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Effect of zinc on grading, quality and yield of potato (*Solanum tuberosum*) in Bangladesh

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Abstract Application of Zn fertilizer at 4 kg ha^{-1} recorded significantly at tuber yield of potato. Total yield of tuber ha^{-1} were also changed significantly (P≤ .05) with the levels of Zn fertilization. In Munshigonj, the highest yield (31.07 t ha^{-1}) was obtained from plots treated with 4 kg Zn ha^{-1} along with the soil test based (STB) fertilizer and the lowest yield (27.44t ha^{-1}) was obtained with 0 kg Zn ha^{-1}plus the STB fertilizer. Similar results were obtained in Rangpur. Soil application of Zn resulted in a significant increase of tuber yield with an increase of Zn concentration in potato. The effect of Zn on tuber yield and Zn concentration in tuber greatly depends on the dose of Zn fertilizer. It can be concluded that soil application of 4 kg Zn ha^{-1}along with STB fertilizer should be encouraged to maintain sustainable production of potato in Bangladesh. Tuber grading was also significantly affected by Zn application. The highest number of tubers > 55 mm in diameter (A grade) was with the dose of 4 kg Zn ha^{-1}in both the locations, which was 51 % and 70 % higher over the control in both locations, respectively. In both the locations, the maximum number of C grade tuber (> 28 mm in diameter) was recorded at the control. The findings revealed that the increase in yield was shown the cumulative effect to increase the number of large sized tubers.

Keywords: Quality potato, Yield of potato, Zinc performance

Introduction

Zinc (Zn) is an important plant nutrient and a deficiency of which not only confines crop production (Cakmak, 2008), but also affects nutritional value and human health. It has been estimated that more than 50% of the Asian soils are Zn deficient (Singh *et al.*, 2005), but Zn is pre dominant in the soils of semi-arid tropical regions. Different agronomic management practices remove large amount of Zn from the native pool of

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soil. For example, a total of 416 g Zn ha^{-1} yr^{-1} was removed with a harvest of 6.5 t grain $ha^{-1}yr^{-1}$ in soybean–wheat cropping systems (Prasad, 2010). In Bangladesh, the major causes for increased Zn deficiency are the adoption of intensive cultivation, imbalanced nutrient application without incorporation of Zn and soils with low organic matter content (Behera *et al*., 2011; Ferdous *et al*., 2017, 2018). In this context, there should be a model shift toward developing strategies to overcome Zn deficit, increasing crop yields and improve human health. Zn deficiency is currently listed as a main risk issue for human physical condition. It has been projected that1/3 of the world's inhabitants lack sufficient Zn for sufficient nutrition (Cakmak, 2008; White and Broadley, 2011). This can be addressed by increasing the dietary Zn intake through several interventions (White and Broadley, 2011; Stein, 2010). Zn is known to occur in a number of discrete chemical forms changeable in their solubility and availability to plants. Application of Zn fertilizer to the soil or foliage with an attempt to increase tissue Zn concentration in edible portion and crop yield are being advocated (White and Broadley, 2009; Bouis and Welch, 2010). Zn is a vital essential nutrient for improving crop yield and productivity (White and Broadley, 2011) and provides nutrition security. Potato-based cropping pattern on presently under-utilized land could substantially benefit smallholder farmers and make considerable contributions to regional and national food security (Anwar *et al*., 2017; Ferdous *et al.*, 2016). Zn insufficiency has become a limiting factor for crop yield and productivity in a lot of agricultural soils. In order to achieve the inherent potential yields of crops, correcting zinc deficiency is necessary (Khoshgoftarmanesh *et al*., 2010). A significant aim in agronomic management and determination of optimum dose of micronutrient is to improve crop grain quality by increasing grain concentration of desirable trace elements and reducing these of potentially harmful trace elements such as Cd (Welch and Graham, 2004). This study aimed to assess the optimum dose of Zn fertilizer to increase yield and tuber Zn concentration at field conditions.

