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INFLUENCE OF LAND TYPE AND CROPPING ON THE DISTRIBUTION OF MICRONUTRIENTS IN GANGES RIVER FLOODPLAIN SOILS OF BANGLADESH

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Abstract

The soils of Ganges River Floodplain (GRFP), an important crop growing zone of the country, are known to be widely deficient in micronutrients. The study was conducted to relate the distribution and the fate of soil micronutrients in relation to land type, soil properties and cropping practices in GRFP. A total of 52 locations were selected for sample collection from across GRFP, varied in land type, soil series and cropping pattern, and analysed for DTPA extractable iron (Fe), manganese (Mn), copper (Cu), zinc (Zn) and hot water soluble boron (B). Most of the samples were found deficient in Zn and B, while a moderate number of samples were Fe-deficient. The major reason of micronutrient deficiency was found to be high soil pH. Among the four soil series studied, Ghior series was most deficient in Zn and B, implying pedogenic differences among the soils. Significant effect of contrasting land types on the distribution of soil micronutrients was observed although the effect was not consistent. The rice-rice cropping pattern was found to have slightly higher contents of Mn, Zn and B compared to rice-non-rice pattern which might be due to longer submergence period in the soils under rice-rice pattern.

Introduction

In Bangladesh, intensive cultivation of high yielding crops has increased crop production resulting in rapid depletion of soil nutrients through huge crop uptake. In addition to the well-identified deficiencies of the major nutrients, deficiencies of micronutrients have emerged considerably in large areas of the country(1). Recent studies revealed that the status of Zn and B decreased substantially in many soils of Bangladesh during the last decade(2). The soils of Ganges River Floodplain, the largest physiographic unit of Bangladesh comprising two important agro-ecological zones (AEZ), are most deficient in micronutrients among the intensively cropped AEZs of the country(3). In addition to the alkaline pH of Gangetic soils, inherited from their calcareous parent material, low soil organic matter (SOM) content and insufficient replenishment of the nutrients removed by the massive crop uptake have been attributed to the low content of Zn, B and Cu in those soils (1). Najafi-Ghiri *et al.*(4)

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reported that soil development, physiography, moisture and temperature significantly affect micronutrient distribution and availability in soil. The distribution of soil micronutrients is also affected by the topography and inundation land type(5). Likewise, variation in land use and cropping pattern influence the availability of micronutrients in soil. Han *et al.*(6) observed strong effects of land uses on soil micronutrient distribution in Mississippi, where paddy soils had higher Fe, Mn and Zn in potential labile fractions than grassland soils. Similarly, intercropping of rice with multiple crops having diverse root systems causes variation in the micronutrient distribution in soil(7). Likewise, submergence of soil for rice cultivation affects the availability of Zn and other micronutrients substantially(8), while puddling of soil has been reported to favour micronutrient extractability in soil(9). The changes in micronutrient level in soil solution during submergence may also be influenced by the landscape position or drainage class of soil(10).

Little information is available on the effect of land type on the distribution of micronutrients in the intensively cropped soils of Bangladesh. The aim of the study was to relate the distribution of soil micronutrients with various land types and rice-based cropping patterns in the Ganges River Floodplain soils to provide information for improved nutrient management.

Materials and Methods

Description of the study site: The study was carried out during 2018 in the Ganges River Floodplain (GRFP) soils (Figure 1). High GRFP and low GRFP are the two sections of GRFP and are demarcated as AEZ 11 and AEZ 12, respectively.

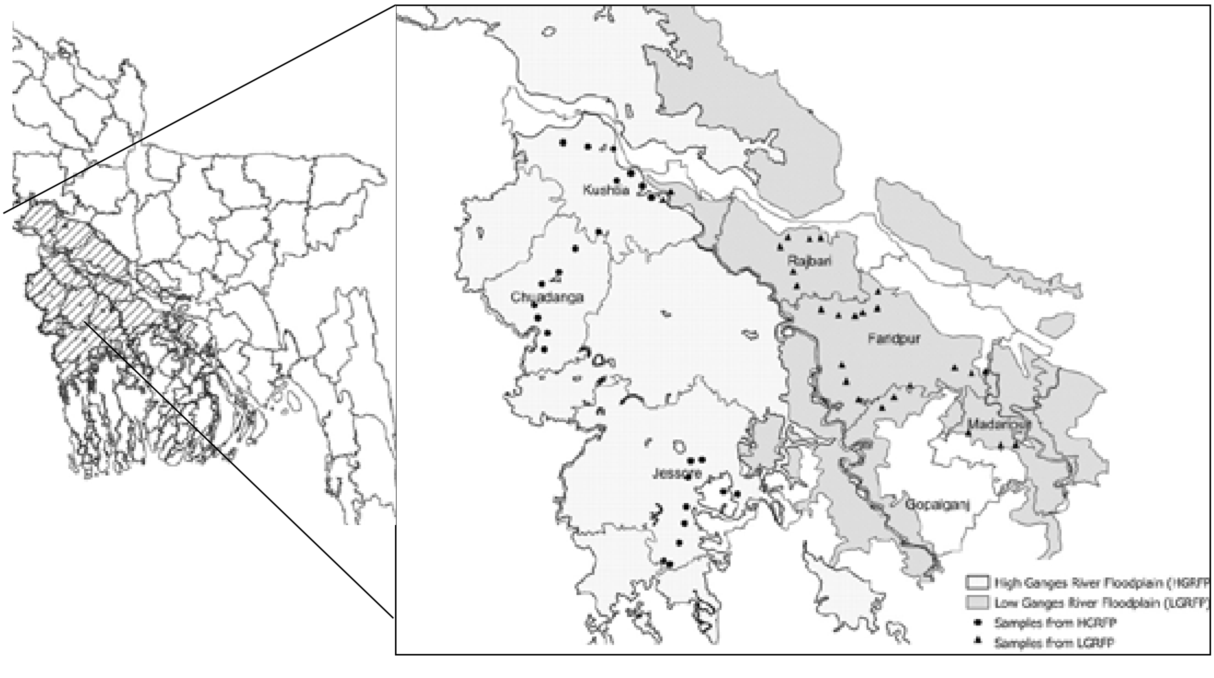

Fig. 1. Location of the sampling sites in High and Low Ganges River Floodplain, Bangladesh.

