture Team, 2006). % SOM will be used to calculate the weight of SOM content in the soil according to the formula:

$$\text{SOM (mg/kg)} = [\%\ \text{SOM} \times (\text{W1}/100)] \times 10^6 \qquad [2]$$

where SOM = Soil organic matter (mg/kg), % SOM = Rate from the first equation, and W_1 = Dry weight of the sample (mg) in the experiment using 2 mg/sample.

However, SOC uses a soil sample from the topsoil at a depth of not more than 20 cm, so Han et al. (2018) and Y. Liao et al. (2015) suggest the following calculation:

$$SOC\ (mg/kg) = \%\ SOM \times 0.58 \times 100$$

where SOC (mg/kg) = Soil organic carbon concentration, % SOM is from formula [1], and 0.58 is the van Bemmelen conversion factor of 58% C in SOM.

Elements in the Soil Content

The soil was collected from 8 points (in a Z shape) in the field and mixed to create 1 sample (difference a soil to use find BD). The soil was dried in a hot 105°C oven for 3 days and then ground using a mortar and pestle. A net 10 mm of sifted soil was selected and maintained at a temperature of −4°C. The soil extraction used in atomic absorption spectrometry (AAS) analysis was a 2 g soil sample with concentrated nitric acid (HNO_3) and concentrated perchloric acid ($HClO_4$) in a 1:1 ratio for 10 mL (United States Environmental Protection Agency, 1996). It was then digested at about 500°C in the SpeedDigester K-425 BUCHI (Switzerland) until dried. Each residue was rinsed with 1% HNO_3, followed by sieving through Whatman No. 1 paper. The supernatant was then transferred to a 50 mL volumetric flask, and 1% HNO_3 was added for continued AAS analysis (Thummahitsakul et al., 2018).

The mineral analysis set the standard of lead (Pb), copper (Cu), cadmium (Cd), zinc (Zn), selenium (Se), iron (Fe), mercury (Hg), potassium (K), and nickel (Ni) prepared by a solution of an Agilent Technologies (United Sates of America) concentration of 1,000 µg/mL stock of each heavy metal and 1% HNO_3, with a linear standard calibration curve to measure mineral samples. The Pb, Cu, Cd, Zn, Se, Fe, Hg, K, and Ni analyzing by AAS, an Agilent series 240AA instrument (United Sates of America).

Whereas, phosphorus in the soil content was analysed using the Bray II method and measured by spectrophotometers in wavelength 882 (nm). Available phosphorus was in the form of potassium dihydrogen phosphate (KH_2PO_4) in soil samples.

Statistical Analysis

Data were analysed using one-way analysis of variance (ANOVA) for variances. Differences in data were compared by post-hoc Tukey's honestly significant difference (HSD) test in $p < 0.05$ between data components. Principal component analysis (PCA) evaluated correlation matrix components with factors of influence related to acidic soil in the central region. Correlation analysis considered the use of Pearson's correlation ($p < 0.05$). Finally, all analyses were conducted using the programs Statistical Package for the Social Sciences (SPSS) V.22 and SigmaPlot 12.0 (free trial).

RESULTS AND DISCUSSION

Soil Physical Properties of the Study Sites

In central Thailand, the soil pH ranged from 2.89–6.30, with an average of 4.71 (± 0.87). The soil pH of Chachoengsao province has a significantly ($p < 0.05$) to that of Pathum Thani and Nakhon Nayok provinces (Table 2). The acidic soil of Phatum Thani and Nakhon Nayok is classified as extremely acidic (pH between 3.5–4.4), and the soil of Chachoengsao is classified as strongly acidic (pH between 5.1–5.5), according to the Natural Resources Conservation Service (NRCS) (1994). The BD averaged 0.34 ± 0.11 g/cm^3. Chachoengsao has a significantly ($p < 0.05$) lower BD (0.28 g/cm^3), while Phathum Thani (0.37 g/cm^3), but not significant to Nakhon Nayok provinces, have a BD of 0.35 g/cm^3. The result indicates that the areas are suitable for agriculture because of the characteristics of loam clay and because BD is related to soil texture and parent material. The % Wet in the soil averaged 36.9% (± 14.4). This high value can be attributed to the data being collected during the rainy season in Thailand. The EC averaged 205 µS (± 133), soil temperature averaged 32.14°C (± 2.90), and the soil moisture level averaged 19.12% (± 5.21), as shown in Table 2. The correlation of soil pH in relation to EC ($r = 0.274$, $p < 0.05$), BD in relation % Wet ($r = 0.354$, $p < 0.01$), and % Wet and EC ($r = 0.410$, $p < 0.01$) are presented in Table 3.