Potato (*Solanum tuberosum* L.) is mainly used as a vegetable crop in Bangladesh. Next to rice (*Oryza sativa* L.) and wheat (*Triticumae stivum* L.), potato is the third major food crop of Bangladesh. Potato is consumed by more than 1 billion people all over the planet; half of them are in the developing countries. It has the maximum food value on a dry matter basis and the most nutritious in proportion to its caloric contents (Welch and Graham, 2004). The productivity of potato in Bangladesh is still very low compared with that of main potato growing countries of the world (BBS, 2011). In 2008, a production of 8 million t of potato was recorded (BBS, 2011). The annual demand of potato is around 5.0 million t. The area under potato production was 5,20,000 ha and the average yield was 17.4 t ha^{-1}(BBS, 2011)., which is very low compared with other potato growing countries in the world. But in Munshigonj, the average yield of potato was

26.0 t ha^{-1}(BBS, 2011). Fertilizer is the key input to increase the yield of potato. Potatoes are heavy feeder demanding large quantities of fertilizer (Islam *et al*., 2013). Plants require varying amounts of 16 essential nutrients during various stages of their development. Uptake of different nutrients by potato per unit area and time is high because of the quick rate of early growth and potato tuber bulking (Islam *et al*., 2013). Although micronutrients are used in smaller quantities, they are just as important as the macronutrients. The availability of these nutrients in the soil depends on the soil and the environment conditions. For example, Zn is a relatively immobile nutrient that is concentrated in the soil organic matter near the soil surface. Cool, wet weather reduces the availability of Zn, possibly resulting in a deficiency. Availability of Zn declines rapidly as soil pH rises above 7. Therefore, deficiencies can occur in soils with high soil pH. Also, sandy soils are more likely to show micronutrient deficiencies than clay soils. Micronutrient deficiency symptoms can be visually identified in potato plants. The potato plant is no exception in its nutrient requirements. Standard fertility management supplies the crop needs. The area of potato cultivation is increasing rapidly over time due to suitable climatic conditions particularly prolonged winter in the north-west part in Bangladesh. However, the yield level is not promising due to an imbalanced use of fertilizer, lack of quality tuber seeds and its higher cost, improper agronomic practices and rapid dissemination of degenerative diseases (Mahmud *et al.*, 2009).

Optimum dose of Zn fertilizer for potato cultivation is one of the most important factors in Bangladesh. Many studies have been conducted presenting the effects of N, P and K fertilizer on the yield and quality of potatoes (Alam *et al*., 2007; Hossain *et al.*, 2003); however, research to find out the optimum dose of Zn for potato cultivation in Bangladesh is limited. Therefore, it is essential to determine the appropriate dose of Zn for potato cultivation. Cognizant of the above facts, a program was designed in order to assess the response of potato to Zn application in two regions of Bangladesh. Zn deficiencies have been reported for potato in many potato-growing regions in Bangladesh, such as the Tuber Crops Research Sub-Station, Munshigonj (0.7 µg/ml) and the On-Farm Research Division, Rangpur (0.45 µg/ml) where the critical limit is 0.60 µg/ml (Table 1).The objective was to determine the optimum dose of Zn for potato cultivation.

Materials and methods

Site description and experimental design

Two experiments were conducted at the Tuber Crops Research Sub-Station (TCRSS), Munshigonj and the On-Farm Research Division (OFRD), Alamnagar, Rangpur during *rabi* season (Mid-November to Mid-March) of

2012–2013 to find out the optimum dose of Zn for potato cultivation. The soil was a loamy soil. The land was prepared by tractor-driven disc plough followed by laddering. The initial soil samples of the experimental fields were collected and analyzed following standard methods (Table 1).The experiment consisted of six treatments that included soil application of 0 (control), 1, 2, 3, 4 and 5 kg Zn ha^{-1} in combination with the soil test- based (STB) chemical fertilizer dose in both the locations. Zinc sulphate monohydrate ($ZnSO_4.H_2O$) was used as a source of Zn. Urea, muriate of potash, triple super phosphate, gypsum and boron were used as thesources of N,K, P,S and B, respectively. A blanket dose of fertilizers were applied at N_{124} P_{20} K_{332} S_8 $B_{1.2}$ (STB) following the fertilizer recommendation guide, (2005) Bangladesh Agricultural Research Council (BARC) in each location (BARC, 2005). The plot size was 5 m ×6 m with a spacing of 60cm × 25cm. The treatments were arranged in three replications with randomized complete block design.