The parent material of GRFP is Ganges alluvium which was calcareous when deposited. However, decalcification occurs in the cultivated basin soils having a neutral to strongly acid topsoil and a near-neutral subsoil over calcareous substratum(11).

Soils of the region are silt loams and silty clay loams on the ridges and silty clay loams to heavy clays on lower sites being typical for cultivation of irrigated rice both in rainy (Transplanted Aman) and dry (Boro) seasons. To study the distribution of zinc (Zn), boron (B), iron (Fe), manganese (Mn) and copper (Cu) in soil, samples were collected from the farmers field in various locations of GRFP (Fig. 1). A total of 52 spots were sampled comprising 25 locations from High GRFP and 27 locations from Low GRFP. Samples were collected based on inundation land type, soil series and existing cropping pattern of the location (Table 1).

Table 1. Description of the sample sites based on soil series, land type and cropping pattern.

AEZ	Physiography	Major land type[a]	Soil series*	Major cropping pattern
11	High Ganges River Floodplain (25)	HL 43%, MHL 32%, MLL+LL 14%	Sara (6), Gopalpur (10), Ishurdi (8), Ghior (1)	Boro rice-Fallow-T. Aman rice
12	Low Ganges River Floodplain (27)	HL 13%, MHL 29%, MLL+LL 44%	Sara (6), Gopalpur (10), Ishurdi (3), Ghior (8)	Wheat-Jute-T.Aman rice

[a]HL=Highland, MHL=Medium highland, MLL=Medium lowland, LL=Lowland; * Values in parentheses represent number of samples.

Lands that are above normal inundation-level during monsoon are termed as highland (HL), those that are normally flooded up to 90 cm deep are medium highland (MHL) while lands which are normally inundated in the range 90-180 cm deep are called medium lowland (MLL) (11). Lowlands (LL) are flooded more than 180 cm deep. The sampled soils belonged to four soil series, namely Sara (Aquic Eutrochrept), Gopalpur (Typic Eutrochrept), Ishurdi (Aeric Haplaquepts) and Ghior (Aquic Haplaquepts) under Inceptisols order in the USDA Soil Taxonomy(12). Out of the 52 samples collected, most samples belonged to Gopalpur series followed by Sara and Ishurdi series (Table 1).

Land use and cropping pattern: For many years, the lands under study were cropped to either two rice crops a year with interim fallow or rice followed by various 'non-rice' (upland) crops (Table 1). The non-rice crops included cereal (e.g., wheat, maize), vegetables, legumes or oil crops. The major cropping sequence of High GRFP was Boro (dry season) rice-fallow-Aman (wet season) rice, while that of Low GRFP was wheat-fallow-Aman rice (Table 1). To observe the effect of rice and other crops on the variability of micronutrient distribution, the samples were divided into two cropping pattern groups: a) rice-rice and

b) rice followed by upland crop. Out of the 52 samples, the rice-rice cropping pattern group represented 15 samples whereas 37 samples were collected from rice-non-rice group.

Soil samples were collected at 0-15 cm (surface) and 15-30 cm (sub-surface) depths. Composite samples were air-dried, mixed and homogenised, sieved (2 mm) and analyzed for soil micronutrients and relevant properties.

Chemical analysis: Available Fe, Mn, Zn and Cu were extracted by DTPA and measured in Atomic Absorption Spectrophotometer(13). Soil available boron or hot water soluble B (HWS-B) was extracted by hot calcium chloride ($CaCl_2$) and analyzed by Azomethine H colorimetric method(14). Soil pH (H_2O) was determined by using a pH meter with glass electrode. Soil organic carbon content was determined by wet oxidation method(15).

The recorded data on different parameters were subjected to statistical analysis. Descriptive statistics of soil micronutrients and various graphs were performed by statistical software Minitab version 21.1.0. The significance of normality was tested by applying z-test using skewness. Calculation of t-test, skewness and z-test were performed in Minitab software. The correlation among variables and the analysis of variance (ANOVA), F test and mean comparison post-hoc test (Duncan's multiple range test -DMRT) for various effects such as, land type, soil series and cropping pattern were carried out using IBM SPSS Statistics, Version 26.0.

Results and Discussion

Status of the micronutrients, soil pH and organic C: The pH of Low GRFP soil (7.88) was higher than that of High GRFP soil (7.62) (Table 2). The high pH of soils implies a decreased availability of micronutrients in soil(16). As a result, considerably lower concentrations of Fe, Mn, Zn and B were observed in Low GRFP (AEZ 12) than that of High GRFP (AEZ 11) (Table 2).

Table 2. Concentration of available micronutrients and organic C in the surface soils (0-15 cm) of High and Low Ganges River Floodplain.

