The Long-term Changes in Heavy Metals Content of Sawah Soil in Relation to Land Management and Cultivation Intensity

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Abstract

Escalating intensity of rice cultivation has increased the burden on to the land in Indonesia through massive additions of chemical fertilizers and pesticides. To examine the long-term effects of intensive rice cultivation on the heavy metal content in sawah soil, a comparative study was conducted in Java, Indonesia. The term sawah refers to leveled and bounded rice fields with inlets and outlets for irrigation and drainage. Soil samples collected in 1970 and new samples from the same sites or close to the original sites were analyzed and compared. For the 40 sites studied, the topsoil layer had increased mean levels of several extractable heavy metals. Lead (Pb) increased from 6.02 to 8.67 ppm (65.5%), boron (B) from 5.92to 7.01 ppm (18.5%), cadmium (Cd) from 1.00 to 1.41 ppm (42.1%), cobalt (Co) from 1.82 to 2.24 ppm (28.6%), copper (Cu) from 7.51 to 8.57 ppm (18.0%), manganese (Mn) from 122.10 to 133.24 ppm (9.8%) and zinc (Zn) from 5.64 to 7.58 ppm (39.5%). The change in the average content of these heavy metals throughout the soil profile was smaller than that in the topsoil layer. Iron (Fe) was the only parameter that decreased over the study period. In the topsoil layer, Fe decline from 175.54 to 149.05 ppm (14.0%), while throughout the soil profile it decreased from 158.89 to 96.44 ppm (9.9%). The changes in extractable heavy metal content are strongly related to chemical fertilizer application and the increase in cultivation intensity. The initial content for all heavy metals examined was higher at seedfarm sites than at non-seedfarm site, because rice was planted at a higher cultivation index and chemical fertilizers were applied according to government recommendations at seedfarm sites. At non-seedfarm sites, on the other hand, rice and upland crops were planted in various rotation patterns with regular use of manure and low doses of chemical fertilizers. In 2003, both sites had equal cultivation indexes; thus, the changes in cultivation intensity at non-seedfarms were greater than at seedfarms over the study period. This resulted in a similar percentage change in the heavy metal content in this soil. Over the study period, the Pb content at seedfarms and non-seedfarms changed by 50.6% and 80.7%, respectively, while changes at seedfarm and non-seedfarm sites for other heavy metals were 20.1% and 17.3% for B; 43.4% and 42.7% for Cd; 27.0% and 22.9% for Co; 17.3% and 18.0% for Cu; -13.8% and 14.0% for Fe; 11.3% and 9.1% for Mn and 27.2% and 47.0% for Zn, respectively. The application of manure might be the main contributor to the large gap between the changes in Pb and Zn content at seedfarm and non-seedfarm sites.

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1. Introduction

Java Island is an island of contrasts. Although the area of Java Island comprises only about 7% of the total land area of Indonesia, the island supports over 130 million people, which constitutes about 60% of Indonesia's total population, at a density of about 1,100 people per square kilometer. This places Java as the most populated island in the Indonesia archipelago (BPS, 2006). Indonesian history has seen this island become an attractive place to live for many people arriving from neighboring islands for several reasons. The nutrient rich lava and ash from Java's many volcanoes have created soil on the island that is much more fertile than that on other islands of the archipelago. In addition, Java is the center of government in Indonesia, and has also become the hub of various industries, especially in areas adjacent to the main cities of the island (Figure 1).

The Food and Agriculture Organization (FAO) (2001) reported that Indonesian people consume 230 kg rice per capita per year. As the major source of calories for more than 220 million people, rice is cultivated intensively, especially in the irrigated sawah of Java. Sawah are leveled and bounded rice fields with inlets and outlets for irrigation and drainage. Since Green Revolution (GR) technology was introduced into Indonesia in the mid-1960s, the cultivation index for rice increased from 1.8 per year to almost 3.0. To support the adoption of GR technology, the Indonesian government established numerous research stations (seedfarm) for rice cultivation throughout Java and supported them with high-quality irrigation facilities, chemical fertilizers, and pesticides as well as qualified staffs. The main function of seedfarms was to facilitate technology transfer from the researchers, mostly from International Rice Research Institute (IRRI) to the farmers and also to act as a food security buffer for the country (Indonesian Ministry of Agriculture, 2001).

Kawaguchi and Kyuma (1977) noted that in 1970, all seedfarms in Java were practicing GR technology through the use of high-yielding varieties (HYVs) of rice, chemical fertilizers and pesticides, and produced about 4.5 Mg ha^{-1} of husked rice on average. As a food security buffer, seedfarms were planted with rice all year round in a monoculture system and chemical fertilizers were applied following the government recommendations of 200 kg urea [$CO(NH_2)_2$], 150 kg super-phosphate [$Ca(H_2PO_4)_2$] and 100 kg potassium chloride (KCl) per hectare per cropping season (Lansing *et al.*, 2001). On the other hand, non-seedfarms were planted with rice and upland crops in rotation with low doses of fertilizers due to water shortages and the limited budgets of farmers.

Brookes (1995) has stated that improper use of inorganic fertilizers has been polluting agricultural land worldwide. In addition, dietary intake of heavy metals via the soil-crop system is considered to be the predominant pathway of human exposure to environmental toxic heavy metals (Chang and Page, 1996; Chang *et al.*, 2002; Swartjes, 1999). The main purpose of this study was to examine the long-term changes in heavy metal content in sawah soils in relation to land management practices and cultivation intensity.

2. Materials and Methods

2.1. Soil samples

Soil samples were collected from each horizon in a profile using 100 cm^3 core samplers to determine the bulk density of soil. Composite soil samples from each horizon were also collected for chemical analysis. In order to obtain the latest information regarding the changes in rice cultivation systems and productivity at seedfarms and non-seedfarms during the period from 1970 to 2003, the staff and farmers working at seedfarm sites were interviewed with the assistance of interpreters.

Soil samples collected in 1970 by Kawaguchi and Kyuma (1977) were used as references in this study. The new samples were collected in 2003 from the same sites or sites closest to the 1970 sampling sites. Figure 1 shows the distribution of sampling sites both in 1970 and 2003. Among the 46 sites sampled in 1970, six were not sampled in 2003 as the land use had changed during the 33-year period. Soil samples were collected from a total of 40 sites in 2003, with 22 located in non-seedfarms and the other 18 sites in seedfarms.

2.2. Laboratory analyses and calculations

The air-dried soil samples were ground and passed through a 0.5 mm sieve. Extractable heavy metals were determined after extracting with 0.25 M HCl by in-

