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Fertility Index of Industrial Polluted Land and Plant Response to Heavy Metal Contamination

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ABSTRACT

Industrial waste in the Sidoarjo Regency, Java, Indonesia has polluted the agricultural land around it. The high level of heavy metal pollution in these fields affects the physical, chemical, and biological characteristics of the soil and plant growth. This study aimed to examine the soil fertility index (SFI) of four agricultural plots of land around the paper, pharmaceutical, animal feed, and leather industries in the Sidoarjo region and the response of food crops to heavy metal contamination. The research was carried out in two stages, Stage (1): Evaluation of the soil fertility index (SFI) based on physical, chemical, and biological characteristics of the main soils; Stage (2): The response of rice plants and maize to heavy metal contamination. The SFI value is derived from the minimum soil chemical-physical-biological characteristic indicator values which include pH, EC, cation exchange capacity (CEC), K, Na, Ca, Mg, heavy metals (Fe, Mn, Zn, Cu, Pb, Hg, Cd) clay, and C-organic soils. The results showed that the value of the soil fertility index of agricultural land around the industries in the Sidoarjo area was low to moderate. The value of SFI is obtained through factor analysis of highly correlated soil features. The main factors determining the low value of SFI are soil pH, soil texture, and heavy metal content of Pb, Cd, Fe, and Zn. Therefore, it is not advisable to cultivate rice and corn in the region due to the significant uptake of high levels of heavy metal elements by these plants, which not only compromises their growth but also human health.

Key words: industry, fertility, heavy metals, plants, pollution

INTRODUCTION

Future industrial development is likely to harm agriculture because industrial waste pollutes rivers and land (Zwolak *et al*. 2019). Industrial waste plays the most important role in pollution, especially heavy metal pollution. Many hazardous wastes contain chemicals rich in heavy metals that can pollute agricultural land (Rosariastuti and Supriyadi 2020). Environmental pollution can reduce health of plants. Heavy metals that pollute the soil reduce the pH of the soil, making the soil acidic (Napitupulu 2008; Adamczyk-Szabela *et al.* 2015; Abdu *et al*. 2017). Plants absorb and accumulate any heavy metals present in the soil (Tangahu *et al.* 2011). The soil quality in the Sidoarjo Regency has decreased because it contains large amounts of heavy metals. Heavy metals such as cadmium (Cd), mercury (Hg), lead (Pb), copper (Cu), chromium (Cr) and zinc (Zn) are considered 'serious' pollutants due to their toxic properties such as the tendency to enter the food chain, and the ability to reside (residence time) in the environment for a long time. Removal of heavy metals from soil is time consuming and costly (Putranto 2011). The liquid waste from the batik industry in Sidokare, Sidoarjo contains Pb 0.173 mg kg^{-1}, Cd 0.009 mg kg^{-1}, and Cr 0.004 mg kg^{-1} while the maximum threshold for the discharge of Pb content into a water body is 0.1 ppm according to the Governor Regulation of The Republic of Indonesia in 2014. Soil with chemical concentrations over this threshold level contain dangerous components or heavy metals (Lenart and Wolna-Koadka 2013). If the land is under agriculture, the plants will uptake these harmful chemicals and human and animal health is likely to be affected if they depend on these plants for foods.

Agriculture, through reusing wastewater for irrigation, contributes to spreading and reintroducing these contaminants into the aquatic environment. Adhani plants carrying heavy metals and pose a risk to people if ingested (Oliver and Gregory 2015; Zwolak *et al.* 2019). The level of Fe, Cd, Zn and Pb do meet the standards of drinking water quality. However, manganese (Mn) in three locations was found to exceed drinking water quality standards (> 0.4 mg/l) (Sholehhudin *et al.* 2019). The cadmium content in the rice fields of the Taman sub-district was 1.90 ppm, while in the soil it was 2.43 ppm. Therefore, the quality of the soil at the four locations was declared to exceed the environmental quality standards. The distribution map shows that the Taman sub-district area has the highest levels compared to other sub-districts (Fitrianah *et al.* 2022). There are indications that the agricultural land around the industries in the Sidoarjo area is contaminated with heavy metals from industrial waste disposal (Khasanah *et al.* 2021). Ameliorating the physical and chemical properties of the soil can reduce associated risks, increase soil productivity, and improve food security (Wuana and Okieimen 2011). Applying a straw powder concentration of 40,000 mg/L and a contact time of 180 min resulted in a significant reduction of 50.35% in the liquid waste's initial concentration of Pb (Dini *et al.* 2013). Planting of *Fimbristylis globulosa* which inoculates bacteria producing *Azotobacter exopolysaccharides* and using activated charcoal, can reduce the content of Cd and Pb in the soil as *F. globulosa* increases its uptake resulting in increased Pb content in its roots (Dewi dan Hindersah 2009).