Parameters[a]	High Ganges River floodplain (n=25)		Low Ganges River floodplain (n=27)		Mean (Overall)	SD[b]	Skewness
	Range	Mean	Range	Mean			
Soil pH	7.17 - 8.22	7.62	6.98 - 8.46	7.88	7.76	0.39	0.01
Organic C (%)	0.41 - 2.27	1.01	0.14 - 1.67	1.04	1.03	0.37	0.38
Fe (mg kg^{-1})	12.8 - 76.5	30.4	2.0 - 67.6	18.6	23.8	16.5	1.13*
Mn (mg kg^{-1})	7.4 - 41.0	18.3	2.6 - 50.4	14.1	16.0	8.9	1.62*
Zn (mg kg^{-1})	0.19 - 2.18	0.82	0.06 - 1.56	0.47	0.62	0.45	1.49*
Cu (mg kg^{-1})	1.20 - 5.70	2.52	1.2 - 6.4	2.97	2.73	1.4	1.39*
B (mg kg^{-1})	0.01 - 0.80	0.30	0.05 - 0.68	0.21	0.25	0.16	1.35*

[a] Zn, Fe, Cu & Mn are DTPA extractable and B is hot $CaCl_2$-extractable, [b] SD = standard deviation
* Distributions are highly skewed (non-normal) based on z-test (α=0.05).

The overall mean pH of the Ganges River floodplain soils was slightly alkaline (7.76). In this way, it is evident that, one of the reasons of very low average concentrations of Zn (0.62 mg kg^{-1}) and B (0.25 mg kg^{-1}) in the Ganges River floodplain soils is its alkaline pH. The distribution of organic C in the studied soils was more or less similar in the two AEZs (Table 2). It ranged from 0.14% to 2.27% with an overall mean of 1.03%. The overall concentration of organic C in the samples was normally distributed as indicated by the insignificant skewness value (Table 2). It is noteworthy that the distributions of Fe, Mn, Zn, Cu and B in GRFP soils are significantly positively skewed implying that a large number of the surveyed samples possess lower than the average concentration of the micronutrients in GRFP soils (Table 2).

DTPA extractable Fe: The mean concentration of DTPA extractable Fe in HGRFP was 30.4 mg kg^{-1} while that of Low GRFP was 18.6 mg kg^{-1} (Table 2). Thus, the higher content of Fe might be related to lower soil pH in High GRFP. The observed values of Fe concentration are consistent with the findings of earlier works in Ganges River floodplain soils(17). The overall mean concentration of Fe (23.8 mg kg^{-1}) in the GRFP soils was considerably higher than the critical level for plant growth (4.0 mg kg^{-1} for rice; 3.0 mg kg^{-1} for upland crops)(18). However, there is no report of Fe-toxicity in rice or other crops in this region.

DTPA extractable Mn: Like Fe, the distribution of Mn in the soils of GRFP was found to be more than adequate with regard to plant nutrition. The concentration of DTPA extractable Mn ranged between 2.6 and 50.4 mg kg^{-1} in the High and Low GRFP soils (Table 2). The range of Mn concentration and the overall mean (16.0 mg kg^{-1}) agreed well with the reported values of the earlier studies(19). Although, the range of Mn concentration in the studied soils was much higher than the critical level (1.0 mg kg^{-1}) for field crops, no cases of Mn-toxicity have yet been reported.

DTPA extractable Zn: In contrast to Fe and Mn, the concentration of DTPA extractable Zn was lower, ranging from as low as 0.06 to 2.20 mg kg^{-1} with a mean of 0.62 mg kg^{-1} (Table 2). The range of the values found in this study (0.06 to 2.18 mg kg^{-1}) was agreed well with the previous studies(20). Unlike Fe and Mn, the concentration of Zn in most of the samples was below to or near the critical soil level (0.6 mg kg^{-1} for rice; 0.5 for upland crops).

DTPA extractable Cu: The concentration of DTPA Cu ranged from 1.2 mg kg^{-1} to 6.24 mg kg^{-1} in GRFP with a mean of 2.73 mg kg^{-1} (Table 2). The values were consistent with the reported values by Moslehuddin *et al.*(21) who found an average of 1.7 mg DTPA extractable Cu kg^{-1} soil in the Ganges alluvium. Here again, the range of Cu was higher than the critical concentration (0.2 mg kg^{-1}) for plant growth. However, there is no report of Cu-toxicity in this region.

Hot water soluble (HWS)-B: Plant available B (hot water soluble B) concentration ranged from as low as 0.01 to 0.8 mg kg^{-1} in GRFP with a mean of 0.25 mg kg^{-1} (Table 2). Most of the samples contained less than 0.5 mg kg^{-1} B as evidenced by significantly positively skewed distribution (Table 2). The values are in agreement with earlier works. Ahmed and Hossain(22) reported that the available B content of the major soil types in Bangladesh ranged between 0.1 and 1.9 mg kg^{-1} soil. Thus, B is the second most deficient micronutrient in GRFP, following Zn.

Interrelationship among the micronutrients: The correlation between soil pH, organic C and the micronutrient concentration in the surface soils (0-15 cm) of GRFP is shown in Table 3. In general, the relationship between the studied micronutrients and soil pH was negative although it was not statistically significant in all the cases (Table 3).

Table 3. Correlation matrix showing relationship between soil micronutrients, soil pH and organic C in Ganges River Floodplain soils (0-15 cm) (n=52).

	soil pH	Org. C	Zn	Fe	Cu	Mn
soil pH	1.00					
Org. C	0.03	1.00				
Zn	-0.15	0.14	1.00			
Fe	-0.28*	0.10	0.42**	1.00		
Cu	-0.15	0.29*	0.07	0.20	1.00	
Mn	-0.42**	0.01	0.38**	0.45**	0.15	1.00
B	-0.34*	0.39**	0.44**	0.32*	0.10	0.17

* significant at 5%, ** significant at 1% level of significance.