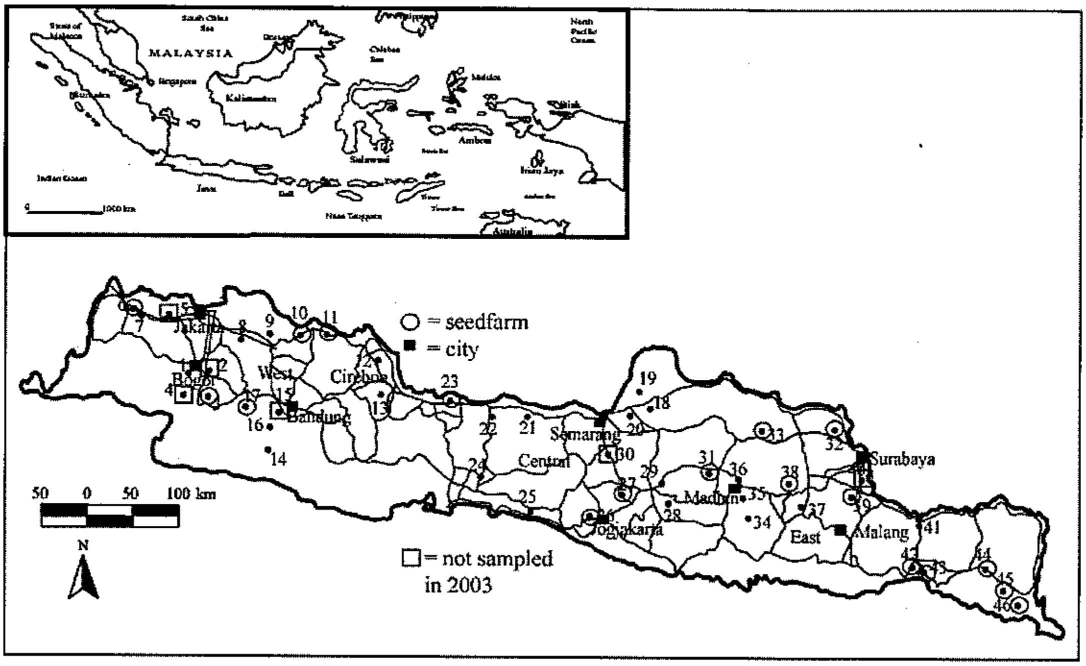

Figure 1. Map of Java Island in Indonesia (inset) showing sampling sites (numbered) and major cities and road networks throughout the island.

ductively coupled plasma-atomic emission spectroscopy (Shimadzu ICPS 2000). To calculate the mean extractable heavy metal content within the soil profile (0-100 cm), each layer of the soil sample was analyzed and then the sum of the heavy metal content was divided by the amount of soil in each layer for each sampling site.

A statistical software program (SPSS version 11.0 for Windows) was used to statistically examine the effects of GR on the levels of heavy metals in the soil during the period from 1970 to 2003. The mean values for the samples collected in 1970 were compared with 2003 samples, taking the different land management practices (seedfarms and non-seedfarms) as categories. To examine the long-term effects of industrial activities on changing patterns of heavy metal content, samples were grouped into urban and rural sites.

3. Results and Discussion

3.1. Long-term changes in heavy metal content of sawah soils

Table 1 shows the changes in cultivation intensity from 1970 to 2003. Within the study period, cultivation intensity found increased at all study sites. In 1970, rice and upland crops were planted at all non-seedfarm sites in various rotation patterns, while rice was planted at most seedfarms throughout the year in a monoculture system (Kawaguchi and Kyuma, 1977). This situation had drastically changed by 2003, where no clear difference was found between seedfarm and non-seedfarm sites in terms of land use pattern, indicating that the cultivation intensity at non-seedfarm sites increased to a greater extent over the period than that at seedfarms.

From a total of eight heavy metals examined in this study, seven were found to have increased with high variation between sites. Extractable iron (Fe) was the only parameter to have declined over the study period. Tables 2 and 3 show that the changes in heavy metal contents in sawah soil mostly occurred in the topsoil layer, rather than throughout the soil profile. In the topsoil layer (0-20 cm), the average content of extractable heavy metals changed from 6.02±2.03 to 8.67±2.07 ppm for Pb; 5.92±1.73 to 6.94±1.89 ppm for B; 1.00±0.26 to 1.41±0.37 ppm for Cd; 1.82±0.74 to 2.24±0.79 ppm for Co; 7.51±3.55 to 8.57±3.76 ppm for Cu; 175.54±56.27 to 149.05±43.73 ppm for Fe; 122.10±31.41 to 133.24±33.37 ppm for Mn nd 5.64±3.16 to 7.58±3.68 ppm for Zn. The extractable Pb had the highest rate of increase (65.5%), followed by Cd (42.1%), Zn (39.5%), Co (28.6%), B (18.5%), Cu (18.0%) and Mn (9.8%), while in the same period Fe decreased by 4.0%. The extractable heavy metal content throughout the soil profiles (0-100 cm) increased by less than that in the topsoil layer (0-20 cm). The extractable Pb increased by 30.0% (3.64±1.26 to 4.66±1.53 ppm), B by 6.7% (3.62±1.13 to 3.86±1.26 ppm), Cd by 36.2% (0.41±0.10 to 0.56±0.15 ppm), Co by 13.7% (1.36±0.48 to 1.50±0.47 ppm), Cu by 12.8% (5.15±2.09 to 5.66±2.16 ppm), Mn by 8.9% (83.80±17.24 to 90.52±19.56 ppm), and Zn by 22.8% (3.80±1.85 to 4.57±2.07 ppm). Fe decreased by 9.9% (108.89±31.21 to 96.44±24.19 ppm). These data indicate that the increased heavy metal content in sawah soils is primarily attributable to human activities (Shanker *et al.*, 2005).

The different levels of extractable heavy metals among the study sites were possibly affected by location and farming practices at the site. The extractable heavy metals were found to have increased dramatically at sites located in the vicinity of cities such as Bogor (Sites 1and 3), Jakarta (Sites 6 and 7) and Bandung (Sites 14 and 16). The other possible explanation for this discrepancy is in-

Table 1. Site name, location, USDA Soil Taxonomy and the changes of land use pattern from 1970 to 2003 on each sampling site.

