International Journal of Ecology and Environmental Sciences 43 (2): 89-98, 2017
ISSN: 2320-5199 (Online)

Phosphorus Build up Influencing Zinc Distribution in Soil and within Plant in Intensively Cultivated Rice Growing Soils of West Bengal

Sudeshna Mondal* [1], Gora Chand Hazra [2], Pabitra Kumar Mani [3] and Biswapati Mandal [4]

Department of Agricultural Chemistry and Soil Science, Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, Nadia-741252, West Bengal, India.

Emails: [1] mondal.sudeshna2010@gmail.com; [2] gchazra@rediffmail.com; [3] pabitramani@gmail.com; [4] mandalbiswapati@rediffmail.com
* Corresponding author

ABSTRACT

Phosphorus is the most important element which interferes on zinc uptake by plants. Long-term application of phosphorus fertilisers to agricultural soils and intensive cultivation leading to P build up in soil which is commonly practiced by the farmers in rice based cropping system resulting in widespread Zn deficiency. Therefore, the present investigation was undertaken to study the effect of phosphorus build up on distribution of available Zn in some intensively cultivated rice (*Oryza sativa* L.) growing soils of West Bengal and also with Zn content within the plants, by collecting about two hundred soil as well as plant samples from four different district of West Bengal namely Burdwan, Bankura, Hooghly and Nadia. Results showed that about 45% of the total collected soil samples are deficient and 34% are low in available Zn. About 48% of the soil samples recorded high available P. The results also revealed that the soil available Zn was significantly and positively correlated with organic carbon ($r= 0.201^{**}$) but negatively correlated with pH ($r= -0.333^{**}$) and sand content ($r= -0.104$) of soil. Plant Zn content was significantly and positively correlated with soil Zn content while it was significantly negatively correlated with soil available P.

Key Words: Distribution; Phosphorus build-up; Rice; Soil; West Bengal; Zinc

INTRODUCTION

In many agricultural systems in which the application of P to the soil is necessary to ensure plant productivity, the recovery of applied P by crop plants in a growing season is very low, because in the soil more than 80% of the P becomes immobile and unavailable for plant uptake because of adsorption, precipitation, or conversion to the organic form (Holford 1997, Sharif et al. 2000). P is rapidly fixed in relatively insoluble forms, depending on soil pH and type (Al, Fe, and Ca content). Converting stable forms of soil P to labile or available forms usually occurs too slowly to meet crop P requirements. Therefore, continual long-term application of fertilizer or manure at levels exceeding crop needs (intensive cropping) and paddy cultivation (Kuligod et al. 2009) lead to P build up and interactions in soils and/or plants affecting agricultural production (Barber 1995). P build up in soil not only affects the availability of micro-nutrients particularly zinc but also the environmental quality.

Zinc deficiency is the fifth most important risk factor of human disorders which affects one-third of the world's population (approximately two billion people), with prevalence rates ranging from 4 to 73% in various regions (WHO 2002), causing serious health and productivity problems for various population groups, especially among resource-poor women, infants and children. An estimated 30% of the world's population experiences inadequate dietary Zn intake (Brown and Wuehler 2000). These deficiencies are particularly widespread in developing countries where diets are rich

in cereal-based foods with low concentration of bio-available Zn which seems to be the major reason for high prevalence of Zn deficiency in human populations (Biesalski 2013). Rice is one of the major staples, feeding more than half of the world population (Rehman et al. 2012), but they are inherently very low in Zn concentrations in grains, particularly when grown on Zn-deficient soils (Mandal et al. 2000). Productivity of rice depends upon balance application of nutrients. The soils of West Bengal are poor in micronutrients due to continuous growing of high yielding varieties and only incorporation of macronutrients in cropping system. The deficiencies of micronutrients are of critical importance for sustaining high productivity of rice in India. Approximately one third of the world's soils are considered Zn deficient (Hacisalihoglu and Kochian 2003). The increased use of phosphorus fertilizers as well as fertilizers with less Zn-containing impurities can exacerbate Zn deficiency (Loneragan and Webb 1993). Almost 50 percent of the world soils used for cereal production is Zn deficient (Gibson 2006). The total area under Zn deficiency is about 10Mha in India and approximately 85% of rice-wheat system cropping takes place in the Indo-Gangetic plain which has calcareous soils with high pH and thus low Zn availability (Singh et al. 2005). In West Bengal, on an average, about 30% of cultivated soils are deficient in plant available Zn (Singh 2009). The antagonism between P and Zn has been researched extensively (Haldar and Mandal 1981, Chatterjee et al. 1982). But results regarding site of P and Zn interaction still remain controversial. With this above background, the present investigation has been undertaken to generate information regarding the distribution of available P and Zn in some intensively cultivated soils of West Bengal and their relationship with other general properties of soil and also whether P build-up is affecting the Zn content in the soil as well as in the plant.

MATERIALS AND METHOD

Collection and Analysis of Soil Samples

About two hundred geo-referenced surface soil samples (0-15 cm) were collected during end of April, 2013 after the harvest of rice from some districts of West Bengal of intensive rice cultivation viz., Burdwan, Bankura, Hooghly and Nadia (Figure 1) by following standard protocol using global positioning system (GPS) (Annexure 1). Average yield and amount of P fertilizer applied in different localities are presented in Annexure 2.

Immediately after collection the composite soil samples were air dried, ground, screened through 2mm nylon sieve and stored in air tight plastic container. The soil samples were analysed for some important chemical properties following the standard protocol. The pH of the soils was determined by in 1:2.5 soil-water suspension using a glass electrode pH meter (Jackson 1973); organic carbon by Walkley and Black (1934) wet digestion method; sand, silt and clay contents by hydrometer method (Bouyoucos 1962); and available P content of the soils by the method of Bray and Kurtz (1945) and Olsen et al. (1954). The available Zn in soil samples was estimated by using atomic absorption spectrophotometry (GBC Avanta, model no. 912) (Mandal et al. 1988) following DTPA extraction method (Lindsay and Norvell 1978).