A negative relationship between soil pH and Fe, Zn, Mn and Cu concentration is well established(16). Similarly, increasing soil pH enhances B adsorption on clay minerals and oxides(14). In this way, it is evident that, alkaline pH of GRFP soils is one of the reasons of very low average concentrations of Zn (0.62 mg kg^{-1}) and B (0.25 mg kg^{-1}). A significant and strong correlation was observed between DTPA-Zn, Mn and Fe concentration. Usually, high Fe and Mn concentration decreases Zn availability in soil due to adsorption by Fe and Mn (hydr) oxides(23). However, according to Bunquin *et al.*(24), the relative concentrations of oxides of Fe and Mn determine their activity in Zn adsorption. They reported that reduction due to flooding and re-oxidation of soil during draining period play role in the solubility of Zn, Fe and Mn.

On the other hand, highly significant positive correlations were found between organic C and DTPA-Cu and HWS-B (Table 3). It implies that the availability of Cu and B is largely influenced by SOC concentration in these soils. This agrees with the findings of Hossain *et al.*(17) who observed strong significant and positive correlation of Cu and Mn with SOC content of GRFP soils. Significant positive correlation between micronutrient and soil organic C was also observed by previous research (25). A strong significant correlation of B with Mn and Zn reflects that the dynamics of these three nutrients is closely related in the study soil.

Distribution of the micronutrients in the soil series: This study was conducted in the four soil series, namely, Sara, Gopalpur, Ishurdi and Ghior. The micronutrient concentrations in surface and sub-surface layers of the four soil series is presented in Table 4.

Table 4. Status of the micronutrients in the four soil series of Ganges River Floodplain.

Soil series	Depth (cm)	Soil pH[a]	Zn	Fe	Cu	Mn*	B
			(mg kg^{-1})				
Sara	0-15	7.89 abc	0.61 ab	18.7bc	1.88 b	14.4	0.18 b
(Aquic Eutrochrept)	15-30	8.21 a	0.44 abc	9.4cd	1.86 b	15.0	0.20 ab
Gopalpur	0-15	7.65 cd	0.64 ab	28.1ab	2.59 b	16.3	0.27 ab
(Typic Eutrochrept)	15-30	8.16 ab	0.31 bcd	9.2cd	1.58 b	12.9	0.35 ab
Ishurdi	0-15	7.85 abc	0.73 a	27.5a	2.61 b	16.4	0.26 ab
(Aeric Haplaquept)	15-30	8.05 abc	0.57 ab	9.6cd	1.70 b	10.8	0.13 b
Ghior	0-15	7.66 cd	0.49 abc	15.8c	4.34 a	17.8	0.33 ab
(Aquic Haplaquepts)	15-30	7.75 cd	0.18 cd	3.9d	2.75 b	13.0	0.43 a

[a] Values followed by same letter in a column are not significantly different at 5% level of significance by DMRT. *Difference of Mn conc. was not significant.

Soil pH was more or less indifferent among the soil series (Table 4). Likewise, the concentration of Mn, Zn and B did not differ too much across the soil series. Only Fe and Cu showed significant variation among the soil series. The concentrations of Fe in Gopalpur and Ishurdi series were significantly higher than the other two series. On the contrary, Cu concentration was significantly higher in Ghior series than that of the other three series.

Regarding the effect of the depth of sampling, soil pH was distinctly higher in the sub. surface (15-30 cm) soils than in the surface soils across the four soil series. The effect of higher soil pH of the sub-surface layer was clearly reflected in contents of Zn, Fe and Cu, as well (Table 4). These elements were considerably higher in the surface soil than in the sub-surface soil. However, the effect of soil pH was not manifested on the depth-wise distribution of Mn and B. This may be related to the less sensitivity of Mn and B to the changes in soil properties compared to Zn, Cu and Fe (26). It was observed that 50% or more of the samples from the four soil series were Zn-deficient, while 27 to 62% samples were B-deficient when the samples were categorized based on critical limit for crops(18) (Table 5). Most of the samples were fertile with respect to Fe, Mn and Cu.

Table 5. Percentage of samples in the four soil series of Ganges River Floodplain below critical limit or above very high level based on soil fertility category.

Soil series	Zn		Fe		Cu		Mn		B	
	Percent of soil sample									
	<CL*	>VH	<CL	>VH	<CL	>VH	<CL	>VH	<CL	>VH
Sara	54	0	8	69	0	100	0	100	62	-
Gopalpur	58	0	6	89	0	100	0	95	42	5
Ishurdi	50	0	9	64	0	100	0	100	27	-
Ghior	89	0	33	33	0	100	0	100	56	-
CL(mg/kg)	0.8		4.5		2		4		0.2	

* CL = critical limit of the micronutrient in soil; VH = very high level of the micronutrient.

The finding that the top soils of GRFP are extensively Zn deficient agrees well with earlier works(3). The soils of Ghior series was found to be the most Zn- and B-poor soil compared to three other soil series in GRFP (Table 5). This may be related to the pedogenic properties of this soil. Hence, crop production in these soils must be accompanied with adequate micronutrient management, particularly for the crops susceptible to Zn and B deficiency like soybean, wheat, etc. Few samples (8-33%) across the soil series were found deficient in DTPA-Fe (Table 5). Since Fe-deficiency in rice soil is a complex phenomenon and many factors contribute to its development, it should carefully be taken into consideration. The overall scale of deficiency of the four soil series was: Zn<B<Fe (Table 5). On the other hand, most of the samples had a very high level of DTPA Fe and almost all of the samples of the four series had very high levels of Cu and Mn based on BARC fertilizer recommendation guide(18) (Table 5). However, there is no report of micronutrient toxicity in crops, so far, in the Ganges River Floodplain, which might be due to oxidation of rhizosphere by rice roots. Marschner (28) stated that rhizosphere oxidation in waterlogged soils by release of O_2 from plant roots prevents accumulation of Fe and Mn to phytotoxic levels.

Status of the micronutrients based on land types: The distributions of the micronutrients based on inundation land types or flood-depth classes of GRFP are presented in Fig. 2 (a-f).