Evaluating soil fertility is crucial for identifying soil features and the external variables that can help create a more sustainable agricultural system. With carefully selected indicators, the fuzzy technique may adequately evaluate soil fertility and offer helpful information for decision making (Khaki *et al.* 2017). In organic management methods, the soil fertility index (SFI) is Class 4, or Extremely High, while in conventional management systems, it is Class 3, or high. Manure that is applied for extended periods increases the SFI and promotes plant nutrition (Prastiwi *et al*. 2021). The reduction in soil fertility of agricultural land near industrial regions has motivated academics to investigate the relationship between alterations in soil properties and plant development in greater depth. Based on the preceding information, this study aims to investigate the SFI of agricultural land surrounding the industrial area in the Sidoarjo region and plant response to heavy metal pollution.

MATERIALS AND METHODS

The research was conducted on farmers' agricultural plots around the industries in Sidoarjo Regency which is located between 112.5^0 and 112.9 ^{0} E longitude and between 7.3 ^{0} N latitude and 7.5 ^{0} S latitude. The study was conducted from June to September 2019. Research methods included identifying the physical-chemical-biological characteristics of the soil to determine the SFI value and observing plant response to metal absorption, particularly growth.

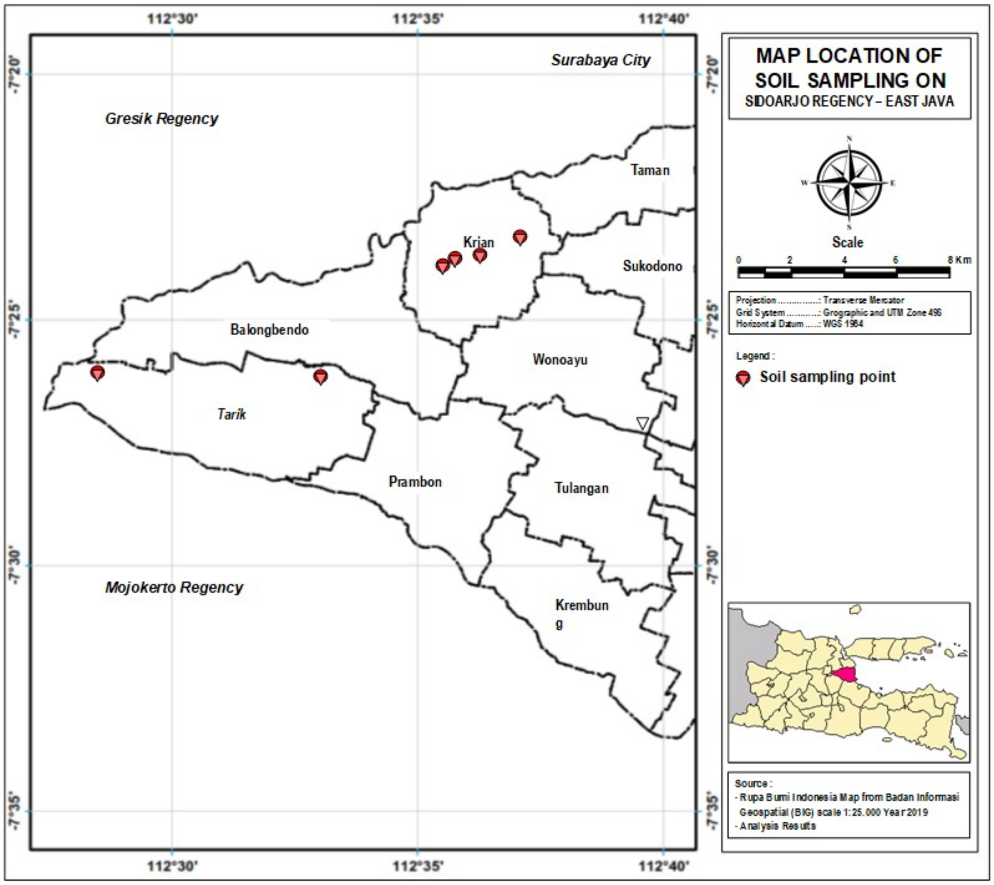

Figure 1. Map of the study sites

Evaluation of Soil Fertility Index of Four Farmlands Around the Industry

A site survey was first carried out to determine the location of the study and the determination of sampling points adjacent to the industries, residents' homes, highway access, and areas irrigated by water from rivers polluted with industrial waste. Soil sampling was conducted adjacent to the plastics (TR), pharmaceutical (TF), animal feed (TP), and paper (TC) industries.

Soil Sampling

At five sampling locations, 0-20 cm soil samples were collected, placed in plastic bags, and labelled with the sampling location. Soil samples were transported to the laboratory for air-drying and sifting using 2-mm and 1-mm sieves.

Soil Analyses

The pH of the soil samples was determined using the 1:2 saturation technique while soil texture was determined using the pipette method. One mm soil samples were analysed for organic carbon using Walkey and Black method, cation exchange capacity (CEC) of potassium, calcium, magnesium, and sodium with ammonium acetate 1 N at pH 7, soil total nitrogen by Kjeldahl method, available phosphorus by Olsen method, and heavy metal content of iron zinc, copper, manganese, lead, and cadmium with 25%HCl extraction. Descriptive statistics examined the findings of soil analysis to determine data flow, regression analysis to determine the relationship between components, factor analysis to determine the most influential factors, and the SFI to determine the degree of soil fertility. The SFI value was computed on a scale of 0 to 1, using the method of Mukashema (2007), while its classification is based on Bagherzadeh *et al.* (2018).