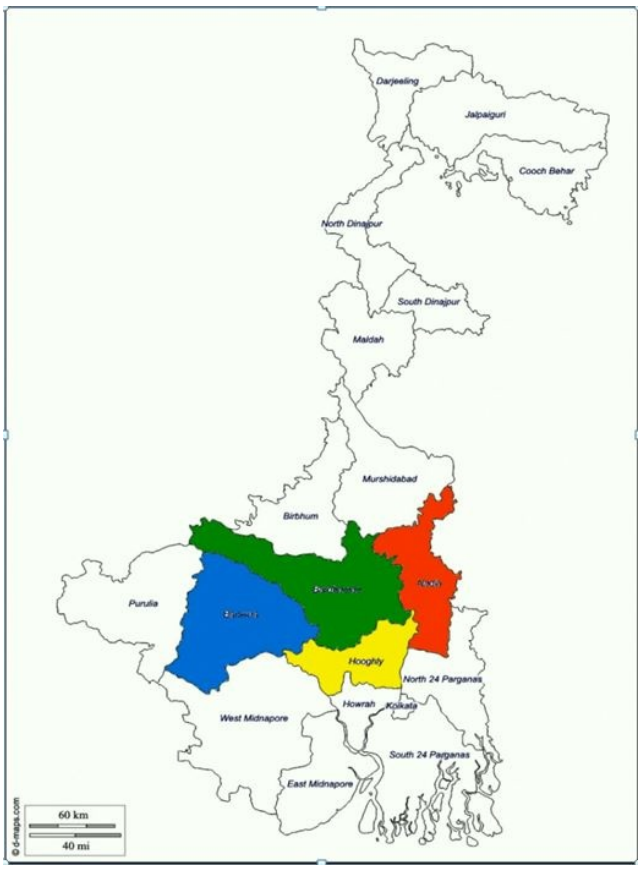

Figure 1. Soil sampling sites

Collection and Analysis of Plant Samples

Plant samples from the respective paddy field were also collected at maturity and the grains and straw are separated. The samples were thoroughly washed with tap water followed by dilute HCl solution and double distilled water, dried (60°C) to a constant weight and grinded in a stainless steel grinder. For total P and Zn content in the plants, 0.5 g of plant samples were digested (wet acid digestion) with 10 mL of concentrated HNO_3 and $HClO_4$ in 9:4 ratio at 80°C until a clear solution was obtained. The digested samples of soil and plants were filtered through Whatman no. 42 filter paper and the filtrates were diluted to 50 mL with double distilled water. P in plant was determined by vanado-molybdo-phosphoric yellow colour method (Jackson 1973) using spectrophotometer. Zn concentrations in plant samples were estimated by using atomic absorption spectro-photometry (GBC Avanta, model no. 912) (Mandal et al. 1988) after appropriate dilutions.

Statistical Analysis

The database generated was analyzed with the help of SPSS software (SPSS 21).

RESULTS AND DISCUSSION

pH

The pH of the soils widely varied from 4.78 to 8.09 with the mean value of 6.51 (Table 1). The mean pH of individual districts are 6.50, 5.54, 6.13 and 7.61 for Burdwan, Bankura, Hooghly and Nadia, respectively. Among the total soil samples collected, 40.0% are acidic and 20.5% are alkaline in reaction. The soils of Burdwan and Hooghly districts are more or less neutral in reaction, Bankura district are slightly to strongly acidic in reaction whereas those of Nadia are slightly alkaline in reaction. About 90% of the collected soils in Bankura district are acidic in reaction which may be due to presence of higher amount iron and aluminium oxides (Kanwar and Grewal 1990).

Organic Carbon

The organic carbon content of the soils ranged from 1.14 to 14.04 g kg^{-1} with a mean value of 4.88 g kg^{-1} (Table 1). The mean organic carbon content for Burdwan, Bankura, Hooghly and Nadia district are 4.27, 3.40, 6.25 and 5.13 g kg^{-1}, respectively. Use of almost nil to very low amount of organic manures application and high temperature during summer which may be responsible for the rapid burning of organic matter, thus resulting in low organic C content in the soils of Bankura district.

Available Phosphorus

Generally the soils of West Bengal where farmers commonly practice higher doses of inorganic phosphatic fertilizer in rice-based cropping system are highly build up with phosphorus. The available P content of the soil varied from 1.02 to 194.07 kg ha^{-1} with an average of 34.29 kg ha^{-1} (Table 1). About 48% of total collected soil samples are high in available P. The mean available P content for Burdwan, Bankura, Hooghly and Nadia district are 43.44, 18.79, 44.94 and 26.52 kg ha^{-1}, respectively. Highest available P was observed in Hooghly and the lowest in Bankura district. Mostly the acid soils were poor in phosphorus which may be due to phosphorus is predominantly present in the form of iron and aluminium phosphate and precipitate in the form of iron and aluminium phosphate which formed the complexes with organic matter (Kanwar and Grewal 1990). Among the total collected soil samples, 56.0% soils of Burdwan, 25.0% of Bankura, 58.2% of Hooghly and 47.3% of Nadia district are high in available P content (Figure 2).

Table 1. General soil properties of the total collected soil samples

	pH	OC (g kg^{-1})	P (kg ha^{-1})	Zn (mg kg^{-1})	Sand (%)	Silt (%)	Clay (%)
Mean	6.51	4.88	34.26	0.83	42.85	32.55	34.31
Minimum	4.78	1.14	1.02	0.10	11.09	18.00	16.20
Maximum	8.09	14.04	194.07	3.91	65.80	47.00	51.30
SD	0.93	1.87	34.15	0.61	10.74	6.49	7.63