In general, soil pH was lower in the surface soils (0-15 cm) than in the sub-surface soils (15-30 cm) (Fig. 2). This may have been the reason for higher concentration of micronutrients in the surface soils than in the sub-surface. Also, association with SOM in the surface soil may increase the levels of micronutrients.

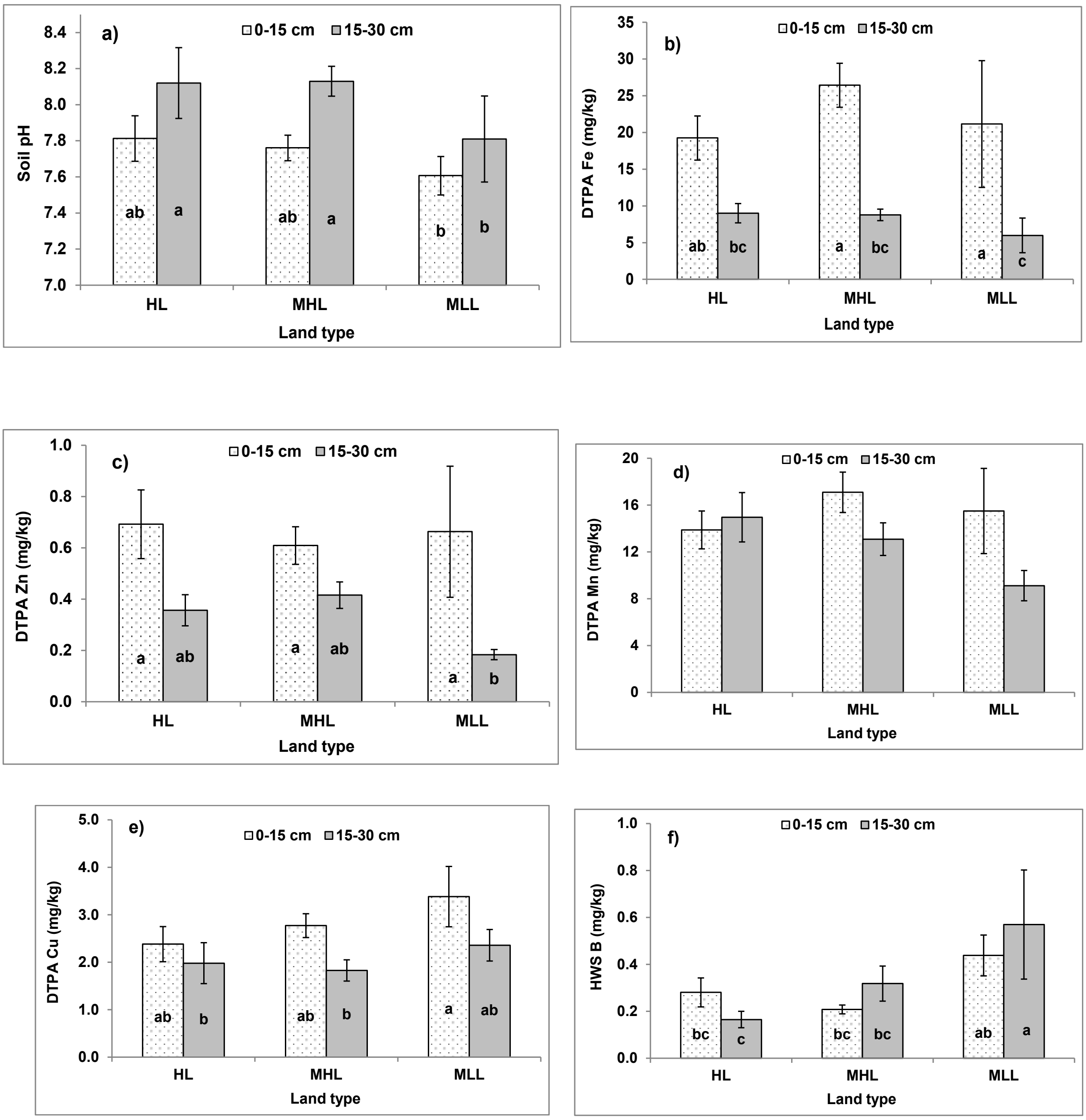

Fig. 2. Effects of different land types on the distribution of a) soil pH, b) DTPA Fe, c) DTPA Zn, d) DTPA Mn, e) DTPA Cu and f) HWS-B (mean±SE) in the Ganges River Floodplain soils (similar letters in the bars denote insignificant difference at 5% significance level by DMRT).

The distribution of all the available micronutrients was not affected consistently by the variation of land types (Fig. 2). Only, Cu and B distributions in the surface soils were relatively greater in LL than those in HL (Fig. 2e and 2f). This is in accordance with the variation in the soil pH in the two types of land (Fig. 2a). Usually, the levels of extractable micronutrients are expected to be greater in the lowland than in highland, due to greater nutrient accumulation near the bottom of catena(29). Haruna *et al.*(29) reported that the level of available Mn gradually decreased in the surface soils of grassland from the summit to the foot-slope of a catena, while that of available Fe was inconsistent. They observed that the variation of Mn coincided with the changes in soil pH.

Also, the effect of land type on the levels of micronutrients in the surface soils did not correspond to their levels in the sub-surface soils (Fig. 2). For example, among all the tested micronutrients in the surface soils, only Cu showed a minor increasing trend from HL to MLL (Fig. 2e), whereas, the sub-surface concentrations of Fe, Zn and Mn exhibited a considerable decreasing trend from the HL to MLL (Fig. 2b, c, d). According to Sharma and Jassal(26), crop residue recycling, leaching and pedogenesis may, simultaneously, be responsible for such variation in DTPA-micronutrients in soils.