Table 2

Physical properties of acidic soil in central Thailand

	pH	Bulk density (g/cm^3)	Percentage of wet soil (% Wet)	Electrical conductivity (µS)	Temperature (°C)	Moisture (%)
Pathum Thani	4.41 ± 0.59[a]	0.37 ± 0.06[a]	41.8 ± 17.35[a]	173 ± 66.4	33.9 ± 2.80[a]	19.8 ± 4.01[b]
Nakhon Nayok	4.18 ± 0.82[a]	0.35 ± 0.08[ab]	38.2 ± 8.69[ab]	155 ± 61.6	29.8 ± 2.45[b]	15.8 ± 6.62[a]
Chachoengsao	5.50 ± 0.54[b]	0.28 ± 0.15[b]	31.1 ± 15.50[b]	291 ± 192	32.6 ± 1.77[ab]	21.5 ± 2.75[b]
Average	4.71 ± 0.87	0.34 ± 0.11	36.9 ± 14.48	205 ± 133	32.1 ± 2.90	19.1 ± 5.21

Note. [a,b] The mean difference is significant at the *p*-value < 0.05 level (HSD)

Table 3

Correlation of physical properties of acidic soil in central Thailand (n = 64)

	pH	Bulk density (BD)	Percentage of wet soil (% Wet)	Electrical conductivity (µS)	Temperature (°C)
BD	−.030	-			
% Wet	−.151	.394**	-		
EC	.274*	.354**	.410**	-	
Temperature	−.048	−.085	−.070	.110	1
Moisture	.245	.055	.159	.241	.216

Note. *Correlation is significant at the 0.05 level (2-tailed); **Correlation is significant at the 0.01 level (2-tailed)

Relationship between SOC, SOM, and C/N ratio in Acidic Soil in Central Thailand

SOC is one indicator of soil quality and is related to microorganism activity. The SOC content of acidic soil in central Thailand averaged 404 ± 303 mg/kg, and the acidic soil level in Phatum Thani, Nakhon Nayok, and Chachoengsao was not significant ($p > 0.05$) (Table 4). The SOM averaged 9,036 ± 4,048 mg/kg, and the acidic soil level in Phatum Thani, Nakhon Nayok, and Chachoengsao was not significant ($p > 0.05$). The C/N ratio averaged 3.69 ± 2.13, significant ($p < 0.05$) in Chachoengsao to Phatum Thani and Nakhon Nayok. However, when considering the correlation between SOC, SOM, and the C/N ratio, it was found that SOM was related to SOC ($r = 0.715$; $p < 0.05$), and SOM was related to the C/N ratio ($r = 0.283$; $p < 0.05$), as seen in Table 5. The C/N ratio increased with the SOM value and decreased with the SOC rate, as presented in Figure 2.

Table 4

Average of SOC, SOM, and C/N ratio in acidic soil in central Thailand

Items	Phatum Thani	Nakhon Nayok	Chachoengsao	Average
SOC (mg/kg)	457 ± 251[a]	468 ± 405[a]	294 ± 201[a]	404 ± 303
SOM (mg/kg)	9866 ± 2627[a]	9615 ± 6045[a]	7690 ± 2207[a]	9036 ± 4048
C/N ratio	3.29 ± 1.22[a]	1.21 ± 0.89[a]	5.05 ± 2.04[b]	3.6 9 ± 2.13

Note. [a,b,c] The mean in row differences is significant at the p-value < 0.05 level (HSD); SOC = Soil organic carbon; SOM = Soil organic matter; C/N ratio = Carbon-to-nitrogen ratio

Table 5

Correlation of SOC, SOM, and C/N ratio in acidic soil in central Thailand

Item	SOC	SOM	C/N ratio
SOC		0.715**	0.118
SOM	0.715**		0.283*
C/N ratio	0.118	0.283*	

Note. *Correlation is significant at the 0.05 level (2-tailed); **Correlation is significant at the 0.01 level (2-tailed); SOC = Soil organic carbon; SOM = Soil organic matter; C/N ratio = Carbon-to-nitrogen ratio