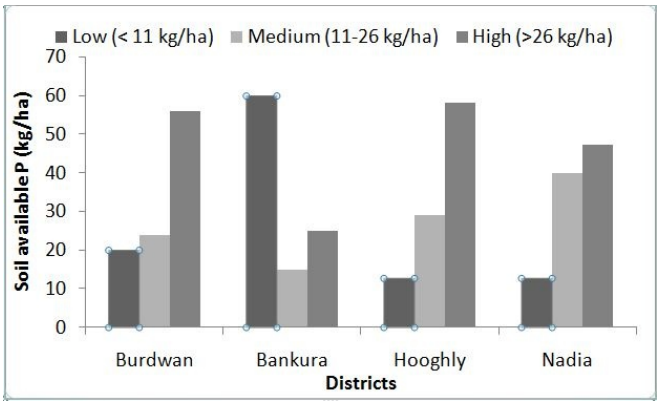

Figure 2. Distribution of available P in the soils of four districts

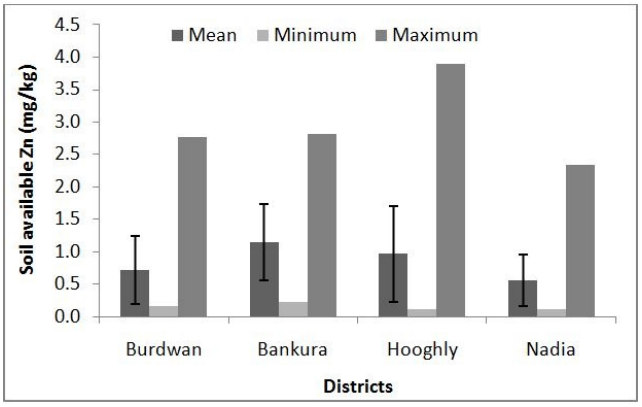

Figure 3. Distribution of available Zn in the soils of four districts

Available Zinc

The available Zn content of the soils varied from 0.10 to 3.91 mg kg^{-1} with an average of 0.83 mg kg^{-1} (Table 1). The DTPA-Zn content of different districts ranged from 0.16 to 2.77, 0.22 to 2.82, 0.10 to 2.95 and 0.12 to 2.34 mg kg^{-1} with mean value of 0.72, 1.14, 0.97 and 0.56 mg kg^{-1} for Burdwan, Bankura, Hooghly and Nadia, respectively. Considering the critical limit of 0.60 mg kg^{-1} (Anonymous 1990), about 45% of the total collected soil samples are deficient, 34% are low and 18% are medium in available Zn. Lowest available Zn content was observed in Nadia district, i.e. about 70.9% soils are deficient (Figure 3).

Soil Textural Variation

Sand, silt and clay content of the soil varied from 11.09 to 65.80%, 18.00 to 47.00% and 16.20 to 51.30%, respectively. Clay content in soils of Burdwan, Bankura, Hooghly and Nadia, varies from 21.23 to 38.50%, 16.20 to 34.40%, 34.90 to 51.30% and 23.00 to 43.73% with a mean value of 31.94, 24.66, 42.68 and 35.13%. Highest content of sand (48.16%), silt (38.88%) and clay (42.68%) was recorded in the soils of Bankura, Nadia and Hooghly, respectively (Table 1).

Correlation Between Availability of Zinc and Soil Properties

Relationship between available Zn and the different chemical properties of the soil are presented in Table 2. The significant negative correlation of soil available Zn with pH ($r= -0.333^{**}$) and significant positive correlation with organic carbon ($r = 0.201^{**}$) confirmed the findings of earlier workers (Sharma et al. 2004, Sidhu and Sharma 2010, Pati and Mukhopadhyay 2011). Available Zn resulted positive correlation with clay content of soil (r= 0.128) and negative correlation with sand (r= -0.104) content of soil. Similar observations were also reported earlier by different workers (Mathur et al. 2006, Pati and Mukhopadhyay 2011). There is a non-significant positive correlation between available Zn and available P content of the soil (r= 0.033) which signifies that P build-up in soil didn't have any effect on DTPA-extractable Zn content in soil. But soil available P had a significant negative correlation with straw Zn content ($r= -0.283^{**}$) (Figure 4A) and grain Zn content ($r= -0.398^{**}$) (Figure 4B). The depressing effect of P application on grain Zn content in wheat was previously reported by Zhang et al. (2012). Results also revealed that straw Zn concentration per unit available soil Zn ($r= -0.176^{*}$) and grain Zn concentration per unit available soil Zn ($r= -0.175^{*}$) were significantly and negatively correlated with soil available P (Figure 5A and 5B). A significant negative correlation was noticed between straw P and Zn content ($r= -0.230^{**}$) (Figure 6A) and grain P and Zn content ($r= -0.226^{**}$) (Figure 6B). Sustaining the earlier reports (Lins and Cox 1988, Payne et al. 1986), there also exist a negative relationship between straw as well as grain Zn concentration and soil pH ($r= -0.476^{**}$ and -0.402^{**}, respectively) (Table 2).

CONCLUSION

The results, therefore, revealed that P is highly build up in Burdwan, Hooghly and Nadia district while Bankura district has lower availability of soil P which may be due to higher content of Fe and Al oxides

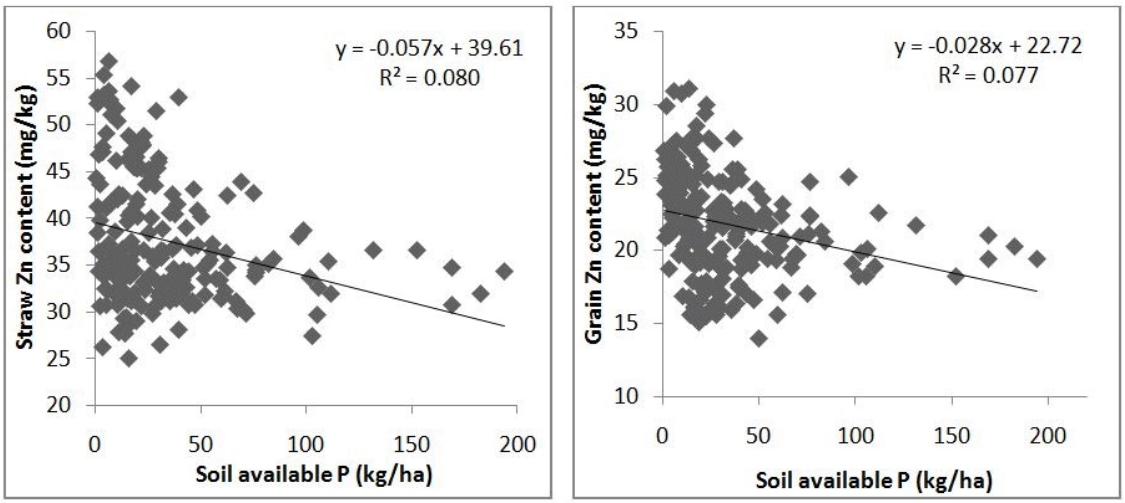

Figure 4. Relation between soil available P and straw Zn concentration in (A) straw and (B) grain