It is observed from Fig. 2b that the difference between the concentrations of DTPA-Fe in the surface and sub-surface soils irrespective of the land types were much wider than that of any other micronutrient indicating that Fe was more concentrated in the surface soils than any other micronutrients in the studied soils. Similar results were also reported by Khan *et al.* (20) who found higher concentrations of DTPA-Fe, ranging from 104 to 300 mg kg^{-1} in the topsoil while that of sub-soil ranged from 14 to 44 mg kg^{-1} in the floodplains of Bangladesh. Retention of Fe in the surface soils is greater than the sub-surface layers due to the formation of organo-mineral complex in higher quantity(30). In addition, high Fe content of the irrigation water may be another reason for higher Fe in the surface soils(31).

It is noteworthy that the content of HWS-B was greater in the sub-surface soils than the surface soil in MHL and MLL (Fig. 2f), indicating that B is more mobile and leached downward than other nutrients through flood water of paddy field. It was reported by Saleem *et al.*(32) that undissociated B acid and borate ions leach freely from the upper soil layers causing decreased B availability in the flooded soils. However, the sub-surface soil layer became enriched with B, which may be exploited by deep rooted crops.

Effect of cropping practices on the distribution of micronutrients: The distribution of Fe, Zn, Cu, Mn and B in soils under two rice-based cropping pattern groups (rice-rice and rice-non-rice) is shown in Figure 3 (a-f).

On the other hand, the average concentration of the micronutrients was generally higher in rice-rice pattern. The concentrations of Zn, Mn and B in the surface soils were considerably higher in the soils of rice-rice pattern than that of rice-non-rice pattern (Fig. 3c, d, f), whereas the content of Fe and Cu slightly differed in the two kinds of soils. One of the major causes of the higher content of the micronutrients in the rice-rice soils may be their lower soil pH (average 7.6) compared to rice-non-rice soils (average 7.8).

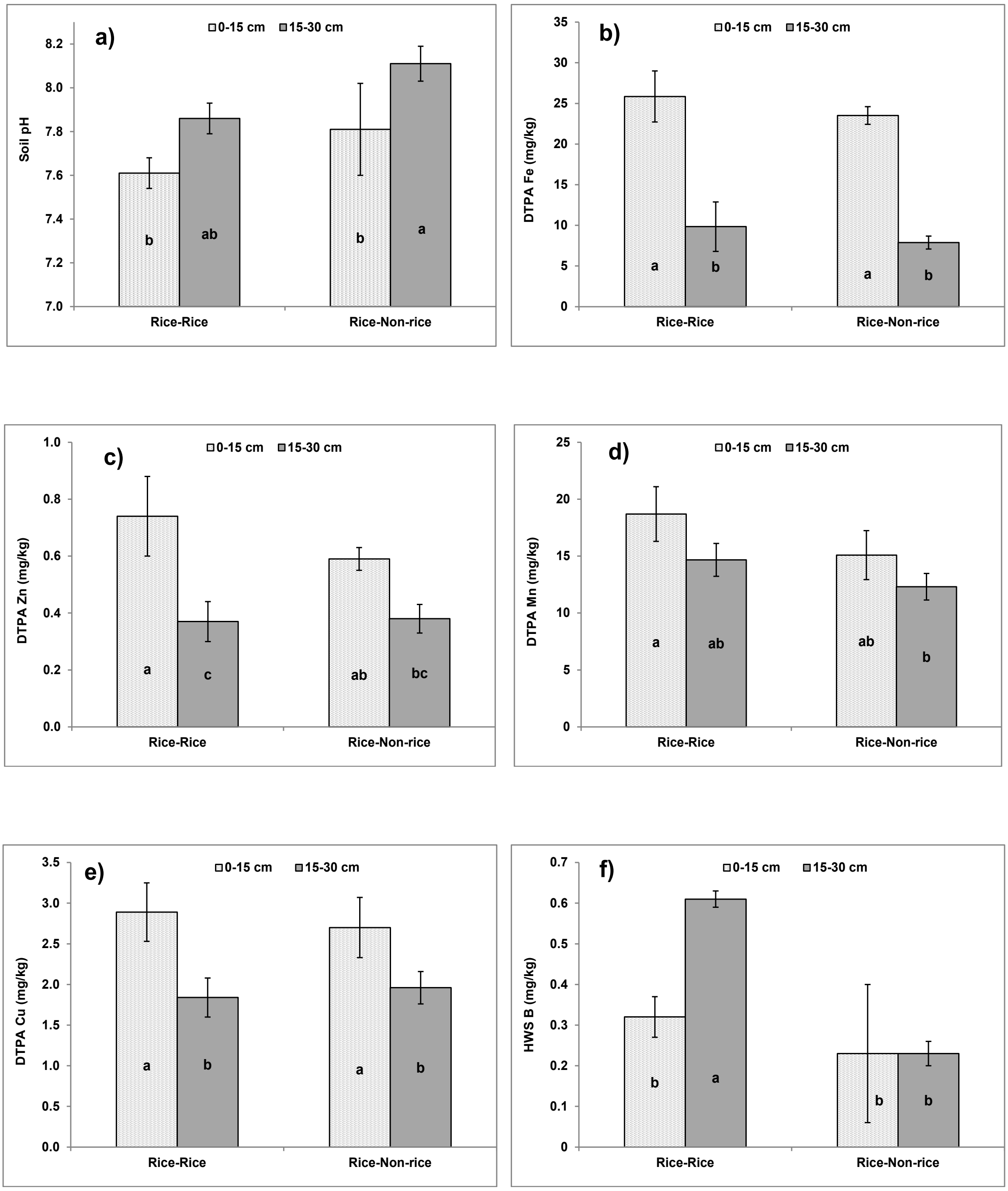

Fig. 3. Mean distribution of a) soil pH, b) Fe, c) Zn, d) Mn, e) Cu and f) B Zn (mean±SE) in soils under rice-rice and rice-non-rice cropping patterns in the Ganges River Floodplain soils (similar letters in the bars denote insignificant difference at 5% significance level by DMRT).