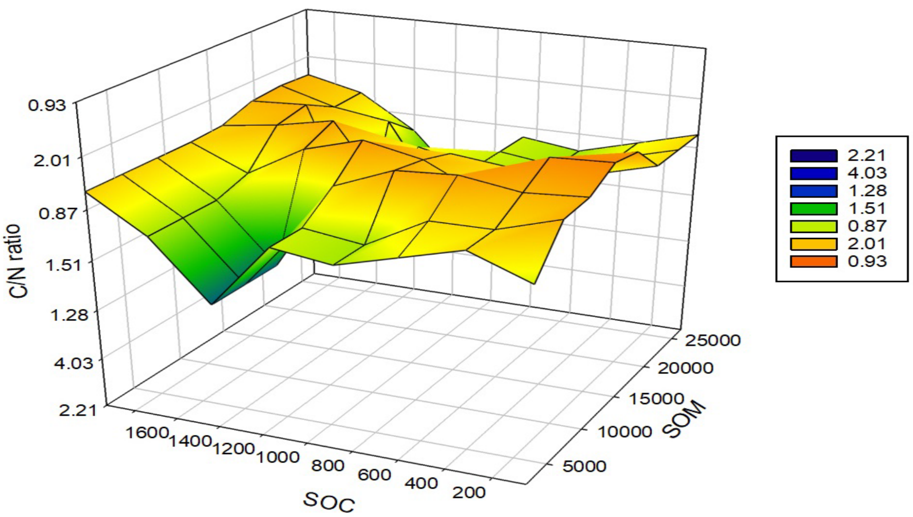


Figure 2. Evaluation rate of C/N ratio between SOC and SOM in acidic soil in central Thailand

Elements of Acidic Soil Content

The study of the mineral content of acidic soil in the central region found Fe present in the highest quantity. At the same time, Ni made up the smallest quantity, as presented in Table 6. Soil elements can be classified into three groups: essential macroelements, including N, P, and K; essential microelements, such as Fe, Cu, Zn, and Ni; and heavy metals, like Pb, Cd, Hg, and Se. The number of essential macroelements showed that N > P > K, and the quantity of N content in Nakhon Nayok > Phatum Thani > Chachoengsao was significant ($p < 0.05$). P levels in the soil content in Phatum Thani and Chachoengsao were significantly higher ($p < 0.05$) than those in Nakhon Nayok, and K levels found in the soil content in Phatum Thani and Chachoengsao were significant ($p < 0.05$), as presented in Table 7. The proportion of N, P, and K in acidic soil is a 13:2:1 ratio.

The number of essential plant microminerals in acidic soil content was Fe > Cu > Zn > Ni. The results showed that the quantity of Fe and Zn in Phatum Thani and Chachoengsao was significant ($p < 0.05$) compared to Nakhon Nayok province. Phatum Thani's Cu quantity was higher ($p < 0.05$) than that of Nakhon Nayok and Chachoengsao provinces, and the Ni quantity of the three provinces differed ($p < 0.05$), as shown in Table 7.

The quantity of the heavy metal Pb in Nakhon Nayok was higher than in Phatum Thani and Chachoengsao ($p < 0.05$), and the quantity of Hg found in Phatum Thani and Nakhon Nayok was not significant ($p < 0.05$) compared to Chachoengsao. However, differences in Cd and Se levels between the three provinces were small.

Table 6

Average total quantity of elements in acidic soil in the central region

Elements (mg/kg)	Average	SD	%
Pb	130	103	0.42
Cd	2.25	1.78	0.02
Hg	5.43	2.16	0.03
Se	1.83	0.70	0.01
Fe	29765	8921	96.2
Cu	40.56	40.2	0.13
Zn	13.35	12.2	0.04
Ni	0.19	0.04	0.00
N	782	377	2.53
P*	131	122	0.42
K	61	29	0.2
		Total	100

*P was determined using the Bray II method. The phosphorus considers P available from potassium dihydrogen phosphate (KH_2PO_4); Pb = Lead; Cd = Cadmium; Hg = Mercury; Se = Selenium; Fe = Iron; Cu = Copper; Zn = Zinc; Ni = Nickel; N = Nitrogen; P = Phosphorus; K = Potassium

Table 7

The quantity of elements for plants in acidic soil content classified by group and province

	Phatum Thani	Nakhon Nayok	Chachoengsao
Essential macro-elements (mg/kg)			
N	842 ± 237^{b}	1,097 ± 359^{a}	425 ± 124^{c}
P	193 ± 151^{a}	80.7 ± 81.4^{b}	121 ± 102^{a}
K	74.2 ± 25.6^{a}	63 ± 34.5^{ab}	47.5 ± 19.9^{b}
Essential micro-minerals (mg/kg)			
Fe	34,479 ± 7,755^{a}	23,997 ± 9,368^{b}	30,772 ± 6,430^{a}
Cu	68.4 ±58.6^{a}	23.3 ± 11.1^{b}	30.2 ± 16.8^{b}
Zn	15.2 ± 12.8^{a}	6.49 ± 7.29^{b}	18.1 ± 12.9^{a}
Ni	0.18 ±0.05^{b}	0.23 ± 0.03^{c}	0.16 ± 0.04^{a}