Sampling Code	Site name	GPS reading		Elevation	Land use pattern		USDA taxonomy	Note
		South	East		1970§	2003		
1	Kedung Halang, Bogor	S 06°33'0.6.3"	E 106°48'26.4"	213 m	rice-upland crop	upland crop	Aeric Epiaquepts	B-NS
3	Bendungan Ciawi, Bogor	S 06°39'43.2"	E 106°51'40.4"	529 m	rice-rice	rice-rice-upland crops	Aeric Epiaquepts	A-SF
6	Kebun Percobaan Singamerta, Ciruas	S 06°07'14.7"	E 106°14'36.5"	26 m	rice-rice	rice-rice-rice	Typic Epiaquepts	A-SF
7	Petung Sentul, Kragilan Serang	S 06°07'52.0"	E 106°16'16.5"	31 m	rice-upland crop	rice-rice-upland crops	Typic Halaquepts	B-NS
8	Pasir Gombong Lemahabang, Bekasi	S 06°07'52.0"	E 106°16'16.5"	31 m	rice-upland crop	rice-rice-upland crops	Typic Kanhapludults	B-NS
9	Palawad, Karawang	S 06°17'30.0"	E 107°21'13.6"	32 m	rice-rice	rice-rice-upland crops	Vertic Epiaquepts	B-NS
10	Balitpa Sukamandi, Subang	S 06°21'27.1"	E 107°38'38.2"	31 m	rice-rice	rice-rice-rice	Aeric Endoaqualfs	A-SF
11	LPPP Pusakanegara, Subang	S 06°16'43.0"	E 107°52'26.6"	22 m	rice-rice	rice-rice-rice	Vertic Epiaquepts	A-SF
12	Sudikampiran, Sliyeg Indramayu	S 06°29'00.7"	E 108°22'44.4"	22 m	rice-rice	rice-rice-upland crop	Vertic Endoaquepts	B-NS
13	Sampora, Cilimus Kuningan	S 06°51'32.3"	E 108°29'26.1"	452 m	rice-upland crop	rice-rice-upland crops	Typic Dystropepts	B-NS
14	Pamoyanan, Ketapang Bandung	S 06°00'08.5"	E 107°33'10.1"	685 m	rice-rice	rice-rice-upland crops	Typic Endoaquepts	B-NS
16	Warungkaweni Cipageran, Cimahi	S 06°51'17.4"	E 107°32'54.1"	825 m	rice-upland crop	upland crop	Mollic Fragiaquepts	B-NS
17	LPPP Ciheya, Ciranjang, Cianjur	S 06°50'15.7"	E 107°16'26.5"	209 m	rice-rice	rice-rice-rice	Aeric Epiaquerts	A-SF
18	Medini, Undaan Kudus	S 06°55'04.6"	E 110°47'43.7"	22 m	rice-upland	rice-rice-rice/upland crops	Vertic Endoaquepts	A-NS
19	Mayong Lor, Mayong Jepara	S 06°45'41.7"	E 110°45'08.4"	25 m	rice-upland crop	rice-rice-upland crops	Aquic Eutropepts	B-NS
20	Katonsari, Demak	S 06°54'42.2"	E 110°36'59.0"	17 m	rice-upland crop	rice-rice-upland crops	Typic Calciaquepts	A-NS
21	Kartoharjo, Buaran Pekalongan	S 06°55'19.5"	E 109°40'16.5"	14 m	rice-upland crop	rice-rice-upland crops	Aeric Epiaquerts	A-NS
22	Sirandu, Pemalang	S 06°54'11.5"	E 109°22'53.2"	25 m	rice-upland crop	rice-upland crop	Aeric Epiaquerts	A-NS
23	Seedfarm Bulakamba, Brebes	S 06°21'27.1"	E 108°57'07.0"	11 m	rice-rice	rice-rice-upland crops	Typic Natraquerts	A-SF
24	Bojong, Purbolinggo	S 07°24'44.4"	E 109°22'31.0"	45 m	rice-upland crop	rice-rice-upland crops	Typic Endoaquepts	B-NS
25	Lajer Ambal, Kebumen	S 07°44'45.6"	E 109°43'28.8"	22 m	rice-upland crop	rice-rice-upland crops	Vertic Endoaquepts	A-NS
26	Seed farm Wonocatur, Bantul	S 07°48'02.5"	E 110°24'27.3"	118 m	rice-rice	rice-rice-rice	Aeric Epiaquepts	A-SF
27	Humo Seed farm, Semangkak	S 07°42'29.5"	E 110°35'51.6"	159 m	rice-rice	rice-upland crop	Aeric Epiaquepts	A-SF
28	Jumapolo, Karanganyar	S 07°42'29.5"	E 111°00'04.8"	339 m	rice-upland crop	rice-rice-upland crops	Typic Dystrustepts	B-NS
29	Papahan, Tasikmadu Karanganyar	S 07°42'38.2"	E 111°17'17.2"	182 m	rice-upland crop	rice-rice-rice/upland crops	Typic Epiaquerts	A-NS
31	LPPP Ngale, Paron Ngawi	S 07°24'37.6"	E 111°22'18.3"	68 m	rice-rice	rice-rice-upland crops	Typic Calciaquerts	A-SF
32	BPMD Sukodadi, Lamongan	S 07°05'28.0"	E 112°19'41.7"	26 m	rice-upland crop	rice-rice-upland crops	Typic Epiaquerts	A-SF
33	BPMD Brenggolo, Bojonegoro	S 07°07'39.4"	E 111°45'21.1"	37 m	rice-upland crop	rice-rice-upland crops	Aeric Endoaquerts	B-SF
34	Kresek Wungu, Madiun	S 07°41'47.9"	E 111°36'58.0"	277 m	rice-upland crop	rice-rice-upland crops	Aeric Epiaquepts	B-NS
35	Banjarsari, Dagangan Madiun	S 07°41'01.5"	E 111°35'49.2"	214 m	rice-upland crop	rice-rice-rice	Typic Calciaquerts	B-NS
36	Patang, Nglames Madiun	S 07°35'31.1"	E 111°32'51.6"	74 m	rice-rice	rice-rice-upland crops	Typic Epiaquerts	A-NS
37	Pelem, Paree Kediri	S 07°45'58.8"	E 112°10'02.4"	113 m	rice-upland crop	rice-rice-upland crops	Typic Epiaquepts	B-NS
38	Seed farm Waung, Baron Nganjuk	S 07°35'51.7"	E 112°02'03.3"	56 m	rice-upland crop	rice-rice-upland crops	Aeric Epiaquepts	A-SF
39	LPPP Mojosari, Mojokerto	S 07°30'27.9"	E 112°31'36.6"	33 m	rice-upland crop	rice-rice-rice	Aeric Epiaquepts	A-SF
41	Maron Kulon, Maron Probolinggo	S 07°50'48.8"	E 113°21'02.2"	78 m	rice-upland crop	rice-rice-rice/upland crops	Typic Epiaquepts	A-NS
42	Labruk Kidul, Lumajang	S 08°08'45.4"	E 113°12'18.6"	89 m	rice-rice	rice-rice-rice/upland crops	Typic Epiaquerts	A-SF
43	BPMD Yasowilangun, Lumajang	S 08°12'58.8"	E 113°18'06.7"	30 m	rice-upland crop	rice-rice-rice	Aeric Endoaquerts	A-SF
44	Balai benih Srimurni, Arjasa Jember	S 08°07'10.4"	E 113°44'47.9"	181 m	rice-upland crop	rice-rice-rice	Fluvaquentic Epiaque	A-SF
45	LPPP Genteng, Banyuwangi	S 08°22'47.4"	E 114°08'37.0"	159 m	rice-rice	rice-rice-rice/upland crops	Aeric Epiaquepts	A-SF
46	Seed farm Sukorejo, Banyuwangi	S 08°29'30.7"	E 114°08'13.3"	93 m	rice-upland crop	rice-rice-rice	Typic Calciaquerts	A-SF

Notes: A = original site; B = close to original site; SF = seedfarm; NS = non-seedfarm; §= data from Kawaguchi and Kyuma dustrial influences. Sites located near industrial areas also exhibited remarkable increases in heavy metal content (Chien and Kao, 2000). The extractable heavy metal content in the soil samples from Sites number 21, 25, 29, 36, 39, 45 and 46, which are surrounded by facilities for textile production, leather and wood processing, dry battery manufacturing and other industrial activities, increased by more than the average value for all sites studied. This was particularly the case for extractable Pb and Cd content, which increased in these samples by more than 50% from 1970 to 2003. Many anthropogenic activities, such as leather processing, electroplating, wood preservation and production of rechargeable nickel-cadmium batteries, have released large amount of heavy metals such as Cd and Pb into the natural environment, causing widespread heavy metal contamination worldwide (Jarup, 2003; Nriagu, 1988 and Shanker *et al.*, 2005).

Although the overall heavy metal content showed a remarkable increase, extractable Fe declined over the study period. The average Fe content in the topsoil layer declined from 175.54±56.27 ppm in 1970 to 149.05±43.73 ppm in 2003; while within the soil profile the total extractable Fe decreased from 108.89±31.21 in 1970 to 96.44±24.19 ppm in 2003. The greatest decrease rate was recorded at seedfarm Balitpa Sukamandi (Site 10), which decreased by 30%, whereas the smallest decrease was at Site 16 (Warungkaweni). Among the 40 sites studied, Sites 7 and 25 exhibited the opposite trend and increased by 7.5% and 5.1%, respectively. This opposing trend could be the result of the different land management practices at these two sites. The sawah soil at these sites is often dug up and used as raw material to make a bricks for house construction. Due to this activity, the topsoil has been removed and never replaced, making the soil more similar to upland soils, even though the sawah was established a long time ago.

The correlation matrix of soil samples taken in 1970 indicated that the soil pH significantly correlated with extractable Pb ($p<0.01$) and Co ($p<0.05$). Strong correlation was also found between the heavy metals themselves. The extractable Fe was found to have a close relationship with Co, Cu and Mn; while Pb strongly correlated with extractable B (Table 4). It appears that the extractable heavy metal content in sawah soils is influenced by soil pH.