Greater frequency and duration of submergence in the rice-eice soils compared to Rice-non-rice soils may be another reason for higher content of micronutrients in those soils since reduced condition has been found to favor increase in Fe, Mn, Cu and Zn (33).

Weil and Holah(10) reported greatest levels of extractable soil micronutrients in submerged condition than in field capacity. Puddling of the rice soils also influences the concentration of micronutrients.

The average SOC contents of the rice-rice and rice-non-rice soils were 1.18 and 0.96%, respectively (data not presented). Higher SOC content has been shown to contribute to higher micronutrient concentration in the soils(34). Greater SOC content in r-r soils with wider submergence period than rice-non-rice soils, might be due to restricted decomposition of OM in the reduce soil condition in the inundated rice soils. Sahrawat *et al.*(8) reported that the OM status of soils under continuous rice (two/three crops/year) is either maintained or even improved compared to soils under rice-upland crop sequence, which in turn, enhances micronutrient availability.

In contrast to Fe, Mn, Zn and Cu, the content of HWS-B in the sub-surface layer was higher compared to that in the surface layer (Fig. 3f). This implies that soluble B in the surface layer is either leached down to the deeper layers through flood water of paddy field(32) or has been exhausted by stranding rice crops(35). This B in the sub-surface layer is important for the nutrition of deeper rooted crops later.

The variation of micronutrient levels between rice-rice and rice-non-rice systems may also be attributed to the variation in the type of root system and uptake ability and rate of fertilizer applied to various crops. Intercropping of rice with multiple crops having diverse root systems causes variation in the profile distribution of micronutrients in soil(7). According to Wei *et al.*(34) the impact of fertilization on micronutrient availability varied with cropping system. Maqueda *et al.*(9) reported that use of green manure or plant compost resulted in higher of Fe, Mn, Cu and Zn compared to that of inorganic fertilizer. Thus, a weak effect of the cropping patterns and management practices on the distribution of the micronutrients was observed.

It is noteworthy that the difference between the concentration of Zn, Cu, Fe and Mn of the rice-rice and rice-non-rice soils were greater in surface soil than that in the sub-surface soils (15-30 cm) (Fig. 3). This implies that the micronutrient levels in the sub-surface soil remains relatively unaffected by the crop management practices.

Conclusion

Apparently most deficient micronutrient in the Ganges River Floodplain was Zn followed by B. It was observed that 50% or more of the surface soils of all the soil series in GRFP were Zn deficient. The most deficient among them were Ghior series. Among the major reasons of micronutrient deficiency were high soil pH and low organic C. Thus, continuous replenishment of soil Zn and B should be taken care of for these intensively cropped soils. Also, deficiency of Fe in some sample of Ghior series needs to be properly addressed. The concentrations of DTPA extractable Fe, Mn and Cu were substantially above critical limits for crops in most of the samples. However, there was no report of micronutrient toxicity in the region. The effect of inundation land type on the micronutrient content was not consistent. The contents of DTPA-Fe were notably higher in the surface soil than that sub-surface, indicating retention of irrigation water Fe by the organo-mineral complexes in the surface soils. A weak effect of the variation in cropping pattern on the distribution of micronutrients was observed. Soils under two rice crops per year showed slightly higher micronutrient content than soils under rice-upland crop sequence, which may be due to higher frequency of submergence. Soil pH and higher organic C also contributed to higher micronutrient contents in the rice soils. Sub-surface layer of lowland rice soils showed higher B content indicating a greater leaching. Leaching of HWS-B to sub-surface and sub-soil layers at a significant rate implies that this B can be exploited by the next crops with deeper root. Further research focusing on a) rooting behavior of the crops under multiple cropping systems affecting the chemistry of micronutrients, and b) the fate of micronutrients under submerged rice cultivation may improve the understanding of micronutrient dynamics in floodplain soils.

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References

1. Jahiruddin, M and M Islam 2014. Requirement of micronutrients for crops and cropping patterns. Project Report (2011-2014). PIU-BARC(NATP-Phase-1) Project ID 339. Bangladesh Agricultural Research Council, Dhaka, Bangladesh
2. Sarker, MMH, M Jahiruddin, AZM Moslehuddin and MR Islam 2020. Changing dynamics of micronutrients in piedmont soil of Bangladesh. Eurasian J. Soil Sci. 9:43-51.
3. Jahiruddin, M, H Harada, T Hatanaka and M Islam 2000. Status of trace elements in agricultural soils of Bangladesh and relationship with soil properties. Soil Sci. Plant Nutri. 46: 963-68.
4. Najafi-Ghiri, M, R Ghasemi-Fasaei and E Farrokhnejad 2013. Factors affecting micronutrient availability in calcareous soils of Southern Iran. Arid Land Res. Manag. 27: 203-215.
5. Zhu, H., Y Zhao, F Nan, Y Duan and R Bi. 2016. Relative influence of soil chemistry and topography on soil available micronutrients by structural equation modeling. J. Soil Sci. Plant Nutr. 16: 1038-51.
6. Han, FX, WL Kingery and JE Hargreaves and TW Walker 2007. Effects of land uses on solid-phase distribution of micronutrients in selected vertisols of the Mississippi River Delta. Geoderma 142: 96–103.