$$SFI = \left(\frac{\sum_{i=1}^{n} Sci}{N}\right) \times 10 \quad \ldots (1)$$

Sc_i= c_j x p_c … (2)
p_c= 1/n_c, … (3)
c_j= w i x s_i … (4)

where
SFI = soil fertility index
Sci= MSFI value, minimum soil fertility indicator (MSFI)
N= number of minimum soil fertility indicators (MSFI)
p_c= probability of SFI class
n_c= SFI class number
w_i= weight index
s_i= score index

The sum of minimum soil fertility indicators (N) was determined based on the value of the correlation between each variable and has two asterisks (**) (sig < 0.01) or an asterisk (*) (sig < 0.05). Sci is the value of the minimum soil fertility indicator (MSFI) calculated by multiplying the probability of the soil fertility index class (p_c) with the weight index (w_i) and the characteristic score index of soil (s_i). The score value of each condition depends on the agreement of several components. The SFI class (p_c) probability is one-sixth of the SFI class. Hence, if the SFI class (n_c) is equal to 5, the value of p=1/5. The number of SFI classes, according to Bagherzadeh *et al.* (2018) are presented in Table 1.

TABLE 1

Soil Fertility Index class according to Bagherzadeh *et al.* (2018)

SFI class	SFI value
Very Low	0.00-0.25
Low	0.25-0.50
Keep	0.50-0.75
Tall	0.75-0.90
Very High	0.90- 1.00

Heavy Metal Uptake by Plant

Plant response to heavy metal Pb and Hg contamination was evaluated against the quantum of metals absorbed by rice and maize plants and the effect on their growth. The experiment was arranged in a Randomized Group Design with the first factor being four plots polluted by industry, the second factor being rice and maize crops as indicators of plant growth. Rice and maize crops were planted in four selected agricultural land in the vicinity of the plastics, pharmaceutical, cattle fodder and paper industries under Stage 1. Heavy metals Hg and Pb uptake by plants are indicators of contamination that harm human health. The crop was harvested 30 days after planting (DAP).

Plant analyses

The entire plant tissue was dried between 60 and 70°C and then strained through an 80-mm mesh screen. Fine plant samples were digested with H_2SO_4 and HNO_3 in water. The Pb and Hg content of the clear extract was determined using atomic absorption spectrophotometer (AAS). Soil samples were taken in the same field planted with rice and maize at a depth of 0-20 cm, and then analysed for Pb and Hg content using the same method as previously. Data from Pb and Hg measurements of plants and soils were tabulated for statistical descriptive analysis, ANOVA, and correlations between treatments.