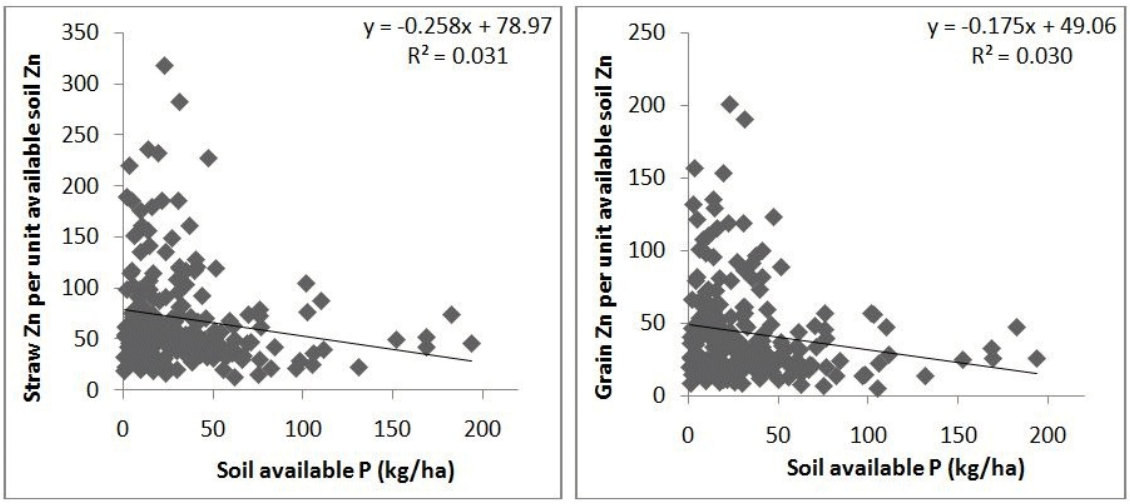

Figure 5. Relation between soil available P and straw Zn concentration per unit available soil Zn in (A) straw and (B) grain

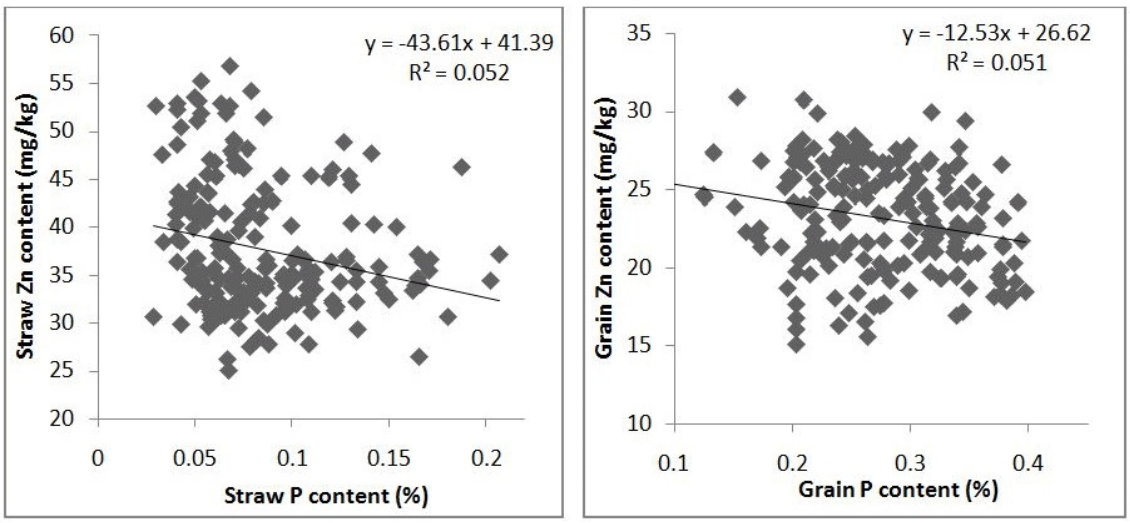

Figure 6. Relation between P and Zn content within rice (A) straw and (B) grain

Table 2. Correlation among different soil properties and P and Zn content in plant

	pH	Organic C	Avail. P	Avail. Zn	Sand	Silt	Clay	Straw P	Straw Zn	Grain P
Organic C (g kg^{-1})	0.177*									
Avail. P (kg ha^{-1})	0.046	0.380**								
Avail. Zn (mg kg^{-1})	-0.333**	0.201**	0.033							
Sand (%)	-0.439**	-0.518**	-0.232**	-0.104						
Silt (%)	0.541**	0.207**	0.081	0.021	-0.712**					
Clay (%)	0.158*	0.554**	0.258**	0.128	-0.802**	0.152*				
Straw P (%)	0.387**	0.084	0.315**	-0.128	-0.335**	0.445**	0.093			
Straw Zn (mg kg^{-1})	-0.476**	-0.124	-0.283**	0.667**	0.234**	-0.162*	-0.191**	-0.230**		
Grain P (%)	-0.098	0.263**	0.681**	0.116	-0.122	-0.014	0.184**	0.306**	-0.128	
Grain Zn (mg kg^{-1})	-0.402**	-0.060	-0.398**	0.489*	0.172*	-0.222*	-0.054	-0.274**	0.693**	-0.226**

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

which bind the P. It was revealed that the soils of Nadia district are deficient in availability of Zn while Burdwan, Bankura and Hooghly district have low status of Zn content in soil. This study also concludes that no such interaction exists between available P and Zn content in the soil but there is a significant negative interaction between P and Zn content within the plant parts i.e., straw and grain and also high P build-up in soil restricts the Zn uptake by the plants.