7. Jiang, Y, YG Zhang, D Zhou, Y Qin and WJ Liang 2009. Profile distribution of micronutrients in an aquic brown soil as affected by land use. Plant Soil Env. 55: 468-76.
8. Sahrawat, KL 2012. Soil fertility in flooded and non-flooded irrigated rice systems. Arch. Agron. Soil Sci. 58: 423-436.
9. Maqueda, C, JF Herencia, JC Ruiz and MF Hidalgo 2011. Organic and inorganic fertilization effects on DTPA-extractable Fe, Cu, Mn and Zn, and their concentration in the edible portion of crops. J. Agric. Sci. 149: 461-72.
10. Weil, RR and SH Holah 1989. Effect of submergence on availability of certain plant nutrients in three Ultisol catenas. Plant Soil 114: 147-57.
11. Islam, S 2012. Banglapedia: National Encyclopedia of Bangladesh. Last modified: 18 June, 2021.
12. SRDI 2001. Land and Soil Resources Utilization Guide. Soil Resources Development Institute, Dhaka, Bangladesh.
13. Lindsay, WL and W Norvell 1978. Development of a DTPA soil test for zinc, iron, manganese, and copper. Soil Sci. Soc. Amer. J. 42: 421-28.
14. Keren, R 1996. In: DL Sparks *et al.* (Eds) Methods of Soil Analysis: Part 3 Chemical methods, SSSA Book Series no. 5. Boron. Madison, WI., USA. pp. 603-26.
15. Nelson, DW and LE Sommers. 1996. In: DL Sparks *et al.* (Eds) Methods of Soil Analysis: Part 3 Chemical methods, SSSA Book Series no. 5. Total carbon, organic carbon, and organic matter. Madison, WI., USA. pp. 961-1010.
16. Brady, NC and RR Weil 2014. The Nature and Properties of Soils. 14th ed. Pearson, Chennai, India.
17. Hossain, MM, ZH Khan and MS Hussain 2009. Nutrient elements in some benchmark soil pedons from the Ganges River Floodplain of Bangladesh. Bangladesh J. Sci. Ind. Res 44: 359-66.
18. BARC 2018. Fertilizer Recommendation Guide-2018. Bangladesh Agricultural Research Council. Dhaka, Bangladesh.
19. Hassan, M 1999. Soils of Bangladesh: Their Genesis, Classification and Use potential. 1st ed. RMIDC, Dhaka, Bangladesh.
20. Khan, Z, A Mazumder, MS Hussain and A Mohiuddin 1997. Total and DTPA-extractable Fe, Mn, Cu and Zn contents in some soils of Bangladesh. J. Indian Soc. Soil Sci. 45: 485-89.
21. Moslehuddin, AZM, S Laizoo and K Egashira 1999. Trace elements in Bangladesh paddy soils. Comm. Soil Sci. Plant Anal. 30: 1975-1996.
22. Ahmed, S and MB Hossain 1997. The problem of boron deficiency in crop production in Bangladesh. In: RW Bell and B Rerkasem (Eds) Boron in soils and plants: Proceedings of the International Symposium on Boron in Soils and Plants, Chiang Mai, Thailand, September 7-11, 1997. Springer, Dordrecht. pp. 1-15.
23. Sajwan, K and W Lindsay 1988. Effect of redox, zinc fertilization and incubation time on DTPA-extractable zinc, iron and manganese. Comm. Soil Sci. Plant Anal. 19:1-11.
24. Bunquin, MAB, S Tandy, SJ Beebout and R Schulin 2017. Influence of soil properties on zinc solubility dynamics under different redox conditions in non–calcareous soils. Pedosphere 27: 96-105.
25. Dhaliwal, SS, RK Naresh, A Mandal, R Singh and MK Dhaliwal 2019. Dynamics and transformations of micronutrients in agricultural soils as influenced by organic matter build-up: A review. Env. Sustain. Indicators 1: 1-14.

26. Sharma, BD and HS Jassal 2013. Study of a toposequence for variability in micronutrients from the moist subhumid Siwalik agro-ecological subregion of Punjab. Arch. Agron. Soil Sci. 59: 573-591.

27. Rahman, M, M Jahiruddin and MR Islam 2007. Critical limit of zinc for rice in calcareous soils. J. Agric. Rural Dev. 5: 43-47.

28. Marschner, P 2012. Marschner's Mineral Nutrition of Higher Plants. 3rd ed. Elsevier/Academic Press, Amsterdam, Netherlands.

29. Haruna, SI 2021. Spatial and fractal characterization of selected soil nutrients along a catena. Catena 204: 2-9.

30. Wissing, L, A Kölbl, P Schad, T Bräuer, ZH Cao and I Kögel-Knabner 2014. Organic carbon accumulation on soil mineral surfaces in paddy soils derived from tidal wetlands. Geoderma 228: 90-103.

31. Zou, YC, XF Yu, XG Lu and M Jiang 2012. Vertical migration and distribution of added dissolved iron in Carex lasiocarpa marsh soil. Ecol. Engg. 44: 36-43.

32. Saleem, M, YM Khanif, I Fauziah, AW Samsuri and B Hafeez 2011. Importance of boron for agricultural productivity: A review. Int. Res. J. Agric. Sci. Soil Sci. 1: 293-300.

33. Shuman, L 2005. In: D. Hillel (Ed), Encyclopedia of Soils in the Environment, vol. 2. Micronutrients. Elsevier/Academic Press, Amsterdam, pp. 479-86.

34. Wei, X, M Hao, M Shao and WJ Gale 2006. Changes in soil properties and the availability of soil micronutrients after 18 years of cropping and fertilization. Soil Tillage Res. 91: 120-30.

35. Yang, XY, G Yu, RW Bell and ZQ Ye 2000. Residual effectiveness of boron fertilizer for oilseed rape in intensively cropped rice-based rotations. Nutr. Cyc. Agroecosyst. 57: 171-181.

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