RESULTS AND DISCUSSION

The results of the statistical descriptive analysis, as presented in Table 2, show that part of the soil is neutral to alkaline with a very low salinity level. All soil cation exchange values are low. N availability is low, but P availability is relatively high. All heavy metals are classified as high. The soil texture is dominated by dust with a low clay content.

Evaluation of Soil Fertility Index of Four Farm Land Around the Industries

Soil texture, CEC, pH, and organic matter content can affect the presence of heavy metals in the soil. The texture of clay and organic matter can determine the absorbency of nutrients or heavy metals on negative charges or fixation of the structure of the interlayer silicate aluminate. The texture of clay can affect attractiveness on negative charges such as C-organic, while silt textures attract fewer ions than clay. The amount and soil texture type determines the magnitude of ion adsorption (Purbalisa *et al.* 2019). The number of cations on a negative charge is equal to CEC. Heavy metals are closely related to soil organic matter levels and soil pH. Organic matter causes chelation in metal cations, making nutrients available to plants. If the pH is low, the concentration of heavy metals is high and is easily absorbed by plants. This condition also indicates a possible influence on the development of microorganisms (Komarawidjaja 2017).

TABLE 2

Physical and chemical characteristics of industrially polluted farmland soil

Parameters	Rate	Description
pH in H_2O	7.52±0.34	Neutral - alkaline
pH in KCl	6.23±0.47	Low-high
EC (mS cm^{-3})	0.51±0.23	Very Low
Org-C (%)	1.85±0.72	Very Low - high
CEC ($cmol_c$ $kg^{-1)}$	5.92±1.35	Very Low-Low
P-Olsen (ppm)	73.84±42.06	High – Very high
N-total (%)	0.29±0.01	Very low
C/N ratio	22.23	
Clay (%)	7.75±1.83	Low
Exchangeable-K ($cmol_c$ kg^{-1})	0.97±0.01	Low-very high
Exchangeable-Na ($cmol_c$ kg^{-1})	0.34±0.10	Very low-medium
Exchangeable-Ca ($cmol_c$ kg^{-1})	0.70±0.43	Very low
Exchangeable-Mg ($cmol_c$ kg^{-1})	0.94±0.38	Very low-medium
Base saturation (%)	50.31±16.90	Low-Very high
Zn (ppm)	82.28±51.83	Very high
Cu (ppm)	54.70±14.43	Very high
Fe (ppm)	1711.43	Very high
Mn (ppm)	844.25	Very high
Hg (ppm)	0.92±0.27	Very high
Pb (ppm)	1.47±0.29	Very high
Cd (ppm)	0.37±0.12	Very high

Source: Soil Chemical, Crops, Water and Fertilizer Analysis (Indonesia Soil Research Institute, 2005)

The results of the correlation analysis between observation variables are presented in Table 3. The variable that has the highest correlation value determines the factors of soil fertility through factor analysis. Variables analysed include H_2O pH, KCl pH, C-org, C/N N-total, P-Olsen, CEC, Exch. K, Exch. Na, Exch. Mg, Zn, Cu, Fe, Mn, and soil clay.