ACKNOWLEDGEMENTS

The overall plan of the work was made by Prof. G.C. Hazra and Prof. B. Mandal and also the experiment was conducted by S. Mondal in their laboratory under their supervision and sincere guidance of Prof. P.K. Mani. The financial assistance was provided by the All India Co-ordinated Research Project on "Micro- and Secondary Nutrients and Pollutant Elements in Soils and Plants" funded by Indian Council of Agricultural Research, Govt. of India for carrying out this research.

Conflict of interest: We declare that there is no conflict of interest.

REFERENCES

Anonymous. 1990. Annual Report, All India Coordinated Scheme of Micro and Secondary Nutrients and Pollutant Elements in Soils and Plants. Indian Institute of Soil Science, Bhopal. 14 pages.

Barber, S.A. 1995. Soil Nutrient Bioavailability. 2nd edition. John Wiley, New York. 384 pages.

Biesalski, H.K. 2013. Hidden Hunger. Springer, Heidelberg, Germany. 255 pages..

Bouyoucos, G.J. 1962. Hydrometer method improved for making particle size analysis of soils. Agronomy Journal 54: 464-465.

Bray, R.H. and Kurtz, L.T. 1945. Determination of total, organic, and available forms of phosphorus in soils. Soil Science 59: 39-45.

Brown, K.H. and Wuehler, S.E. 2000. Zinc and Human Health: Results of Recent Trials and Implications for Program Interventions and Research. International Development Research Center, Micronutrient Initiative, Ottawa. 69 pages.

Chatterjee, A.K.; Mandal, L.N. and Haldar, M. 1982. Interaction of Zinc and Phosphorus in relation to micronutrient nutrition of rice plant at two different growth stages. Zeitschrift für Pflanzenernährung und Bodenkunde 145: 460-469.

Gibson, R.S. 2006. Zinc: the missing link in combating micro-nutrient malnutrition in developing countries. Proceedings of the Nutrition Society 65 (1): 51-60.

Hacisalihoglu, G. and Kochian, L.V. 2003. How do some plants tolerate low levels of soil zinc? Mechanisms of zinc efficiency in crop plants. New Phytologist 159: 341–350.

Haldar, M and Mandal, L.N. 1981. Effect of phosphorus and zinc on the growth and phosphorus, zinc, copper, iron and manganese nutrition of rice. Plant and Soil 59: 415-425.

Holford, I.C.R. 1997. Soil phosphorus: its measurement, and its uptake by plants. Australian Journal of Soil Research 35: 227–239.

Jackson, M.L. 1973. Soil Chemical Analysis, Prentice Hall of India, New Delhi. 498 pages

Kanwar, J.S. and Grewal, J.S. 1990. Phosphorus Fixation in Indian Soils: A Review. Revised edition. Publications and Information Division, Indian Council of Agricultural Research, New Delhi. 61 pages.

Kuligod, V.; Kulkarni, G.N. and Shirahatti, M.S. 2009. Intensive cropping induced changes in soil fertility and chemical properties in canal commands of north Karnataka. Journal of Ecotoxicology and Environmental Monitoring 19 (6): 561-565.

Lindsay, W.L. and Norvell, W.A. 1978. Development of a DTPA soil test for Zn, iron, manganese and copper. Soil Science Society of America Journal 42: 421-428.

Lins, I.D.G. and Cox, F.R. 1988. Soil Science Society of America Journal 52:1681-1685.

Loneragan, J.F. and Webb, M.J. 1993. Interactions between zinc and other nutrients affecting the growth of plants. Pages 119-134, In: Robson A.D. (Editor), Zinc in Soils and Plants. Kluwer Academic Publishers, Dordrecht. The Netherlands.

Mandal, B.; Hazra, G.C. and Mandal, L.N. 2000. Soil management influences on zinc desorption for rice and maize nutrition. Soil Science Society of America Journal 64 (1): 699–705.

Mandal, B.; Hazra, G.C. and Pal, A.K. 1988. Transformations of zinc under submerged condition and its relation with zinc nutrition of rice. Plant and Soil 106 (1):121–126.

Mathur, G.M.; Deo, R. and Yadav, B.S. 2006. Status of zinc in irrigated north-west plain soils of Rajasthan. Journal of the Indian Society of Soil Science 54 (3) : 359-361.

Olsen, S.R.; Cole, C.V.; Watanabe, F.S. and Dean, L.A. 1954. Estimation of Available Phosphorus in Soils by Extraction with Sodium Bicarbonate. US Department of Agriculture Circular 939. 19 pages.

Pati, R. and Mukhopadhyay, D. 2011. Distribution of Cationic Micronutrients in Some Acid Soils of West Bengal. Journal of the Indian Society of Soil Science 59 (2): 125-133.

Payne, G.G.; Sumner, M.E. and Plank, C.O. 1986. Yield and composition of soybeans as influenced by soil pH, phosphorus, zinc and copper. Communication in Soil Science and Plant Analysis 17: 257-273.

Rehman, H.; Aziz, T.; Farooq, M.; Wakeel, A. and Rengel, Z. 2012. Zinc nutrition in rice production systems: a review. Plant and Soil 361: 203–226.

Sharif, M.; Sarir, M.S. and Rabi, F. 2000. Biological and chemical transformation of phosphorus in some important soil series of NWFP. Sarhad Journal of Agriculture 16: 587-592.

Sharma, B.D.; Arora, H.; Kumar, R. and Nayyar, V.K. 2004. Relationships between soil characteristics and total and DTPA-extractable micronutrients in Inceptisols of Punjab. Communications in Soil Science and Plant Analysis 35: 799–818.

Sidhu, G.S. and Sharma, B.D. 2010. Diethylene triamine penta acetic acid– Extractable Micronutrients Status in Soil under a Rice–Wheat System and Their Relationship with Soil Properties in Different Agroclimatic Zones of Indo-Gangetic Plains of India. Communications in Soil Science and Plant Analysis 41: 29-51.

Singh, B.; Natesan, S.K.A.; Singh, B.K. and Usha, K. 2005. Improving zinc efficiency of cereals under zinc deficiency. Current Science 88: 36-44.

Singh, M.V. 2009. Micronutrient nutritional problems in soils of India and improvement for human and animal health. Indian Journal of Fertilizers 5 (4): 11–16, 19–26 and 56.