Table 1. Chemical properties of the experimental soil (initial) at the experimental field, Tuber Crop Research Sub-Station (TCRSS), Munshigonj and On-Farm Research Division (OFRD), Alamnagar, Rangpur

Soil parameters	pH	OM (%)	Ca	Mg	K	Total N%	P	S	B	Cu	Fe	Mn	Zn
			meq/100ml						µg/ml				
TCRSS, Munshigonj	6.1	1.3	4.2	1.4	0.1	0.07	28	73	0.18	1.6	82	9.2	0.70
OFRD, Rangpur	5.6	1.1	2.1	0.8	0.1	0.06	225	12	0.1	0.5	33	4.4	0.45
Critical level			2.0	0.5	0.12		7.0	10	0.2	0.2	4.0	1.0	0.6

Crop management

Well-sprouted tubers were planted in the furrows as per treatment. N, K, P, S and B were used at the dose of 124, 332, 20, 8 and 1.2 kg ha^{-1}, respectively. Applied all fertilizers and tubers were covered with soils by properly making a ridge. Then two small openings were created at a depth of 5–6 cm on either side of the planted tubers (10–12 cm apart) along the ridge where half of N and all other fertilizers were applied. The planting was done on 13 November 2012. Weeding was conducted once to keep the plots weed-free. Irrigations were provided at stolonization (22–23 days after planting-DAP), tuberization (33–35 DAP) and bulking (55–56 DAP) stages. Earthing up was done once after top-dressing of the remaining N at 30–32 DAP. Preventive measures were taken to control blight diseases by applying appropriate fungicides. Mancozeb, Mancozeb + Metalaxyl and Malathion were applied at the rate of 2 kg, 1.5 kg and 1 L ha^{-1}, respectively. Mancozeb, Mancozeb + Metalaxyl were applied twice, while Malathion was applied three times. Plants were dehaulmed at 100 days after planting and after 7 days of dehaulming the tubers were harvested.

Soil analysis

Soil pH was measured by a glass/calomel electrode method. Organic carbon was determined by wet oxidation method (Walkley and Black, 1935). Total N was determined by modified Kjeldahl method (Jackson, 1973). Ca and Mg were determined by KCl extractable method. K, Cu, Fe, Mn, Zn were determined by $NaHCO_3$ extraction followed by Atomic Absorption Spectrophotometer (AAS) reading. Available P was extracted from the soil by shaking with 0.03 M NH_4F-0.025 M HCl solution at pH < 7.0 by following the method of Bray and Kurtz, 1945. S was determined by $CaH_4\ (PO_4)_2.H_2O$ extraction followed by turbidimetric method with $BaCl_2$. B was determined by $CaCl_2$ extraction method (Petersen, 2002).

Data collection and statistical analysis

After defaulting, 5 hills were harvested randomly to record the number of tubers and weight of tuber per hill. Fresh potato tuber was harvested from randomly selected central areas (about 9 m^2) of each plot and converted into the t ha^{-1}. Mean data were analyzed statistically and were subjected to analysis of variance (ANOVA) using general linear model to evaluate significant differences between means at 95% confidence level. It was performed using the MSTAT-C (Gomez and Gomez, 1984). Further statistical validity of the differences among treatment means was estimated using the least significant difference (LSD) comparison method.

Results

Yield and yield components of potato

Zn fertilizer significantly affected most of the yield components and yield at both locations (TCRSS, Munshigonj and OFRD, Rangpur) (Tables2 and 3). At both locations, application of Zn at the rate of 4 kg ha^{-1} was found the most effective followed by the dose of 5 kg ha^{-1} in combination with the soil test- based (STB) chemical fertilizer dose. About 9% increase in plant height was observed with the 4 kg Zn ha^{-1}dose compared with the control where no Zn was applied in Munshigonj. Similarly, an increase of almost 40% stem $hill^{-1}$, about 45% tuber $hill^{-1}$ and 13% total yield was recorded for the same treatment (4 kg Zn ha^{-1}) compared with the control in Munshigonj. It was followed by the dose of 5kg Zn ha^{-1}. In Rangpur, similar trend was observed and the performance of potato was better with the dose of 4 kg Zn ha^{-1} with about 11% increase in plant height, 41% stem $hill^{-1}$, 40% tuber $hill^{-1}$ and about 23% greater yield compared with the control. It was followed by the dose of5kg Zn ha^{-1}.The application of chemical fertilizer was effective and the highest yield (31.07 and 36.30t ha^{-1}

in Munshigonj and Rangpur, respectively) was obtained with the dose of 4 kg Zn $ha^{-1}$and the lowest yield (27.44 and 29.50 t ha^{-1} in Munshigonj and Rangpur, respectively) was obtained from the control in both the locations. An application of Zn up to 4 kg Zn ha^{-1} significantly increased potato yield (31.07and 36.30 t ha^{-1} in Munshigonj and Rangpur, respectively) and with the highest level of Zn application (5 kg Zn ha^{-1}), yield was declined (30.54 and 35.83 t ha^{-1} in Munshigonj and Rangpur, respectively) (Tables 2and 3).