TABLE 3

Correlation matrix of soil physical-chemical indicators

	pH H_2O	C-org	CEC	N-total	Exch. K	Exch. Na	Exch. Mg	Zn	Cu	Fe	pH KCl	C/N	Cd	P-Olsen	Clay	Mn
pH H_2O	1,00	**-.564****	0,12	-0,15	-0,01	-0,41	0,37	-0,40	**-.607****	0,02	**.914****	-0,06	-0,42	**-.460***	**-.460***	**-0,07**
C-Org		1,00	-0,41	-0,35	-0,29	0,25	**-.686****	**.826****	**.854****	-0,10	-0,41	**.637****	**.609****	**.527***	**.527***	0,43
CEC			1,00	0,41	.554*	0,19	0,30	-0,30	-0,23	0,02	0,03	-0,40	-0,19	-0,09	-0,09	0,05
N-total				1,00	0,43	**.590****	**.590****	-0,38	-0,23	-0,03	-0,28	**-.908****	**-.526***	0,28	0,28	-0,24
Exch. K					1,00	-0,01	0,29	-0,30	-0,17	0,08	-0,19	-0,36	-0,23	0,10	0,10	0,16
Exch. Na						1,00	0,05	0,23	0,31	-0,10	**-.474***	-0,37	-0,07	0,44	0,44	-0,02
Exch. Mg							1,00	**-.592****	**-.687****	-0,11	0,24	**-.738****	**-.649****	-0,18	-0,18	-0,36
Zn								1,00	**.881****	**-.528***	-0,20	**.615****	**.486***	0,26	0,26	**.520***
Cu									1,00	-0,36	**-.466***	**.510***	**.489***	0,31	0,31	**.648****
Fe										1,00	-0,17	0,02	0,14	0,08	0,08	-0,40
pH KCl											1,00	0,05	-0,36	-0,40	-0,40	-0,06
C/N												1,00	.687**	-0,08	-0,08	0,39
Cd													1,00	-0,01	-0,01	0,29
Polsen														1,00	**1.00****	0,05
Clay															1,00	0,05
Mn																1,00

The factor analysis of selected soil characteristic variables resulted in five main components (PC1 - PC5) with a composite value of 85.68%. The results of the matrix correlation analysis led to the grouping of soil characteristic variables into the main components (PC). Furthermore, PC integration is carried into the formula for calculating SFI. The weight index (wi) is calculated based on the division of the proportional value of the variable in the PCA column, with the highest cumulative value having an eigenvalue greater than 1, which is 85.68% (Table 4).

wi= proportion/ cumulative......................... (5)

TABLE 4

Determining component factors of SFI of polluted land

	Main Component (PC)									
	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10
Eigenvalue	5.48	3.66	1.85	1.67	1.05	0.76	0.51	0.38	0.28	0.14
Proportion	34.24	22.85	11.59	10.44	6.57	4.76	3.21	2.35	1.73	0.86
Cumulative	34.24	57.09	68.68	79.11	85.68	90.45	93.65	96.00	97.73	98.59

The results of the factor analysis of the 16 soil characteristics showed that the first level of determinants were C-organic, C/N ratio, total-Fe, total-Cu, and total-Cd. N-total and Exch-Na were at the second level, clay-texture and available-P at the third level, pH in KCl, total-Zn, and total-Mn at the fourth level, and pH in water, CEC, Exch. K, and Exch. Mg soil at the fifth level of determining factors. The sixteen variants (wi)of the soil features were calculated and multiplied by the value of s_i (variable score) to obtain the score of Sci (equation 6) The variable soil characteristics were scored 1-5 according to the method of Bagherzadeh *et al.* (2018).

Sci= wi x si............ .... (6)

The SFI value is calculated based on a formula presented in Equation 1. The results of the simulation of SFI calculations with different soil characteristic variables are presented in Table 7. The selected determinants of soil characteristic indicators greatly affect the value of SFI. If all high-correlated elements are included in the SFI calculation, then the SFI value is lower, about 40-45%. If the correlation of soil characteristics is low, Ca and some microelements are not included in the SFI assessment. This will lead to a greater SFI value (Table 5).

TABLE 5

SFI values of industrial polluted land

SFI	Industries			
	Plastic	Pharmacy	Feed	Paper
Value	0.45- 0.65	0.44-0.63	0.42-0.52	0.44-0.55
	Low -Medium	Low -Medium	Low -Medium	Low -Medium

Note: Data processing with factor analysis; SFI, soil fertility index

Overall, the soil fertility index in a land polluted with industrial waste is low to moderate, depending on the determinants of soil characteristics indicators. The variety of heavy metals greatly affects the availability of essential plant nutrients. N, P, K, Ca and Mg availability becomes low because the soil trap is filled with heavy metal ions. Although the P-Olsen measurement results are high, its position in the trap is easily bound by soil metals because it is positively charged, causing P to be unavailable to plants.

The content of organic matter plays an essential role in the concentration of heavy metals. The low content of organic matter in the soil causes an increase in concentration of metals This is because organic matter is one of the most important components in the soil. It plays a role in the development of soil structure, regulates the transfer of pollutants in the soil, and plays an important role in the cycle of turnover and storage of nutrients and water. Humic compounds also play a role in forming complex bonds with metals. The presence of complex formations affects the reactivity and toxic effects of the metal (Adhani and Husaini 2017).