Walkley, A. and Black, I.A. 1934. Estimation of soil organic carbon by chromic acid titration method. Soil Science 37: 29- 38.

World Health Organization. 2002. The World Health Report: Reducing Risks, Promoting Healthy Life. WHO, Geneva. 248 pages.

Zhang, Y.Q.; Deng, Y.; Chen, R.Y.; Cui, Z.L.; Chen, X.P.; Yost, R.; Zhang, F.S. and Zou, C.Q. 2012. The reduction in zinc concentration of wheat grain upon increased phosphorus-fertilization and its mitigation by foliar zinc application. Plant and Soil 361: 143–152.

Received 24 February 2017
Accepted 24 June 2017

Annexure 1: Details of the sampling site

	Locations	Longitude	Latitude
District: Burdwan			
	Block: Memari I		
1	Talpata, Kiskinda	23°10′98.0″N	88°06′69.5″E
2	Gantal, Bahappur	23°11′65.5″N	88°07′71.8″E
3	Diyarmore, Dia	23°13′14.0″N	88°08′12.8″E
4	Radhakantapur	23°13′46.0″N	88°08′30.0″E
5	Kamalpur, Mallickapur	23°14′59.0″N	88°08′34.7″E
6	Koley, Mallickpur	23°15′23.0″N	88°08′99.8″E
7	Satgachia, Begunia	23°15′37.2″N	88°08′55.3″E
8	Kathalia, Satgachia	23°15′50.2″N	88°08′32.0″E
	Block: Memari II		
9	Begune, Begunia	23°15′74.6″N	88°07′93.4″E
10	Bilbari, Begunia	23°15′97.2″N	88°07′80.5″E
11	Dhunui, Paharhati	23°15′47.3″N	88°06′31.0″E
12	Kandakpur, Paharhati	23°15′79.2″N	88°06′16.7″E
13	Bijur	23°16′80.9″N	88°06′15.8″E
14	Kalyanpur, Bijur	23°16′83.7″N	88°06′45.0″E
15	Dihipolason	23°17′84.6″N	88°06′20.8″E
16	Mondolgram, Boropolason	23°20′72.5″N	88°04′36.8″E
	Block: Burdwan I		
17	Bondul	23°20′99.6″N	88°02′36.7″E
18	Faridpur	23°19′77.6″N	88°02′42.5″E
19	Jagathpur, Faridpur	23°18′84.5″N	88°02′12.4″E
27	Nerodighi, Ryan	23°16′06.0″N	87°52′66.3″E
28	Deoandighi, Mirjapur	23°18′41.3″N	87°53′16.2″E
	Block: Burdwan II		
20	Korori	23°17′88.6″N	88°01′25.4″E
21	Notunpallir Math, Soddagram	23°17′36.9″N	88°00′12.5″E
22	Borso	23°16′41.3″N	87°59′30.1″E
23	Hoergram	23°15′37.3″N	88°00′14.4″E
24	Atagarh	23°14′45.1″N	87°58′19.1″E
25	Napara	23°14′76.4″N	87°55′40.0″E
26	Khalasipara	23°14′16.2″N	87°53′16.3″E
	Block: Bhatar		
29	Khetia, Kamrana	23°19′12.9″N	87°53′11.1″E
30	Mahachanda, Sixmile	23°20′30.5″N	87°53′27.7″E
31	Norja	23°22′57.0″N	87°54′14.5″E
32	Belenda	23°23′17.4″N	87°54′88.2″E
33	Bhatar	23°25′20.9″N	87°55′44.0″E
34	Nityanandapur, Bolgola	23°27′66.4″N	87°56′93.5″E
	Block: Mangolkote		
35	Matrum, Simuliya	23°31′62.2″N	87°59′14.0″E
36	Koichor	23°32′26.4″N	88°00′61.0″E
37	Notungram, Koichor	23°32′74.0″N	88°00′79.6″E
38	Dhakeshwardihi	23°33′35.6″N	88°01′41.8″E
39	Bonkapasi	23°34′85.1″N	88°02′65.0″E
40	Durmur	23°35′52.5″N	87°03′39.6″E
	Block: Katwa I		
41	Gangulidanga, Kosigram	23°37′30.2″N	88°05′42.3″E
42	Jajigram	23°37′97.2″N	88°06′85.5″E
43	Panchgharia	23°37′48.2″N	88°07′70.6″E
44	Thekurgachi	23°36′35.2″N	88°08′46.4″E
	Block: Katwa II		
45	Ramdaspur, Gajipur Daihat	23°34′46.4″N	88°12′10.0″E
46	Ghoragacha, Daihat	23°33′81.7″N	88°13′65.0″E
	Block: Purbasthali II		
47	Hamidpur	23°33′17.1″N	88°13′74.4″E
48	Srirampur	23°32′65.2″N	87°14′24.0″E
49	Biswarambha, Kalekhatla	23°29′19.5″N	87°16′86.4″E
50	Bargachi	23°27′29.3″N	87°18′18.0″E
District: Bankura			
	Block: Kotulpur		
1	Akhorgeria	22°58′95.3″N	87°38′32.1″E
2	Sihasmore, Sarisadighi	22°59′78.9″N	87°37′23.5″E
3	Joldermore	22°59′93.8″N	87°35′79.9″E
4	Muidara	22°59′35.3″N	87°36′98.0″E
5	Gogra	23°00′98.9″N	87°35′81.0″E
6	Asude	23°01′36.4″N	87°34′52.1″E
7	Gopalpur	23°01′88.7″N	87°33′88.2″E
	Block: Joypur		
8	Subijora	23°02′56.3″N	87°31′82.1″E
9	Chatra	23°02′77.9″N	87°30′58.6″E
10	Gelia, Avirampur	23°02′95.4″N	87°29′78.3″E
11	Rajagram, Solda	23°03′20.0″N	87°28′76.8″E
12	Baghajol, Solda	23°03′30.0″N	87°28′26.4″E
13	Kumbhosthol	23°03′37.9″N	87°27′85.6″E
	Block: Bishnupur		
14	Lotihir	23°03′96.9″N	87°21′82.4″E
15	Bandhgaba	23°04′48.5″N	87°20′67.0″E
16	Chakdah	23°05′81.6″N	87°19′73.3″E
17	Subhaspalli	23°06′22.3″N	87°19′88.8″E
18	Janata	23°06′97.2″N	87°20′23.4″E
19	Gopalpur	23°04′97.9″N	87°18′37.1″E
20	Tejpal	23°05′60.0″N	87°17′43.6″E
	Block: Onda		
21	Ramsagar	23°05′48.7″N	87°17′18.0″E
22	Kollari, Lagarpur	23°06′74.0″N	87°15′17.0″E
23	Damodarbati	23°07′64.0″N	87°14′48.3″E
24	Khamarberia	23°07′63.3″N	87°13′36.9″E
25	Chandrakona	23°09′22.9″N	87°10′82.0″E
26	Choikumro	23°09′86.1″N	87°10′32.7″E
27	Dhabani	23°11′20.3″N	87°08′63.6″E
28	Bheduasole	23°11′94.6″N	87°06′95.4″E
	Block: Bankura I		
29	Tamrisole, Benageria	23°10′32.1″N	87°04′10.9″E
30	Dubrakona, Punisole	23°09′57.0″N	87°04′15.6″E
	Block: Bankura II		
31	Ekteswar, Mudrasonkorhati	23°12′94.2″N	87°04′87.7″E
32	Makurgram	23°16′20.5″N	87°07′12.1″E
	Block: Barjora		
33	Bongram, Ramchandrapur	23°18′97.9″N	87°12′48.9″E