Table 2. Yield and yield components of potato as influenced by Zn fertilizer in combination with the soil test- based (STB) chemical fertilizer dose at the Tuber Crop Research Sub-Station Munshigonj during *rabi* season of 2012–2013

Treatment	Plant height (cm)	Stem $hill^{-1}$	Number of tuber $hill^{-1}$	Tuber grading (Number $plot^{-1}$)			Dry matter (%)	Yield (t ha^{-1})	Zinc concentration in potato (µg g^{-1})
				<28mm	28-55mm	>55mm			
0 kg Zn ha^{-1}	57.00	3.57	6.67	22.61	72.19	2.70	20.30	27.44	46.3 c
1 kg Zn ha^{-1}	57.62	3.83	7.00	21.69	75.24	2.80	21.14	27.47	48.3
2 kg Zn ha^{-1}	57.87	3.93	8.00	18.83	78.26	3.31	21.19	29.37	49.3
3 kg Zn ha^{-1}	60.60	5.00	8.00	20.47	76.09	3.30	21.04	29.67	48.0
4 kg Zn ha^{-1}	62.19	4.13	9.67	17.84	78.35	4.09	21.55	31.07	54.0
5 kg Zn ha^{-1}	60.83	3.90	9.00	16.34	79.86	3.65	21.41	30.54	52.7
$LSD_{(0.05)}$	3.25	0.32	1.68	--	3.42	0.67	--	2.47	0.06
Level of significance	**	**	**	NS	**	**	NS	**	**

**Significant for $P< 0.01$, NS = Not significant

Tuber grading

In both locations, the application of Zn showed a pronounced positive effect on the number and size of tubers (Tables 2 and 3). Tuber grading was also significantly affected by Zn application. The highest number of tubers > 55 mm in diameter (A grade) was with the dose of 4 kg

Zn ha^{-1} in both the locations, which was 51 % and 70 % higher over the control in both locations, respectively. The control produced the lowest (2.7and 2.3 mm in Munshigonj and Rangpur, respectively) in this grade. B grade tubers (28–55 mm in diameter) also varied significantly due to the application of different Zn doses. In Munshigonj, the 5 kg Zn ha^{-1} dose produced the highest number (79.86) of this grade tuber, which was similar with the dose of 4 kg Zn ha^{-1} (78.35). The lowest number (72.19) was recorded at the control. In Rangpur, the 4 kg Zn ha^{-1} dose produced the highest number (75.86) of this grade tuber. The lowest number (70.50) was observed at the control. In both the locations, the maximum number of C grade tuber (> 28 mm in diameter) was recorded at the control. The findings reveal that the increase in yield was the cumulative effect of increased number of large sized tubers.

Table 3. Yield and yield components of potato as influenced by Zn fertilizer in combination with the soil test- based (STB) chemical fertilizer dose at the On Farm Research Division, Alamnagar, Rangpur during *rabi* season of 2012–2013

Treatment	**Plant height (cm)**	**Stem hill^{-1}**	**Number of tuber hill^{-1}**	**Tuber Grading (Number Plot^{-1})**			**Dry matter (%)**	**Yield (t ha^{-1})**	**Zinc concentration in potato (μg g^{-1})**
				<28mm	28-55mm	>55mm			
0 kg Zn ha^{-1}	78.07	5.4	8.33	27.02	70.50	2.37	22.02	29.50	35.3
1 kg Zn ha^{-1}	79.27	5.8	9.67	24.02	72.55	3.25	21.40	32.15	39.3
2 kg Zn ha^{-1}	80.73	6.13	9.33	24.13	73.30	3.71	21.51	34.48	39.6
3 kg Zn ha^{-1}	85.80	6.47	10.67	22.0	74.57	3.61	21.62	35.47	36.0
4 kg Zn ha^{-1}	86.87	7.63	11.67	20.70	75.86	4.03	21.17	36.30	39.7
5 kg Zn ha^{-1}	85.47	7.47	11	22.1	75.21	3.80	21.05	35.83	41.0
$LSD_{(0.05)}$	4.04	0.63	1.23	2.22	3.23	1.22	--	2.35	0.01
Level of significance	**	**	**	**	**	**	NS	**	**