Plant Response to Heavy Metal Contamination

The research was arranged in a Randomized Group Design with two factors. The first factor was two types of food crops (rice and maize as indicators of metal uptake). The second factor was four kinds of agricultural land near the pollutant source, namely from waste in the paper, pharmaceutical, animal feed, and leather industries. Each treatment was repeated thrice. Soil samples were taken at 0-20 cm depth and then dried and ground. The soil samples were sifted with a 2-mm sieve. The soil subsamples were weighed to 5 kg TKO and put into a pot for metal uptake and plant growth tests. NPK fertilizer equivalent to 350 kg ha^{-1} was added to meet the nutritional needs. Maize and rice crops were planted on all four lands. Each treatment was repeated thrice. So, the total number of treatments was 2x4x3= 24. Plants were harvested after 30 days of planting, and all plant parts were dried at a temperature of 60-70ºC, then mashed and sifted to pass a 0.1-mm sieve. HCLO 4 was added to the finely meshed plants at a ratio of 1g: 4 ml (plant material: digestion solution) and boiled until the solution was clear. This solution was used to determine Pb and Hg metal levels using AAS. The results of the descriptive analysis of metal levels in the soil and plant tissues are presented in Table 6**.** Soil Pb content was greater than the soil Hg content. Both food crops were found to absorb heavy metals in small quantities.

TABLE 6

Descriptive analysis of metal levels in plant tissue and soil

No	Plant	Descriptive statistics	Pb (ppm)		Hg (ppm)	
			Plant	Soil	Plant	Soil
1	Corn	Mean	0.01 ±0.01	0.03±0.01	0.01±0.00	0.03±0.01
		Median	0.01	0.03	0.01	0.03
		Minimum	0.01	0.02	0.00	0.02
		Maximum	0.01	0.04	0.01	0.05
2	Rice	Mean	0.01±0.00	0.05±0.01	0.01±0.00	0.03±0.01
		Median	0.01	0.05	0.01	0.03
		Minimum	0.01	0.03	0.00	0.02
		Maximum	0.01	0.07	0.01	0.05