After 33 years of intensive rice cultivation with application of chemical fertilizers and pesticides, the correlation patterns of extractable heavy metals in Java sawah soils had changed. In 2003, the extractable Pb positively correlated with Cd ($p<0.01$) and cultivation intensity. The reverse trend was found between extractable Pb and manure application, where extractable Pb negatively correlated with manure application (Table 4). These data indicate that the main source of Pb and Cd in the sawah soils was possibly chemical fertilizer application (Brookes, 1995).

3.2. Effects of land management and cultivation intensity on change in extractable heavy metal content

Increases in cultivation intensity place greater burdens on the land due to the addition of large amounts of chemical fertilizers and pesticides. According to Lansing *et al.* (2001), the Indonesian government urged farmers to use 125 kg $Ca(H_2PO_4)_2$, 100 kg potassium as KCl and 200 kg $CO(NH_2)_2$ per hectare per cropping season. Since the average cultivation intensity in Java is 2.5, every hectare of sawah received at least 312.5 kg $Ca(H_2PO_4)_2$, 250 kg KCl and 500 kg urea per year. This practice seems to have contributed to the differences in extractable heavy metal content of sawah soils in 1970. Seedfarms where rice had been planted in a monoculture system since the beginning of GR had higher levels of most heavy metals examined in this study (Table 5).

Although the cultivation intensity of seedfarms and non-seedfarms was similar in 2003 (Table 1), the land management differed between the site types. The Indonesian government supplied seedfarms with all the necessary supplies for rice cultivation. Futhermore, in order to guarantee the food security, most of the seedfarms were planted with rice over the whole year, using modern cultivation management systems. On the other hand, rice cultivation at non-seedfarm sites was affected by the availability of water, chemical fertilizers and pesticides, depending on each farmer's budget. Most non-seedfarms were managed by farmers, making the history of chemical fertilizer application on these sites difficult to track (Darmawan *et al.*, 2006). These differences in land management practices could explain some of the differences in

Table 2. Changes in extractable lead (Pb), boron (B), cadmium (Cd) and cobalt (Co) content in top soils and within the soil profile of sawah soils in Java in 1970 and 2003. All values are given in parts per million (ppm).

Site number/name	Extractable lead (Pb) 0-20 cm 1970	0-20 cm 2003	0-20 cm % change	0-100 cm 1970	0-100 cm 2003	0-100 cm % change	Extractable boron (B) 0-20 cm 1970	0-20 cm 2003	0-20 cm % change	0-100 cm 1970	0-100 cm 2003	0-100 cm % change
1. Kedunghalang Bogor	4.35	6.71	54.1	4.23	5.25	24.2	2.83	4.56	61.0	2.40	2.54	5.8
3. Bendungan Ciawi	4.18	8.47	102.9	2.43	3.01	24.1	3.43	5.04	47.0	2.71	2.86	5.5
6. Singamerta Ciruas	8.38	9.37	11.7	2.82	3.79	34.1	2.83	3.40	20.1	1.42	1.54	8.5
7. Petung Sentul	6.57	7.14	8.7	2.61	2.87	10.0	1.28	1.37	6.5	0.87	0.93	7.3
8. Pasir Gombong	3.08	5.28	71.2	2.10	2.86	36.2	2.44	2.78	13.7	1.66	1.77	6.5
9. Palawad Karawang	8.88	9.42	6.0	3.61	3.90	8.0	2.37	3.24	37.1	1.90	1.86	-2.4
10. Balitpa Sukamandi	6.32	9.48	50.1	4.03	4.68	16.2	3.12	3.57	14.4	1.95	2.14	9.7
11. LPPP Pusakanegara	4.19	7.29	73.9	2.61	3.35	28.5	4.89	5.46	11.8	2.94	2.26	-23.2
12. Sudikampiran Sliyeg	6.22	9.05	45.4	2.91	4.02	38.4	5.28	5.91	11.9	2.04	2.43	19.0
13. Sampora Cilimus	4.84	6.30	30.3	1.89	2.69	42.0	5.65	6.94	22.9	2.54	2.55	0.5
14. Pamoyanan Ketapang	7.00	8.43	20.5	3.61	4.21	16.6	6.96	7.25	4.3	3.97	3.42	-13.9
16. Warungkaweni Cipageran	0.46	3.70	701.0	2.12	3.19	50.7	6.27	7.61	21.2	3.60	3.86	7.1
17. LPPP Ciheya	5.73	10.19	77.7	3.62	4.66	28.7	6.31	7.29	15.6	3.59	3.74	4.2
18. Medini Undaan, Kudus	5.11	7.33	43.4	3.38	4.93	45.9	6.98	7.13	2.1	3.99	3.20	-19.9
19. Mayong Lor Jepara	3.34	5.67	69.8	2.66	3.71	39.4	7.42	8.06	8.7	4.49	4.71	5.0
20. Katonsari Demak	5.26	7.91	50.5	3.93	4.53	15.4	7.32	8.12	10.9	4.70	4.97	5.7
21. Kartoharjo Buaran	7.06	9.68	37.2	4.16	5.47	31.7	7.89	8.18	3.7	4.95	5.30	6.9
22. Sirandu Pemalang	4.06	8.21	102.1	3.11	4.93	58.2	7.02	8.75	24.5	4.68	4.61	-1.3
23. Bulakamba Brebes	7.21	11.74	62.7	6.24	8.89	42.5	7.01	9.58	36.6	4.76	4.74	-0.6
24. Bojong Purbolinggo	2.52	6.07	141.0	1.75	3.31	88.8	6.89	8.25	19.9	3.42	3.71	8.4
25. Lajer Ambal, Kebumen	3.08	6.59	114.3	2.25	2.74	22.1	6.95	7.47	7.6	3.63	3.96	9.3
26. Wonocatur Bantul	8.27	10.13	22.4	4.07	4.34	6.6	5.94	6.76	13.9	2.54	2.82	10.8
27. Semangkak Klaten	5.86	9.50	62.1	4.47	5.71	27.7	6.98	7.57	8.5	3.67	3.97	8.2
28. Jumapolo Karanganyar	3.97	5.52	39.0	2.26	3.23	42.7	5.12	6.13	19.7	3.73	3.70	-0.7
29. Tasikmadu Karanganyar	5.61	8.44	50.5	4.33	5.39	24.6	7.23	8.07	11.6	4.79	5.72	19.4
31. LPPP Ngale	7.77	9.72	25.2	2.93	3.53	20.5	7.92	8.31	4.9	4.73	4.90	3.6
32. BPMD Sukodadi	8.03	11.35	41.4	7.68	9.43	22.8	5.20	7.28	40.2	3.51	4.19	19.6
33. BPMD Brenggolo	8.84	10.60	20.0	6.16	6.87	11.5	6.32	7.21	14.1	4.79	4.97	3.9
34. Krese Wungu	4.65	6.82	46.7	4.06	4.87	19.8	7.17	8.96	25.1	4.14	4.52	9.0
35. Banjarsari Dagangan	6.38	8.46	32.5	3.89	4.99	28.2	6.78	7.97	17.6	3.83	4.39	14.5
36. Patang, Nglames	5.01	8.22	64.0	4.21	6.18	46.9	6.43	7.68	19.5	4.27	4.48	5.0
37. Pelem Paree	6.14	7.24	18.0	2.19	2.76	26.0	7.18	8.44	17.6	4.56	5.61	22.9
38. Waung Baron Nganjuk	8.92	10.25	14.9	5.07	5.68	12.1	7.14	8.78	23.0	5.28	5.70	8.1
39. LPPP Mojosari	7.29	11.62	59.5	5.25	6.38	21.6	5.20	6.59	26.6	3.10	3.22	3.9
41. Maron Kulon	6.64	8.60	29.4	4.04	4.94	22.3	7.57	8.64	14.2	4.63	4.90	5.9
42. Labruk Kidul Lumajang	7.16	10.53	47.2	3.27	4.04	23.5	6.24	8.01	28.3	4.68	4.99	6.7
43. BPMD Yosowilangun	7.58	10.54	39.0	4.61	4.98	7.9	6.56	7.74	18.0	3.17	4.42	39.4
44. Srimurni Arjasa	9.63	11.87	23.3	3.31	4.34	31.4	7.28	8.17	12.1	4.57	4.97	8.8
45. LPPP Genteng	7.98	12.89	61.5	4.18	6.49	55.2	7.18	7.78	8.4	4.85	4.97	2.5
46. Sukorejo Bangorejo	7.01	10.58	51.0	3.67	5.35	45.8	6.40	7.50	17.2	3.79	4.93	29.9
Mean	6.02	8.67	65.5	3.64	4.66	30.0	5.92	6.94	18.5	3.62	3.86	6.7
SD	2.03	2.07		1.26	1.53		1.73	1.89		1.13	1.26	
T-test		***			**	**		ns			***	