Locations		Longitude	Latitude
34	Beliatore	23°19′63.6″N	87°13′63.9″E
35	Bolorampur	23°20′65.9″N	87°14′23.0″E
36	Gosaipur	23°21′91.9″N	87°14′94.2″E
37	Jagannathpur, Jambedia	23°23′13.5″N	87°15′59.0″E
38	Chandar	23°18′41.0″N	87°15′58.2″E
39	Brindabonpur	23°18′60.4″N	87°16′41.6″E
40	Borkora	23°19′23.5″N	87°17′82.1″E
District: Hooghly			
	Block: Chinsurah- Mogra		
1	Kuntighat	23°00′57.5″N	88°24′18.4″E
	Block: Bolagarh		
2	Sherpur	23°01′56.9″N	88°25′20.1″E
3	Fulpukur, Shimlagar	23°02′10.0″N	88°25′54.4″E
4	Dumurdaha, Kamalpur	23°02′60.1″N	88°25′35.2″E
5	Baneshwarpur	23°03′83.0″N	88°26′92.9″E
6	Lokespur	23°04′83.5″N	88°27′17.9″E
7	Hasimpur	23°05′61.2″N	88°27′32.4″E
8	Bauipara	23°06′54.4″N	88°27′34.0″E
9	Somrabazar	23°08.23.6″N	88°25′78.3″E
	Block: Pandua		
10	Muktikuri	23°06′71.7″N	88°21′25.0″E
11	Daspur	23°06′34.1″N	88°20′24.1″E
12	Deypara, Mondolai	23°05′91.0″N	88°19′29.6″E
13	Berui	23°05′44.2″N	88°18′33.1″E
14	Khannan	23°02′56.4″N	88°18′56.1″E
15	Itachuna	23°01′14.3″N	88°18′24.1″E
	Block: Polba- Dadpur		
16	Patna, Halusai	22°59′80.5″N	88°17′80.7″E
17	Songrampur	22°58′86.9″N	88°17′85.0″E
18	Polba	22°57′58.4″N	88°18′40.7″E
19	Uchai	22°56′65.2″N	88°18′35.1″E
20	Morigeria	22°55′44.7″N	88°18′63.0″E
21	Borunanpara	22°54′95.7″N	88°18′36.2″E
22	Harit	22°55′63.5″N	88°16′60.0″E
23	Gholsara	22°55′83.0″N	88°14′52.7″E
24	Sinet	22°56′64.0″N	88°13′54.3″E
25	Puinan	22°56′35.2″N	88°12′41.9″E
	Block: Dhaniakhali		
26	Belmuri, Jelepara	22°56′88.3″N	88°09′88.3″E
27	Mallickpur	22°57′50.6″N	88°07′50.6″E
28	Ghonosyampur	22°57′93.0″N	88°04′93.0″E
29	Kananadi	22°58′40.0″N	88°03′40.0″E
30	Dasghora	22°57′85.1″N	88°01′85.1″E
31	Radhanagar	22°56′98.9″N	88°00′98.9″E
	Block: Tarakeswar		
32	Bhimpur	22°52′20.7″N	88°00′20.7″E
33	Ramnarayanpur	22°51′54.3″N	87°59′54.3″E
34	Muktarpur	22°50′53.7″N	87°58′53.7″E
	Block: Pursurah		
35	Pursurah	22°50′42.2″N	87°57′42.2″E
36	Kandipur	22°49′69.3″N	87°54′69.3″E
37	Saota	22°50′40.4″N	87°55′40.4″E
	Block: Arambagh		
38	Kable	22°50′61.9″N	87°52′61.9″E
39	Mayapur	22°50′96.6″N	87°51′69.3″E
40	Bolarampur	22°51′54.5″N	87°50′35.4″E
41	Joyrampur	22°51′85.1″N	87°49′13.0″E
42	Gorbari	22°52′43.0″N	87°49′40.0″E
43	Kalipur	22°52′98.7″N	87°46′18.1″E
	Block: Goghat I		
44	Balibela	22°52′94.0″N	87°45′51.2″E
45	Patulsara	22°52′89.8″N	87°44′50.1″E
46	Vikdas	22°52′94.6″N	87°43′71.7″E
47	Rathtala	22°53′34.2″N	87°42′36.2″E
48	Bokultala	22°53′21.7″N	87°41′63.1″E
49	Kantali	22°53′62.3″N	87°40′24.5″E
	Block: Goghat II		
50	Maheshpur	22°53′34.8″N	87°39′52.6″E
51	Rangamati	22°52′54.1″N	87°39′11.5″E
52	Mandaron	22°52′17.3″N	87°39′38.0″E
53	Tarahat	22°51′76.3″N	87°31′82.0″E
54	Chandpur	22°50′71.2″N	87°38′48.3″E
55	Singrapur	22°51′50.0″N	87°38′54.3″E
District: Nadia			
	Block: Haringhata		
1	Raghunathpur	22°56′93.8″N	88°33′58.0″E
2	Subarnapur	22°57′52.2″N	88°34′68.0″E
3	Mollabelia	22°57′09.6″N	88°35′38.0″E
4	Kurumbelia	22°58′54.0″N	88°36′74.3″E
5	Bharali, Uttar Dattapara	22°58′80.9″N	88°36′16.4″E
6	Madhabpur	22°58′37.1″N	88°37′09.9″E
7	Kasthodanga	22°58′30.4″N	88°37′76.1″E
8	Mitrapur	22°59′83.1″N	88°37′89.0″E
	Block: Chakdah		
9	Kalibazar, Mondolhat	23°01′67.2″N	88°35′27.3″E
10	Ghetugachi	23°01′92.0″N	88°34′41.8″E
11	Maniktala	23°01′96.1″N	88°32′76.5″E
12	Rautari	23°02′71.0″N	88°32′09.6″E
13	Panchpota	23°02′76.8″N	88°32′26.1″E
14	Joykrisnapur	23°04′24.3″N	88°32′58.1″E
15	Chatimtala	23°04′69.5″N	88°32′63.2″E
16	Palagacha	23°05′81.9″N	88°32′84.4″E
	Block: Ranaghat II		
17	Ghatigacha	23°07′29.9″N	88°33′84.0″E
18	Patuli	23°08′39.5″N	88°33′90.7″E
	Block: Ranaghat I		
19	Debipur	23°12′70.7″N	88°33′57.8″E
20	Kamgachi	23°13′44.9″N	88°33′52.5″E
21	Radhanagar	23°13′90.0″N	88°33′59.3″E
22	Birnagar	23°14′22.6″N	88°33′19.0″E
23	Tetultala, Najirpara	23°14′51.0″N	88°32′97.0″E
24	Taherpur	23°15′26.8″N	88°32′67.2″E
25	Barasat	23°16′45.0″N	88°32′42.2″E
26	Bhaduri	23°17′42.0″N	88°32′07.5″E