Table 7 *(Continued)*

	Phatum Thani	Nakhon Nayok	Chachoengsao
Heavy metals (mg/kg)			
Pb	82.5 ± 31.3^{a}	226 ± 135^{b}	85.6 ± 11.8^{a}
Cd	2.75 ± 0.89^{a}	2.11 ± 0.99^{a}	1.89 ± 2.73^{a}
Hg	5.13 ± 2.61^{a}	6.33 ± 1.77^{a}	4.86 ± 1.81^{a}
Se	1.90 ± 0.12^{a}	4.86 ± 11.9^{b}	1.20 ± 0.37^{c}

Note. [a,b,c] The mean in row differences is significant at the *p-value* < 0.05 level (HSD); N = Nitrogen; P = Phosphorus; K = Potassium; Fe = Iron; Cu = Copper; Zn = Zinc; Ni = Nickel; Pb = Lead; Cd = Cadmium; Hg = Mercury; Se = Selenium

Relationship of Some Elements to Acidic Soil

The results of the correlation of acidic soil with elements Pb, Cu, Cd, Zn, Se, Fe, Hg, Ni, K, P, and N are as follows. In the soil, pH was tested using Pearson's correlation coefficient. Levels of N ($r = -0.606$; $p < 0.01$), Ni ($r = -0.339$; $p < 0.01$), Pb ($r = -0.503$; $p < 0.01$), and Zn ($r = 0.292$; $p < 0.05$) are presented in Table 8. The correlation between N and soil pH is negative because, in soil, N forms ammonium (NH_4^+) and undergoes nitrification by microorganisms present in the hydrogen (H^+) in the environment, which is related to an increase in soil acidity. The correlation of N to soil pH is in accordance with the relationship between soil pH and the C/N ratio ($r = 0.690$; $p < 0.01$), so soil pH is possibly affected by heterotrophic nitrification because a neutral soil pH (pH 6–7) is suitable for microorganism activity (Zhang et al., 2019).

Table 8

Correlation of soil physical properties, mineral soil content, SOC, SOM, and C/N ratio of acidic soil in central Thailand

	pH	BD	Pb	Cu	Cd	Zn	Se	Fe
BD	ns							
Pb	−.503**	ns						
Cu	ns	ns	ns					
Cd	ns	ns	ns	ns				
Zn	.292*	ns	−.255*	.494**	ns			
Se	ns	.247*	ns	ns	ns	ns		
Fe	ns	ns	−.450**	ns	ns	ns	ns	

Table 8 *(Continued)*

	pH	BD	Pb	Cu	Cd	Zn	Se	Fe
Hg	ns	ns	ns	ns	ns	ns	ns	ns
K	ns	ns	ns	ns	ns	ns	ns	ns
Ni	−.339**	ns	.508**	ns	ns	−.330**	ns	−.423**
P	ns	ns	ns	ns	ns	ns	ns	ns
N	−.606**	ns	.573**	ns	ns	−.388**	ns	−.265*
SOM	ns	.273*	ns	ns	ns	ns	ns	ns
SOC	ns	.597**	ns	ns	ns	ns	.254*	ns
C/N ratio	.690**	ns	−.508**	ns	ns	.515**	ns	ns

	Hg	K	Ni	P	N	SOM	SOC	C/N ratio
K	ns							
Ni	ns	ns						
P	−.385**	ns	ns					
N		ns	.547**	ns				
SOM	ns	ns	ns	ns	ns			
SOC	ns	ns	ns	ns	ns	.715**		
C/N ratio	−.251*	ns	−.424**	ns	−.741**	.283*	ns	

Note. *Correlation is significant at the 0.05 level (2-tailed); **Correlation is significant at the 0.01 level (2-tailed); BD = Bulk density; Pb = Lead; Cu = Copper; Cd = Cadmium; Zn = Zinc; Se = Selenium; Fe = Iron; Hg = Mercury; K = Potassium; Ni = Nickel; P = Phosphorus; N = Nitrogen; SOM = Soil organic matter; SOC = Soil organic carbon; C/N ratio = Carbon-to-nitrogen ratio; ns = Not significant