**Significant for *P*< 0.01, NS=Non significant

Zn concentration

In case of dry matter, there was no significant difference among the treatments between TCRSS, Munshigonj and OFRD, Rangpur station. A significant difference in Zn concentration of potato was observed among the treatments of potato in both the locations. In Munshigonj, Zn concentration of potato was the highest (54.0 μg g^{-1}) with the dose of4 kg Zn $ha^{-1}$and the lowest (46.3 μg g^{-1}) was found at the control. In Rangpur, Zn concentration of potato was the highest (41.0 μg g^{-1}) with the dose of 5 kg Zn ha^{-1}, which is similar with the doses of 4 kg Zn ha^{-1}(39.7 μg g^{-1}), 2 kg Zn ha^{-1}(39.3 μgg^{-1}) and 1 kg Zn ha^{-1}(35.3 μg g^{-1}) and the lowest (35.3 μg g^{-1})was found at the control.

Discussion

An additional potato tuber yield is achievable after application of Zn with organic and chemical/inorganic NPK fertilizers (Ferdous *et al*., 2014, 2018). This suggests that farmers could benefit more when organic and NPK fertilizers were supplemented with Zn fertilizer. Positive crop yield benefits have also been reported with other micronutrients such as Cu, B and Fe (Alloway, 2008). It is well known that Zn kick-starts growth and development through improved seedling vigour, root growth and chlorophyll concentration resulting in improved nutrient uptake and crop yield productivity (Alloway, 2008). Adequate Zn fertilization can also alleviate biotic and abiotic stress events in crops grown at farmers' fields due to benefits on several physiological processes including biosynthesis of growth hormones essential for photosynthesis (Wang *et al.*, 2012; Cakmak *et al*., 2010). Application of Zn with other nutrients usually increases crop productivity. This has been demonstrated for a variety of crops (Wang *et al.*, 2012; Cakmak *et al*., 2010). Although the individual application of Zn could not produce any significant effect on the tuber yield, but combined application appreciably increased tuber yields. Our results revealed that Zn concentrations in tuber increased gradually with increased application rates, which was similar with previous results (Cakmak *et al.*, 2010). The poor mobility and rapid adsorption of Zn by clay minerals are evident in soils having low moisture and low organic matter[1], leading to low availability of soil-Zn or fertilizer Zn to roots (Datta *et al*., 2015). Under field conditions, root Zn uptake is often limited due to low water availability and reduced root activity, and consequently continuous root uptake, shoot transport and grain deposition of Zn is limited (Cakmak *et al*., 2010;). The yield increases were in agreement with the findings of Khoshgoftarmanesh *et al.* (2010), who also reported that an application of Zn along with other nutrient increased the average tuber yield to a considerable extent. These results are in agreement with the findings of Khoshgoftarmanesh *et al.* (2013) and Cakmak (2008).

Zn is an important micronutrient for humans, plants and animals. Zn deficiency is a major world health problem. It is an important micronutrient in biological systems because of increasing reports about Zn deficiencies in crop and plants (Cakmak, 2008; Alloway, 2008). The relatively more increase in grain yield of crop with Zn application indicates the importance of Zn fertilizer and necessity of finding an appropriate dose of Zn for correcting its deficiency (Khoshgoftarmanesh *et al.,* 2013). A significantly increased yield was recorded with soil application of Zn (Khoshgoftarmanesh *et al.,* 2013).

Zn status in crop plants is directly correlated with crop yield, plant growth, and nutritional quality of the product (Cakmak, 2008; Alloway, 2008). It is possible to enhance nutrient concentrations and to maintain the high yield at the same time. They are exemplified in the cases of between Fe/Zn contents and yield in seeds of common bean (*Phaseolus vulgaris*), between mineral contents and yield in tubers of potato, and between shoot nutrient levels and biomass production in *Brassica* **(**White and Broadley, 2009**)**. Moreover, positive relationship between improved nutrient concentrations and yield in edible tissues has been observed. For example, Zn fertilization not only significantly increases wheat (*Triticum aestivum*) grain concentration and grain yield in Zn-deficient soil, but also enhances Zn level in grains without yield penalty in soil with adequate Zn availability (Cakmak *et al.,* 2010). Thus, it is a compelling case to develop Zn-enriched food crops as a sustainable complement to Zn fortification and supplementation in fighting global Zn deficiency (Welch and Graham, 2004). Zn plays a vital role in more than 300 enzymes and is a constituent in thousands of proteins including transcription factors (Hänsch and Mendel, 2009). Zn fertilization is effective in rising Zn level in grains, particularly in Zn deficient soils (Cakmak *et al.,* 2010). Strong increase in grain Zn concentration up to four-fold change has been observed in Zn-deficient wheat growing regions following Zn fertilization (Cakmak *et al.,* 2010). Zn concentration in any crop grains grown in Zn sufficient soils is also noticed to increase significantly with increased Zn application (Zhang *et al.,* 2012).
It can be concluded from the study that Zn at the rate of 4 kg ha^{-1} along with soil test- based (STB) chemical fertilizer dose can be regarded as the best combination for two locations in Bangladesh for achieving high yield goal of potato. Application of Zinc in appropriate dose helps to increase tuber yield and Zn concentration in potato.