Site number/name	Extractable cadmium (Cd) 0-20 cm 1970	0-20 cm 2003	0-20 cm % change	0-100 cm 1970	0-100 cm 2003	0-100 cm % change	Exctractable cobalt (Co) 0-20 cm 1970	0-20 cm 2003	0-20 cm % change	0-100 cm 1970	0-100 cm 2003	0-100 cm % change
1. Kedunghalang Bogor	0.82	1.23	50.8	0.49	0.65	34.0	2.25	2.51	11.3	1.38	1.44	4.1
3. Bendungan Ciawi	1.36	1.84	35.0	0.54	0.73	36.2	1.05	1.57	49.4	1.30	1.20	-8.1
6. Singamerta Ciruas	1.19	1.44	21.9	0.38	0.63	66.3	1.09	1.21	11.1	1.02	1.11	8.6
7. Petung Sentul	0.92	1.48	60.7	0.44	0.79	80.0	0.95	0.67	-29.4	0.64	0.49	-22.6
8. Pasir Gombong	1.37	1.52	11.0	0.33	0.46	38.6	1.40	2.81	101.5	1.21	1.82	49.8
9. Palawad Karawang	0.63	0.90	43.1	0.25	0.45	79.8	3.55	3.16	-10.9	2.25	1.84	-18.1
10. Balitpa Sukamandi	0.86	1.23	43.5	0.34	0.47	39.7	2.88	3.14	8.9	1.75	1.93	10.0
11. LPPP Pusakanegara	0.92	1.30	41.4	0.34	0.43	26.8	3.22	2.61	-19.0	2.15	1.59	-26.2
12. Sudikampiran Sliyeg	0.56	0.63	12.2	0.28	0.33	19.4	2.18	2.38	9.2	1.94	2.03	4.4
13. Sampora Cilimus	0.64	0.97	51.9	0.31	0.32	4.2	2.08	2.75	32.6	1.76	1.73	-1.7
14. Pamoyanan Ketapang	0.71	1.13	58.9	0.30	0.46	52.2	0.66	0.77	16.9	1.46	1.50	2.9
16. Warungkaweni Cipageran	0.51	0.72	41.4	0.34	0.39	13.7	1.75	1.52	-13.3	1.72	1.69	-1.8
17. LPPP Ciheya	0.97	1.40	44.6	0.35	0.55	58.9	2.44	3.06	25.3	1.79	2.34	31.3
18. Medini Undaan, Kudus	0.83	0.94	12.4	0.49	0.71	43.9	0.64	0.94	46.2	0.70	0.75	5.8
19. Mayong Lor Jepara	0.72	1.02	42.2	0.33	0.49	49.7	2.06	2.15	4.5	1.77	1.81	2.3
20. Katonsari Demak	0.82	1.20	46.1	0.40	0.46	15.6	0.88	1.49	68.4	0.46	0.88	88.8
21. Kartoharjo Buaran	0.75	1.47	95.4	0.40	0.74	86.7	2.29	3.64	59.4	1.75	2.55	45.4
22. Sirandu Pemalang	0.82	1.12	36.0	0.35	0.39	9.9	2.47	2.26	-8.7	1.65	1.64	-0.6
23. Bulakamba Brebes	0.96	1.33	38.1	0.44	0.57	27.5	2.20	2.90	32.1	1.95	2.06	5.4
24. Bojong Purbolinggo	1.17	1.45	24.0	0.50	0.73	47.7	2.03	2.89	42.7	1.11	1.55	40.0
25. Lajer Ambal, Kebumen	0.72	1.12	56.3	0.29	0.32	11.0	1.49	1.93	30.0	0.96	1.11	15.8
26. Wonocatur Bantul	1.25	1.63	30.7	0.34	0.43	27.8	1.10	1.45	32.0	0.72	0.82	13.7
27. Semangkak Klaten	1.12	1.52	35.4	0.45	0.65	43.6	0.98	1.33	35.5	0.82	0.93	14.1
28. Jumapolo Karanganyar	0.66	0.93	39.8	0.29	0.35	19.5	2.25	2.62	16.6	1.41	1.58	12.4
29. Tasikmadu Karanganyar	0.80	1.24	55.1	0.56	0.72	29.9	2.13	2.80	32.0	1.66	1.69	1.9
31. LPPP Ngale	1.19	1.55	29.9	0.42	0.55	30.5	1.33	3.38	153.8	1.02	1.72	68.6
32. BPMD Sukodadi	1.29	1.61	25.3	0.61	0.71	16.6	0.90	1.29	44.2	0.99	1.15	16.3
33. BPMD Brenggolo	1.28	1.75	36.7	0.59	0.75	25.4	0.68	0.94	37.6	0.64	0.70	9.7
34. Krese Wungu	0.86	1.26	45.7	0.56	0.87	54.8	2.89	2.95	2.1	2.26	2.27	0.5
35. Banjarsari Dagangan	0.92	1.31	42.6	0.37	0.50	35.2	1.44	1.59	10.3	0.97	1.20	23.7
36. Patang, Nglames	0.90	1.44	59.8	0.52	0.69	32.2	1.39	1.89	36.1	0.99	1.32	33.3
37. Pelem Paree	0.96	1.16	21.8	0.25	0.32	27.6	1.38	1.95	41.3	0.65	0.84	30.5
38. Waung Baron Nganjuk	1.28	1.80	39.8	0.54	0.61	12.6	1.99	2.93	47.3	1.44	1.97	37.1
39. LPPP Mojosari	1.18	2.14	80.8	0.40	0.69	71.9	1.97	2.09	5.9	1.31	1.37	4.5
41. Maron Kulon	1.23	1.63	32.4	0.47	0.58	22.9	2.72	2.83	4.1	1.79	1.86	3.8
42. Labruk Kidul Lumajang	1.28	1.84	42.9	0.45	0.59	32.6	2.08	2.78	33.6	1.46	1.71	17.1
43. BPMD Yosowilangun	1.42	1.95	37.4	0.51	0.65	26.1	2.80	2.97	6.3	1.69	1.73	2.4
44. Srimurni Arjasa	1.49	2.23	49.4	0.41	0.52	27.4	2.06	2.62	27.5	1.28	1.10	-14.1
45. LPPP Genteng	1.25	1.94	55.0	0.38	0.51	34.7	1.21	2.10	73.1	1.11	1.38	25.0
46. Sukorejo Bangorejo	1.20	1.86	55.0	0.48	0.64	32.9	2.02	2.76	36.7	1.29	1.47	13.9
Mean	1.00	1.41	42.1	0.41	0.56	36.2	1.82	2.24	28.6	1.36	1.50	13.7
SD	0.26	0.37		0.10	0.15		0.74	0.79		0.48	0.47	
T-test		***			***						ns	

*** significant at 0.001 level; ** significant at 0.01 level; ns = not significant

Table 3. Changes in extractable Copper (Cu), Iron (Fe), Manganese (Mn) and Zinc (Zn) content in top soils and within the soil profile of sawah soils in Java in 1970 and 2003. All values are expressed as parts per million (ppm).