Factors of Acidic Soil Components

Factor analysis of the parameters of the 16 components of acidic soil properties was done by PCA. Prior to this, acidic soil components were tested using Kaiser-Meyer-Olkin (KMO) and Bartlett's test. The KMO Measure of Sampling Adequacy was 0.618 (Table 9), and there was a significant difference in the eigenvalues ($p < 0.001$). The components found in six PCs had an eigenvalue over 1 and explained 71.628% of the total variance in the data set (Table 10). The components had a percentage of the variance of > 10%, as shown in PC1 and PC2. PC1 had 24.047% of the variance (Table 10, Figure 3a). The C/N ratio was the most significant contributor, and factor loading was 0.853, which was selected first. Second were soil pH (0.712) and Zn (0.598), so the correlation between C/N ratio and soil pH was r = 0.692, and the correlation between C/N ratio and Zn was r = 0.515 (Table 8). PC2 explained 14.887% of the variances (Table 10). SOC was the most significant contributor, and factor loading was 0.873, which was selected first. Second were BD (0.748) and SOM (0.717), so the correlation between SOC and BD was r = 0.597, and the correlation between SOC and SOM was r = 0.715 (Table 8). The relationship of an eigenvalue to components in principle analysis and component loading of PCs is presented in Figure 3(b). Figure 4 shows the cluster analysis for classified groups as a dendrogram. This dendrogram construction presents two major, distinct clusters with four groups from SOC and SOM clustered together in one group and Pb, Se, pH, and C/N ratio in another. The third group comprises Fe, soil moisture, Cu, Zn, percentage of wet material in the soil, and EC. The final group contains P, Hg, and soil temperature. This final group is dissimilar to groups A, B, and C. K and Cd could not be grouped with the others (Figure 4).

Table 9

Results of KMO and Bartlett's test of acidic soil components in central Thailand

Kaiser–Meyer–Olkin Measure of Sampling Adequacy	.618
Bartlett's Test of Sphericity Approximate Chi-Square	367.983
df	120
Sig.	.000

Note. df = Degree of freedom; Sig. = Significant

Table 10

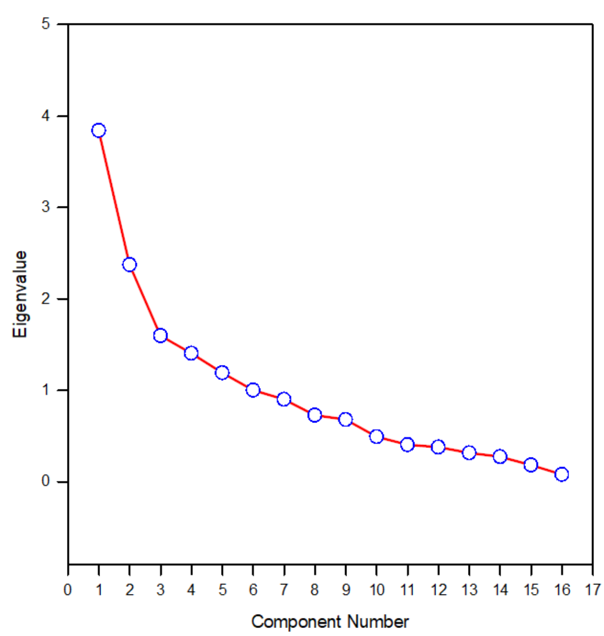
Results of PCA of the statically significance of acidic soil in central Thailand

PCs	Component					
	PC1	PC2	PC3	PC4	PC5	PC6
% of variance	24.04	14.8	10.03	8.83	7.50	6.32
Cumulative %	24.04	38.9	48.9	57.8	65.3	71.6
Eigenvalue	3.84	2.38	1.60	1.41	1.20	1.01
pH	.71	−.08	−.41	−.08	−.02	−.06
SOM	.17	.71	−.36	−.10	−.07	.31
C/N ratio	.85	−.02	−.24	−.17	.08	.09
SOC	.16	.87	−.16	.04	.14	.07