	Locations	Longitude	Latitude
	Block: Hanskhali		
27	Badkulla	23°18′30.0″N	88°32′19.8″E
28	Beltalapara	23°18′86.0″N	88°32′65.6″E
29	Dosotina	23°19′35.0″N	88°33′24.2″E
30	Parua	23°19′50.3″N	88°34′04.7″E
31	Bpujinagar	23°19′80.5″N	88°34′34.6″E
32	Mandapghat	23°20′47.0″N	88°34′68.8″E
33	Daharbuicha	23°20′51.9″N	88°35′17.9″E
34	Daspur	23°21′76.0″N	88°35′84.0″E
35	Batikamari	23°22′14.9″N	88°37′56.1″E
	Block: Krisnaganj		
36	Bablabon	23°24′11.5″N	88°39′63.2″E
37	Shantipara	23°24′43.7″N	88°40′33.5″E
38	Chougachakutirpara	23°25′48.8″N	88°39′79.9″E
39	Sakda	23°25′56.6″N	88°39′36.1″E
	Block: Krisnanagar I		
40	Dafarpota	23°25′48.2″N	88°38′19.5″E
41	Dhakuriapota	23°25′23.0″N	88°37′30.1″E
42	Naikura	23°24′94.4″N	88°36′96.4″E
43	Asannagar	23°25′57.0″N	88°36′44.4″E
44	Thakberia	23°25′84.0″N	88°35′85.6″E
45	Jhautala	23°26′05.4″N	88°35′20.6″E
46	Kulgachi	23°25′45.7″N	88°34′15.4″E
47	Gobrapota	23°25′36.5″N	88°32′51.6″E
	Block: Shantipur		
48	Bagdiya	23°18′88.0″N	88°26′71.9″E
49	Gobindapur	23°17′94.6″N	88°26′33.2″E
50	Ramnagarpara	23°14′10.4″N	88°25′48.3″E
51	Sutragor	23°13′83.9″N	88°25′27.0″E
52	Kalitala	23°13′62.5″N	88°25′21.4″E
53	Bokultala	23°14′87.0″N	88°24′85.7″E
54	Sahebdanga	23°13′84.8″N	88°23′76.4″E
55	Munsirpul	23°14′38.0″N	88°24′38.2″E

Annexure 2. Fertilizer applied and average yield in different blocks

Locations	Average yield (Mg ha^{-1})	P fertilizer dose (kg ha^{-1})
District: Burdwan		60-65
Block: Memari I	6.8	
Block: Memari II	6.84	
Block: Burdwan I	7.17	
Block: Burdwan II	7.06	
Block: Bhatar	6.5	
Block: Mangolkote	6.4	
Block: Katwa I	6.70	
Block: Katwa II	6.72	
Block: Purbasthali II	6.9	
District: Bankura		55-60
Block: Kotulpur	6.5	
Block: Joypur	6.5	
Block: Bishnupur	5.5	
Block: Onda	5.0	
Block: Bankura I	5.1	
Block: Bankura II	5.2	
Block: Barjora	6.0	
District: Hooghly		65-70
Block: Chinsurah- Mogra	6.9	
Block: Bolagarh	6.7	
Block: Pandua	6.81	
Block: Polba- Dadpur	6.63	
Block: Dhaniakhali	6.49	
Block: Tarakeswar	6.60	
Block: Pursurah	6.51	
Block: Arambagh	6.58	
Block: Goghat I	6.50	
Block: Goghat II	6.47	
District: Nadia		60-65
Block: Haringhata	6.42	
Block: Chakdah	6.51	
Block: Ranaghat II	6.22	
Block: Ranaghat I	6.20	
Block: Hanskhali	6.13	
Block: Krisnaganj	6.69	
Block: Krisnanagar I	6.64	
Block: Shantipur	6.51	