Site number/name	Extractable copper (Cu)						Extractable iron (Fe)						Extractable manganese (Mn)						Exctractable zinc (Zn)					
	0-20 cm			0-100 cm			0-20 cm			0-100 cm			0-20 cm			0-100 cm			0-20 cm			0-100 cm		
	1970	2003	% change	1970	2003	% change	1970	2003	% change	1970	2003	% change	1970	2003	% change	1970	2003	% change	1970	2003	% change	1970	2003	% change
1. Kedunghalang Bogor	6.21	4.55	-26.7	4.93	6.20	25.6	75.00	53.42	-28.8	49.41	56.08	13.5	70.63	76.70	8.6	61.74	65.00	5.3	8.28	13.92	68.1	3.73	5.56	49.3
3. Bendungan Ciawi	6.42	7.98	24.3	4.64	5.90	27.2	139.05	132.00	-5.1	100.88	76.10	-24.6	122.75	112.69	-8.2	78.26	67.12	-14.2	18.85	19.59	3.9	11.90	12.63	6.1
6. Singamerta Ciruas	5.02	6.40	27.4	2.76	3.25	17.6	89.57	65.20	-27.2	51.87	44.26	-14.7	99.49	82.84	-16.7	56.43	46.23	-18.1	13.89	13.79	-0.8	6.49	7.57	16.8
7. Petung Sentul	3.22	5.26	63.6	3.29	4.33	31.6	98.86	106.24	7.5	65.53	70.04	6.9	87.12	101.18	16.1	61.20	52.79	-13.7	2.32	3.76	62.0	1.91	2.88	50.5
8. Pasir Gombong	3.63	4.27	17.5	2.31	3.51	52.2	115.96	107.01	-7.7	41.05	48.34	17.7	87.54	95.69	9.3	52.87	60.27	14.0	3.46	6.69	93.3	2.31	4.23	83.1
9. Palawad Karawang	7.68	6.97	-9.3	5.90	4.25	-27.9	241.20	201.44	-16.5	127.57	117.57	-7.8	215.88	183.14	-15.2	129.05	128.79	-0.2	2.35	3.83	62.5	1.64	2.09	27.7
10. Balitpa Sukamandi	3.37	4.07	20.7	2.95	2.84	-3.9	299.73	209.91	-30.0	153.20	115.50	-24.6	111.83	142.80	27.7	80.30	80.25	-0.1	3.76	7.05	87.2	2.76	4.85	76.1
11. LPPP Pusakanegara	3.22	3.33	3.4	2.57	2.97	15.5	122.37	109.57	-10.5	87.26	79.90	-8.4	121.65	148.12	21.8	82.82	98.04	18.4	6.44	5.78	-10.3	4.44	4.23	-4.6
12. Sudikampiran Sliyeg	6.19	5.90	-4.7	5.14	4.36	-15.2	199.84	114.52	-42.7	108.65	86.31	-20.6	97.33	81.41	-16.4	75.65	81.93	8.3	4.40	7.36	67.5	5.29	6.62	25.3
13. Sampora Cilimus	10.01	9.00	-10.0	7.81	7.31	-6.4	114.89	102.60	-10.7	93.57	83.77	-10.5	129.36	133.78	3.4	73.06	84.40	15.5	3.86	5.96	54.5	3.28	4.11	25.2
14. Pamoyanan Ketapang	5.49	6.06	10.3	4.89	5.05	3.3	271.35	222.04	-18.2	150.67	131.06	-13.0	213.75	226.17	5.8	116.82	124.66	6.7	9.92	17.07	72.0	4.45	6.52	46.6
16. Warungkaweni Cipageran	11.29	12.78	13.2	9.91	10.46	5.5	219.87	214.96	-2.2	159.32	144.96	-9.0	113.08	115.26	1.9	91.56	101.26	10.6	7.74	8.83	14.0	5.31	6.04	13.7
17. LPPP Ciheya	6.70	7.10	6.0	4.74	4.69	-1.1	109.79	103.85	-5.4	103.41	102.09	-1.3	101.27	107.84	6.5	84.84	97.39	14.8	3.72	2.62	-29.5	1.92	1.78	-7.3
18. Medini Undaan, Kudus	0.60	0.97	60.8	0.59	0.82	38.0	119.78	110.85	-7.5	98.64	89.33	-9.4	141.02	169.67	20.3	112.24	128.04	14.1	2.76	4.38	58.4	1.64	2.50	52.9
19. Mayong Lor Jepara	8.66	11.67	34.8	7.19	9.49	32.0	264.99	185.98	-29.8	182.09	152.37	-16.3	129.89	142.51	9.7	92.89	110.57	19.0	5.69	8.83	55.2	5.02	6.45	28.6
20. Katonsari Demak	6.28	7.08	12.7	4.95	4.61	-6.9	143.25	138.36	-3.4	84.33	82.24	-2.5	98.24	99.41	1.2	74.57	78.44	5.2	3.68	5.31	44.3	2.80	3.19	13.7
21. Kartoharjo Buaran	5.21	7.74	48.6	4.10	5.28	28.6	259.20	219.31	-15.4	160.62	135.49	-15.7	125.60	133.18	6.0	96.73	107.12	10.7	5.59	6.67	19.3	4.63	4.95	7.1
22. Sirandu Pemalang	10.66	11.87	11.4	8.17	7.77	-4.9	201.89	155.76	-22.8	131.35	107.09	-18.5	122.76	130.35	6.2	97.20	91.01	-6.4	3.66	5.76	57.4	3.63	4.18	14.9
23. Bulakamba Brebes	11.49	11.59	0.9	7.64	7.37	-3.5	237.46	211.13	-11.1	154.16	127.15	-17.5	174.37	161.24	-7.5	113.56	119.65	5.4	5.62	6.58	17.0	4.48	4.79	7.0
24. Bojong Purbolinggo	15.39	14.36	-6.7	9.47	8.89	-6.1	266.91	219.33	-17.8	125.71	111.53	-11.3	115.07	167.11	45.2	82.76	96.93	17.1	9.30	13.59	46.1	7.05	9.55	35.5
25. Lajer Ambal, Kebumen	8.66	12.08	39.4	4.93	5.92	20.0	119.72	125.79	5.1	83.09	78.94	-5.0	137.79	185.81	34.8	95.00	113.48	19.4	2.95	3.98	35.0	3.70	3.99	7.8
26. Wonocatur Bantul	8.27	10.88	31.6	5.68	6.45	13.7	199.46	167.03	-16.3	116.11	112.55	-3.1	114.67	125.41	9.4	77.57	80.00	3.1	4.31	6.90	60.0	3.42	4.12	20.7
27. Semangkak Klaten	7.90	9.10	15.2	5.65	6.26	10.8	212.09	171.36	-19.2	125.29	102.85	-17.9	121.08	146.14	20.7	102.26	114.02	11.5	4.63	5.29	14.1	2.69	3.33	23.8
28. Jumapolo Karanganyar	8.05	11.02	36.9	6.64	8.29	25.0	178.88	148.98	-16.7	123.18	109.80	-10.9	135.75	155.03	14.2	92.46	105.70	14.3	5.80	8.94	54.1	4.64	5.57	19.9
29. Tasikmadu Karanganyar	5.83	7.30	25.2	4.96	5.50	10.9	169.02	128.38	-24.0	122.24	104.83	-14.2	99.52	106.55	7.1	90.93	86.34	-5.0	5.87	6.12	4.3	5.14	5.04	-2.0
31. LPPP Ngale	7.76	9.20	18.5	3.20	4.71	47.2	190.82	162.65	-14.8	100.73	97.47	-3.2	108.94	115.54	6.1	75.99	83.49	9.9	3.33	5.96	79.0	1.51	2.26	50.2
32. BPMD Sukodadi	2.94	3.42	16.3	2.42	2.55	5.5	149.59	124.10	-17.0	81.90	75.85	-7.4	102.32	104.27	1.9	75.54	84.37	11.7	2.97	3.54	19.0	2.85	3.02	5.9
33. BPMD Brenggolo	3.19	4.12	29.1	2.51	3.14	25.2	139.54	120.54	-13.6	82.51	73.18	-11.3	96.84	112.33	16.0	80.52	92.83	15.3	5.36	7.31	36.4	3.67	3.98	8.5
34. Krese Wungu	8.87	11.71	32.0	6.65	8.63	29.7	179.88	162.39	-9.7	124.59	113.21	-9.1	105.43	116.62	10.6	71.24	92.36	29.6	4.37	6.93	58.7	3.38	3.92	16.0
35. Banjarsari Dagangan	6.88	7.29	5.9	4.13	4.32	4.6	141.28	123.71	-12.4	91.63	81.86	-10.7	112.75	118.93	5.5	76.87	78.64	2.3	4.93	6.85	39.1	3.29	3.68	12.0
36. Patang, Nglames	7.83	8.44	7.8	5.91	6.80	15.1	176.49	169.28	-4.1	116.95	107.85	-7.8	127.26	133.30	4.7	103.38	102.99	-0.4	4.99	5.87	17.7	4.23	5.17	22.3
37. Pelem Paree	6.36	7.93	24.6	4.93	5.35	8.7	158.49	132.34	-16.5	95.42	85.70	-10.2	109.12	118.25	8.4	52.64	57.89	10.0	5.57	7.64	37.2	2.78	3.29	18.3
38. Waung Baron Nganjuk	9.81	10.74	9.5	6.92	7.47	8.0	162.52	154.61	-4.9	99.80	90.94	-8.9	96.65	155.09	60.5	72.24	87.22	20.7	4.95	6.30	27.1	3.92	5.00	27.7
39. LPPP Mojosari	6.20	6.61	6.6	4.42	4.44	0.5	149.84	129.73	-13.4	106.05	91.41	-13.8	112.86	114.81	1.7	75.06	77.43	3.2	2.35	4.29	82.4	1.62	1.90	17.3
41. Maron Kulon	10.25	11.14	8.7	6.26	6.50	3.8	155.23	132.95	-14.4	99.19	84.92	-14.4	108.54	121.66	12.1	72.19	81.97	13.6	5.36	6.30	17.4	4.19	4.39	4.8
42. Labruk Kidul Lumajang	15.79	16.76	6.1	6.10	6.59	8.1	239.38	223.44	-6.7	121.91	116.76	-4.2	159.28	186.70	17.2	84.29	96.74	14.8	5.36	6.92	29.1	2.87	3.34	16.2
43. BPMD Yosowilangun	15.25	17.21	12.8	7.87	9.18	16.6	238.83	183.79	-23.0	136.89	111.16	-18.8	114.38	139.03	21.6	81.58	94.48	15.8	5.65	6.99	23.6	3.14	3.29	4.7
44. Srimurni Arjasa	4.14	6.83	65.0	2.66	3.25	22.0	178.36	168.92	-5.3	117.64	95.80	-18.6	128.02	132.42	3.4	77.30	81.33	5.2	5.71	7.42	29.9	2.58	3.01	17.0
45. LPPP Genteng	13.66	15.28	11.8	6.89	7.35	6.6	123.22	104.49	-15.2	80.21	76.40	-4.8	118.02	127.68	8.2	75.26	78.53	4.3	8.32	13.32	60.1	4.84	5.80	19.9
46. Sukorejo Bangorejo	5.90	6.95	17.8	3.31	4.21	27.3	167.96	144.19	-14.2	101.12	84.81	-16.1	196.05	203.12	3.6	105.06	111.06	5.7	7.73	8.86	14.6	3.07	4.06	32.4
Mean	7.51	8.57	18.0	5.15	5.66	12.8	175.54	149.05	-14.0	108.89	96.44	-9.9	122.10	133.24	9.8	83.80	90.52	7.9	5.64	7.58	39.5	3.80	4.57	22.8
SD	3.55	3.76		2.09	2.16		56.27	43.73		31.21	24.19		31.41	33.37		17.24	19.96		3.16	3.68		1.85	2.07	
T-test		ns			ns			*			*			ns			ns			*			ns	