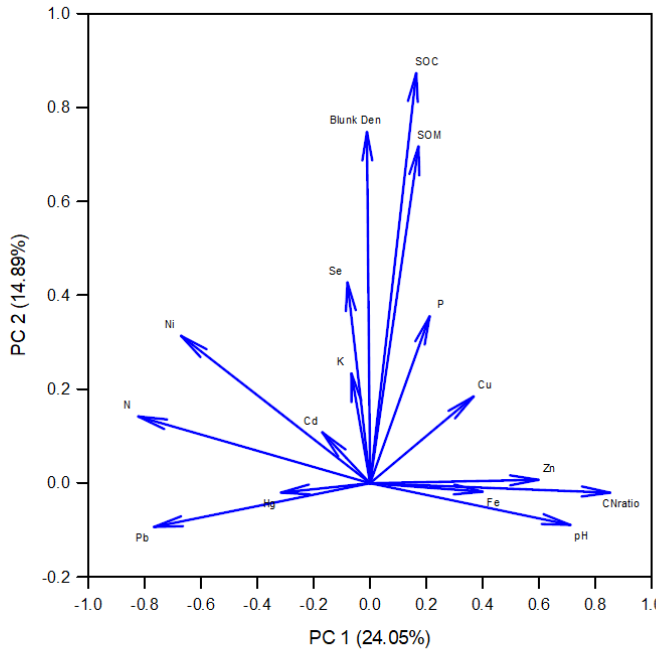
Table 10 *(Continued)*

PCs	Component					
	PC1	PC2	PC3	PC4	PC5	PC6
BD	−.01	.74	.04	.23	.11	−.27
Pb	−.76	−.09	−.00	−.26	.21	.06
Cu	.36	.18	.51	−.03	.47	.19
Cd	−.17	.10	−.02	.56	−.04	.49
Zn	.59	.01	.28	−.31	.48	.09
Se	−.08	.42	−.18	−.12	−.22	−.49
Fe	.39	−.01	.21	.70	−.20	.01
Hg	−.31	−.02	−.22	.45	.64	−.29
Ni	−.67	.31	−.16	−.26	.03	.19
K	−.06	.23	.55	−.01	−.01	−.33
P	.21	.35	.60	−.16	−.36	.07
N	−.82	.14	.18	−.03	.00	.18

Note. PC = Principal analysis; underlined factor loading is weighted higher when within 10% of the variation of the absolute value of the highest factor loading in each PC; SOM = Soil organic matter; C/N ratio = Carbon-to-nitrogen ratio; SOC = Soil organic carbon; BD = Bulk density; Pb = Lead; Cu = Copper; Cd = Cadmium; Zn = Zinc; Se = Selenium; Fe = Iron; Hg = Mercury; Ni = Nickel; K = Potassium; P = Phosphorus; N = Nitrogen



(a)



(b)

Figure 3. Results of PCA for acidic soil components in central Thailand: (a) the eigenvalue of components in principal analysis; (b) the component loading of PCs, so PC1 is carbon-to-nitrogen ratio > pH > zinc (C/N ratio > pH > Zn), and PC2 is soil organic carbon > bulk density > soil organic matter (SOC > BD > SOM)

Physical and Land Use of Acidic Soil in Central Thailand

The soil pH of the study sites in Phatum Thani and Nakhon Nayok is in the extremely acidic group; some Phatum Thani parts have ultra-acidic soil with a pH below 3.5 (Attanandana, 1993; Intorpetch et al., 2014). Nakhon Nayok has a soil pH below 4 (Seeboonruang & Ichikawa, 2007), and Chachoengsao belongs to the strongly acidic group because soil pH in the province is between 4.3 and 6 (Prawach et al., 2017). However, soil pH below 5.5 will affect plant growth (Sumner et al., 1991). Therefore, low pH levels may be an obstacle to agricultural production. Farmers apply manure and water to the soil to prepare the land for planting. Because the study site sits almost entirely inside the irrigation zone, the water supply is directly related to the percentage of wet material in the soil and the soil EC (Lesturgez et al., 2006; Parkpian et al., 1991), supporting the plant growth mechanism.

Influence of soil pH on Some Indicators of Acidic Soil

Soil pH is essential to agricultural production because of its connection to the biogeochemistry of plant and