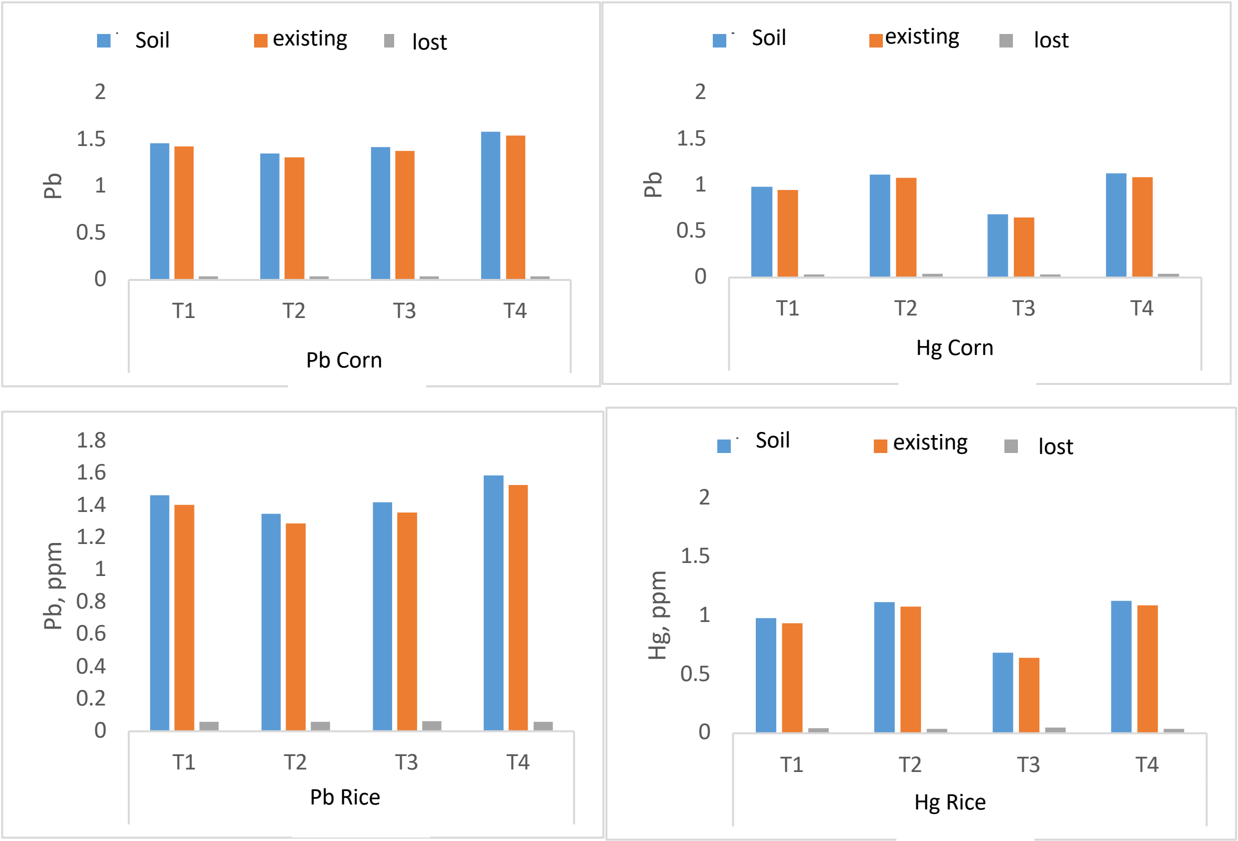

Figure 2. Soil Pb and Hg levels in rice and maize crops

Levels of Pb and Hg elements in maize and rice plants aged 30 DAP (Figure 2), show that rice absorbed a higher amount of metal than corn. Though rice growth as measured by plant length differed between polluted lands, the difference was more clearly seen in maize plants than in rice plants. The number of leaves and the length of the plant did not differ markedly between treatments.

Rice plants can absorb more soil metals compared to maize. Rice has root fibres that have a high ability to absorb nutrients in the soil. The maize plant, although rooted in fibres, has fewer root hairs causing its absorption ability to be less than the maximum. Rice plants are considered the most tolerant to cultivation in polluted land, and it may be suspected that rice can adapt to metal-polluted environments. However, the accumulation of metals in rice plants is harmful when consumed by humans. Root growth and leaf count positively correlated with the amount of metal in the soil. Plant growth is inhibited if the metallic elements in the soil exceed their needs. A high level of almost all metals was found in the soil.

The results of the correlation between plant growth attributes show that plant root length was negatively correlated with plant length (Table 8). All plant growth attributes were negatively correlated to soil Hg levels but positively correlated with soil Pb except for plant length. This shows that Hg is very dangerous to plant life in soil, especially leaf growth which becomes inhibited. However, the existing level of Pb in soil is still safe for plant growth.

TABLE 7

Response of maize and rice plant growth to heavy metal contamination under various field conditions

Farmland near	Root length (cm)	Number of leaves	Plant length (cm)	Plant Length Corn (cm)	Plant Length Rice (cm)
Paper mill	43.25	11.67	30	9.80 c	0.00 a
Pharmaceutical factory	39.65	21.33	59.95	9.40 c	0.00 a
Animal feed mill	30.65	12.33	61.93	10.43 c	0.00 a
Leather factory	32.9	13.17	57.38	7.03 b	0.00 a
LSD 5%	ns	ns	54	1.38	ns

Note: ns= not significance, LSD = least square design

TABLE 8

Correlation test between heavy metal levels and plants

	Root length	Number of leaves	Plant length	Existing Pb	Existing Hg
Root length	1				
Number of leaves	0.25	1.00			
Plant Length	**0.76**	0.43	1.00		
Existing Pb	0.46	0.49	0.12	1.00	
Existing Hg	0.30	**0.64**	0.16	0.24	1

Note: Pb, lead; Hg, mercury

CONCLUSION

The degree of heavy metal pollution in agricultural land near industries affects the physical, chemical, and biological characteristics of the soil and plant growth. The value of SFI is obtained through factor analysis of highly correlated soil features. The main factors determining the low value of SFI are soil pH, soil texture, and heavy metal content, mainly Fe. The SFI value of agricultural land around the industries in the Sidoarjo area is low to moderate, depending on the various variables used for assessment. Growth of rice and maize crops in the region was inhibited because of relatively high metal absorption.

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