*** significant at 0.05 level; ns = not significant

Table 4. Correlations matrix of extractable heavy metals in the topsoils and sawah management practices in 2003 (left to right) and 1970 (up to down) for samples from Java, Indonesia

		Soil pH	Pb	B	Cd	Co	Cu	Fe	Mn	Zn	Manure	Cultivation intensity
							2003					
Soil pH			0.487**	0.267	0.218	-0.194	-0.091	-0.082	0.211	-0.207	-0.039	0.039
Pb		0.578**		0.306	0.444**	0.031	-0.110	0.078	0.225	-0.222	-0.421**	0.421**
B		0.304	0.446**		0.201	0.348*	0.015	0.189	0.297	0.132	-0.031	0.031
Cd		-0.205	0.134	0.160		-0.120	-0.117	-0.100	-0.048	0.063	-0.268	0.268
Co		-0.334*	-0.069	0.170	-0.001		0.343*	0.445**	0.262	0.069	0.071	-0.071
Cu	1970	-0.040	-0.105	0.047	-0.045	0.361*		0.522**	0.16	0.322*	0.216	-0.216
Fe		0.026	0.097	0.143	0.198	0.470**	0.488**		0.649**	0.015	0.130	-0.13
Mn		-0.074	0.185	0.151	0.307	0.273	0.167	0.610**		-0.145	0.100	-0.100
Zn		-0.280	-0.195	0.020	0.087	0.126	0.288	0.118	-0.035		0.082	-0.082
Manure		-0.276	-0.395*	0.069	0.083	0.072	0.238	0.064	0.087	0.090		-0.854**
Cultivation intensity		0.276	0.395*	-0.069	-0.083	-0.072	-0.238	-0.064	-0.087	-0.090	-0.854**	

**. Correlation is significant at the 0.01 level; *. Correlation is significant at the 0.05 level

the changes to heavy metal content in sawah soils.

Table 5 shows the effects of cultivation intensity and land management on the changes in extractable heavy metal content in Java sawah soils for seedfarms and non-seedfarms from 1970 to 2003. In the topsoil layer (0-20 cm), the extractable Pb, B, Cd, Co and Zn at seedfarms increased significantly at the 0.001-1005; 0.001 and 0.05 significance levels, respectively; while there were no differences found for Cu, Fe and Mn. Even though Cu and Fe changed more than 10 %, they were not found to be significantly different, owing to the wide variation in values among the sites studied (Table 5). The pattern of content changes was different for the same parameters at non-seedfarm sites.