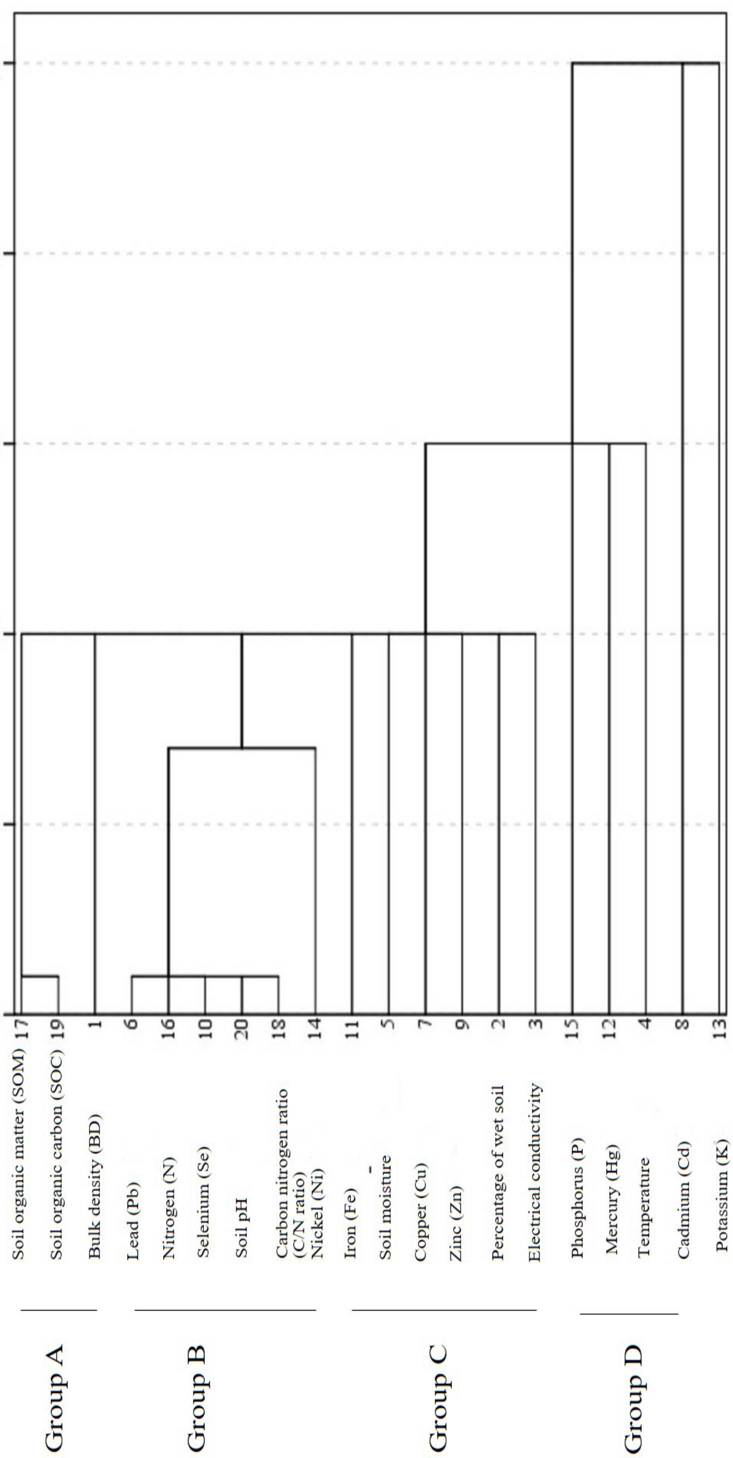


Figure 4. Dendrogram of hierarchy cluster analysis based on acidic soil components of central region parameters

microorganism activity in the soil (Neina, 2019). Components of soil pH, SOM, SOC, and C/N ratio are related to iron in the earth due to ferrous disulfide (FeS_2). In a test to determine the influence of soil pH on components related to C/N ratio > N > Ni > Pb > Zi, it was found that the acidic soil contained large amounts of Fe and Al oxides (Kamprath & Smyth, 2005). Kawaguchi and Kyuma (1974) reported that Fe, Mn, and Si in the central region were higher than in other parts of the country. Results of a similar study showed that the quantity of Fe was higher than that of other elements (Table 3). However, the correlation between the pH of acidic soil and Pb, Zn, and Ni may be due to the parent materials of the soil (Anderson, 1988; B. Liao et al., 2005; Brogowski et al., 2014; Nair & Cottenie, 1971). The soil's parent material in Thailand's central region is non-calcareous sediment, sulfur derived from pyrite, and clay, whose components are kaolinite, muscovite/illite, and smectite (Office of Soil Survey and Land Use Planning, 2010; Spaargaren et al., 1981).

The pH of acidic soil often varies depending on soil level (Arunrat et al., 2017; Kavinchan et al., 2015; Oechaiyaphum et al., 2020; Perie & Ouimet, 2007) and is related to the C/N ratio. Similarly, Tonon et al. (2010) explained that soil pH could influence the transformation of organic matter in the soil. However, SOM and SOC are grouped with BD in the dendrogram (Figure 4). Furthermore, it is connected to the result of factor analysis (Figure 3), meaning that there is a positive relationship between SOM, SOC, and BD ($p < 0.05$).

Factors of Soil Organic Matter and Soil Organic Carbon in Some Components of Acidic Soil

The study shows SOM and SOC in directly related to BD in the dendrogram (Figure 4) of cluster analysis. PCA and component loading of SOM, SOC, and BD are significant components of PC2 (Figure 3). Therefore, generally, SOM must relate to SOC because it uses a percentage of carbon in its calculation (Han et al., 2018; Y. Liao et al., 2015). However, the relationship between SOM, SOC, and BD is closely related to the organic and inorganic materials in the soil content (Perie & Ouimet, 2007) and soil type (Athira et al., 2019; Sakin, 2012). Therefore, SOM is important in understanding the behaviour of microbial activity in soil (Gmach et al., 2019; Grand & Luvkulich, 2012) because it is related to SOC and total nitrogen in the ecology zone. Nevertheless, Sun et al. (2017) reported that capillary water, SOC, and nitrogen have positive interactions with the C/N ratio, and the C/N ratio will decrease with an increase in soil pH. Therefore, the C/N ratio can explain certain minerals in the area (Hamilton et al., 2003; Yang et al., 2019).

Soil Fertility in Acidic Zones of Central Thailand

This study focused on N, P, K, Fe, Cu, Zn, and Ni. The quantity of Fe and Cu is high in acidic soil (von Uexküll, 1986). Gazey and

Davies (2009) explained that pH is inversely related to nutrient availability of Fe, Cu, and Zn. Conversely, N and K increase with pH, and P is optimised at a pH of 6.5. At the study site, however, the number of essential macro and microelements was high compared with the ideal soil for plants (Table 11). Abundant soil is a valuable element for plants. This study analysed and found a high quantity of N, K, Fe, Cu, Zn, and Ni in crude soil samples. The level of P availability in plants was determined using the Bray II method.

Table 11
Soil element quantity compared with ideal (abundant) soil for plants

Elements (mg/kg)	Study site	Shehata and El-Ramady (2012)	Brunetti (1950)	FAO	Mahler (2004)
Fe	29,765	53,600	50–100	50,000[B]	50–10,000
Cu	40.5	60	2–5	70[B]	2–20
Zn	13.3	70	6–12	80[B]	10–100
Ni	0.19	84	-	100[B]	-
N	782	100–200	30,000–50,000	30,000–34,000[A]	10,000–50,000
P	131	30–50	30,000–50,000	1,100–1,200[A]	1,000–5,000
K	61.3	10–200	40,000–50,000	1,800–2,300[A]	5,000–50,000

Note. A represents information in Food and Agriculture Organization of the United Nations (FAO) (1980), and B represents information in FAO (1979); Fe = Iron; Cu = Copper; Zn = Zinc; Ni = Nickel; N = Nitrogen; P = Phosphorus; K = Potassium

Heavy Metal Contamination in Acidic Soil in Central Thailand

The soil collected in the agricultural area was tested for heavy metals Pb, Cd, Hg, and Se. The contamination level did not exceed the standards set by the Pollution Control Department (2004) for soil in habitat and agricultural areas. The level of Pb did not exceed any of the limits shown in Table 12, but Cd and Hg surpassed the limit according to reports by Crommentuijn et al. (1997) and the FAO (2005), and Se exceeded the limit set by Crommentuijn et al. (1997). However, Pb has a negative correlation to soil pH ($r = -.503$; $p < 0.05$), so it may stimulate fungi activity in acidic soil (Lenart & Wolny-Koladka, 2013). B. Liao et al. (2005) discovered that the relationship between a high level of Cd and its correlation with soil pH is related to soil EC.

Table 12

Limits of heavy metal contamination in soil

Elements (mg/kg)	Study site	Thailand[1]	Raymond and Felix (2011)	Crommentuijn et al. (1997)	FAO (2005)
Pb	130	400	600	140	200
Cd	2.25	37	100	1.6	1
Hg	5.43	23	270	2.2	2
Se	1.83	390	ND	0.81	20

Note. [1]Pollution Control Department standard for soil quality in habitat and agricultural areas; Pb = Lead; Cd = Cadmium; Hg = Mercury; Se = Selenium; *ND* = No data

CONCLUSION

The evaluation of soil acidity in central Thailand found an average pH of 4.71 ± 0.87. The soil acidity level can be categorised as very strongly acidic in Phatum Thani and Nakhon Nayok and strongly acidic in Chachoengsao. Soil pH and BD are about 0.34 g/cm^3 in the soil pH relationship to % Wet and EC. The % Wet is related to BD and SOC and SOM value because it is linked to microorganisms in soil surface decomposition activity. However, the dendrogram of hierarchical cluster analysis shows that Se, Ni, and N have similar pH clusters; it also shows that Fe is a majors mineral in soil acidity in central Thailand. The correlation of soil pH to Pb, Ni, N, C/N ratio, and Zn is as follows: PC1 is C/N ratio > pH > Zn, and PC2 is SOC > BD > SOM. Soil pH, SOM, and SOC are similar groups, and soil abundance at the study site contained essential macro and microelements below the ideal level needed for plants. The heavy metal contamination of the acidic soil in the central region did not exceed the standard limit. However, the correlation between SOM and SOC (r = 0.715; $p < 0.01$) indicates soil quality and microbial activity.

The acidic soil area in central Thailand is a significant zone for agricultural production in the country. The study found a relationship between the element content and soil physical properties. However, the connection is not strong enough to offer suggestions to farmers who have improved their soil over time because the study found many factors related to soil acidities, such as microorganisms in the area or the chemical behaviour of soil acidity in the country. These factors impact farmers improving the soil by stabilisers such as lime, calcite, and dolomite for adjusting pH in the soil. Therefore, this topic should find practical support in the future, as the search for a solution to soil acidity continues.

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