In the topsoil layer, the extractable content of Pb, B, Cd, Co and Zn at seedfarms increased significantly from 1970 to 2003; from 7.05±1.58 to 10.30±1.41 ppm for Pb; 5.77±1.53 to 6.88±1.79 ppm for B; 1.18±0.19 to 1.70±0.31 ppm for Cd; 1.94±0.72 to 2.37±0.68 ppm for Co; and 6.75±4.29 to 8.11±4.32 ppm for Zn. The content of other heavy metals such as Cu, Fe and Mn changed, although not significantly, from 8.21±4.14 to 9.39±4.31 ppm for Cu; 177.98±58.96 to 151.95±45.30 ppm for Fe and 126.16±28.39 to 139.06±30.53 ppm for Mn, over the same period. The changes in heavy metal content at non-seedfarm sites differed from those at seedfarm sites. No significant differences were found for extractable Co; while Pb content increased greatly from 5.01±1.86 to 7.31±1.50 ppm (80.7%), followed by Zn from 5.13±2.12 to 7.48±3.40 ppm (47.3%) and Cd from 0.83±0.21 to 1.18±0.26 ppm (42.7%). Paired comparisons of the changes in heavy metal content between seedfarms and non-seedfarms revealed significant differences for Pb and Zn in the topsoil layer, while throughout the soil profile only Zn showed a significant difference (Table 5).

For the total soil profile (0-100 cm), only extractable Pb and Cd were found to have changed significantly over the study period at both seedfarm and non-seedfarm sites. The extractable Pb and Cd content at seedfarms increased by 27.1% and 37.7%, respectively, while at non-seedfarms these parameters increased by 33.5% and 36.8%, respectively. Statistically, the extractable Pb and Cd content at seedfarm and non-seedfarm sites were different at the 0.05 and 0.01 significance levels. A comparison of data obtained for the topsoil layer and throughout the soil profile indicates that most heavy metals accumulated in the topsoil. This might be because all sites studied were located in old sawah, except for Sites 6 and 7. The findings of this study are consistent with research conducted by Brookes (1995) and Oliver *et al.* (1994) who have stated

Table 5. Effects of cultivation intensity and land management system on the extractable heavy metal content at the topsoil (0-20 cm) and throughout the soil profile (0-100 cm) at seedfarm and non-seedfarm sites in 1970 and 2003 in Java, Indonesia

0-20 cm

Extractable heavy metal	Seedfarm				Non-seedfarm				T-test[b]
	n	Mean±SD 1970	Mean±SD[a] 2003	Change (%)	n	Mean±SD 1970	Mean±SD[a] 2003	Change (%)	
Lead (Pb) (ppm)	18	7.05±1.58	10.30±1.41***	3.25 (50.6)	22	5.01±1.86	7.31±1.50***	2.30 (80.7)	3.352**
Boron (B) (ppm)	18	5.77±1.53	6.88±1.79*	1.11 (20.1)	22	5.56±1.94	6.89±2.09ns	1.33 (17.3)	1.773[ns]
Cadmium (Cd) (ppm)	18	1.18±0.19	1.70±0.31***	0.52 (43.4)	22	0.83±0.21	1.18±0.26***	0.34 (42.7)	0.365[ns]
Cobalt (Co) (ppm)	18	1.94±0.72	2.37±0.68*	0.43 (27.0)	22	1.86±0.74	2.21±0.80ns	0.35 (22.9)	1.295[ns]
Copper (Cu) (ppm)	18	8.21±4.14	9.39±4.31ns	1.18 (17.5)	22	7.42±3.12	8.43±3.32ns	1.01 (18.0)	0.244[ns]
Iron (Fe) (ppm)	18	177.98±58.96	149.25±42.34ns	-26.03 (-13.8)	22	176.00±58.76	148.89±45.83ns	-27.11 (-15)	0.113[ns]
Manganese (Mn) (ppm)	18	126.16±28.39	139.06±30.53ns	12.09 (11.3)	22	121.98±35.01	132.35±36.68ns	10.37 (8.0)	0.258[ns]
Zinc (Zn) (ppm)	18	6.75±4.29	8.11±4.32*	1.36 (27.2)	22	5.13±2.12	7.48±3.40***	2.35 (47.0)	2.372*

0-100 cm

Extractable heavy metal	Seedfarm				Non-seedfarm				T-test[b]
	n	Mean±SD 1970	Mean±SD 2003	Change (%)	n	Mean±SD 1970	Mean±SD 2003	Change (%)	
Lead (Pb) (ppm)	18	3.98±1.05	5.05±1.48*	1.07 (27.1)	22	3.15±0.89	4.13±1.07**	0.98 (33.5)	0.621[ns]
Boron (B) (ppm)	18	3.53±1.14	3.82±1.27ns	0.29 (8.1)	22	0.85±0.31	0.96±0.43ns	0.20 (3.8)	1.568[ns]
Cadmium (Cd) (ppm)	18	0.42±0.07	0.58±0.09**	0.16 (37.7)	22	0.39±0.10	0.53±0.18**	0.14 (36.8)	0.383[ns]
Cobalt (Co) (ppm)	18	1.40±0.40	1.51±0.44ns	0.11 (8.9)	22	1.39±0.52	1.53±0.50ns	0.14 (14.6)	0.001[ns]
Copper (Cu) (ppm)	18	4.99±1.86	5.48±1.97ns	0.49 (11.2)	22	5.59±2.17	6.07±2.26ns	0.48 (12.1)	0.098[ns]
Iron (Fe) (ppm)	18	110.39±26.80	95.18±21.12ns	-15.21 (-13.0)	22	110.67±35.38	99.24±27.08ns	-11.83 (-8.1)	1.194[ns]
Manganese (Mn) (ppm)	18	83.12±14.23	88.63±19.02ns	5.51 (6.0)	22	85.14±20.20	92.30±22.10ns	7.16 (8.6)	0.780[ns]
Zinc (Zn) (ppm)	18	4.41±2.51	4.65±2.65ns	0.24 (18.0)	22	3.82±1.35	4.72±1.68*	0.90 (26.1)	2.119*

[a] Paired sample T-test; [b] Independent sample T-test between the change rate of mean values from 1970 to 2003 in Seedfarm and Non-seedfarm
***significant at 0.001 level; **significant at 0.01 level; *significant at 0.05 level; ns = not significant

that the improper use of chemical fertilizers might be a source of contamination in agricultural lands.

Conclusions

Rice is the major source of calories for the Indonesian people. The increasing population places greater pressures on sawah land as the main area for rice production. As the primary location for rice production, Java Island contains about 60% of the irrigated sawah with a high cultivation index. To ensure food security, a considerable amount of chemical fertilizers and pesticides are applied to sawah in Java, potentially contributing to the accumulation of heavy metals in these soils. This study found that some extractable heavy metals had increased over the 33-year period from 1970 to 2003. The pattern of the increases for the heavy metals studied was related to cultivation intensity and land management systems. At seedfarm sites, extractable Pb and Cd increased with the highest significant level, while at non-seedfarms Zn was also found to have increased considerably. Application of chemical fertilizers and sampling location might be responsible for the Pb and Cd accumulation, but for Zn, the increase appears to be caused by long-term addition of manure during cultivation. To determine whether these heavy metals have entered the food chain, we plan to analyze the heavy metal content of rice grains grown on sawah soils in future research.

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