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References

Alam, M. N., Jahan, M. S., Ali, M. K., Ashraf, M. A. and Islam, M. K. (2007). Effect of Vermicompost and Chemical Fertilizers on Growth, Yield and Yield Components of

Potato in Barind Soils of Bangladesh. Journal of Applied Sciences Research, 3:1879-1888.

Alloway, B. J. (2008). Zinc in Soils and Crop Nutrition. Second ed. International Zinc Association (IZA) and International Fertilizer Association (IFA), Brussels, Belgium and Paris, France.

Anwar, M., Ferdous, Z., Sarker, M. A., Hasan, A. K., Akhter, M. B., Zaman, M. A. U., Haque, Z. and Ullah, H. (2017). Employment Generation, Increasing Productivity and Improving Food Security through Farming Systems Technologies in the Monga Regions of Bangladesh. Annual Research Review and Biology, 16:1-15.

Bangladesh Bureau of Statistics (BBS) (2011). Statistical Yearbook of Bangladesh. Ministry of Planning, Government of the People's Republic of Bangladesh.

BARC (2005). Fertilizer Recommendation Guide, Bangladesh Agricultural Research Council, BARC, Farmgate, Dhaka, 1215.

Behera, S. K., Singh, M. V., Singh, K. N. and Todwal, S. (2011). Distribution variability of total and extractable zinc in cultivated acid soils of India and their relationship with some selected soil properties. Geoderma, 162:242-250.

Bouis, H. E. and Welch, R. M. (2010). Biofortification – a sustainable agricultural strategy for reducing micronutrient malnutrition in the global South. Crop Science, 50:S20-S32.

Bray, R. H. and Kurtz, L.T. (1945). Determination of total, organic and available forms of phosphorus on soils. Soil Science, 59:39-46.

Cakmak, I., Kalayci, M., Kaya, Y., Torun, A. A., Aydin, N., Wang, Y., Arisoy, Z., Erdem, H., Yzici, A., Gokmen, O., Ozturk, L. and Horst, W. J. (2010). Biofortification and localization of zinc in wheat grain, Journal of Agricultural and Food Chemistry, 58:9092-9102.

Cakmak, I. (2008). Enrichment of cereal grains with zinc: agronomic or genetic biofortification? Plant Soil, 302:1-17.

Datta, A., Shrestha, S., Ferdous, Z. and Win, C. C. (2015). Strategies for Enhancing Phosphorus Efficiency in Crop Production Systems. In: A. Rakshit, H.B. Singh, and A. Sen (Eds.), Nutrient Use Efficiency: from Basics to Advances. Springer, ISBN 978-81-322-2169-2, pp. 59-71. Available from: http://link.springer.com/chapter/10.1007/978-81-322-2169-2_5 (verified August 07, 2016).

Ferdous, Z., Ullah, H., Datta, A., Anwar, M. and Ali, A. (2018). Yield and Profitability of Tomato as Influenced by Integrated Application of Synthetic Fertilizer and Biogas Slurry. International Journal of Vegetable Science. doi.org/10.1080/19315260.2018.1434585.

Ferdous, Z., Datta, A. and Anwar, M. (2017). Effects of plastic mulch and indigenous microorganism on yield and yield attributes of cauliflower and tomato in inland and coastal regions of Bangladesh. Journal of Crop Improvement, 31:261-279.

Ferdous, Z., Datta, A., Anal, A. K., Anwar, M. and Khan, M. R. (2016). Development of home garden model for year round production and consumption for improving resource-poor household food security in Bangladesh. NJAS – Wageningen Journal of Life Science, 78:103-110.

Ferdous, Z., Anowar, M. M., Haque, Z., Mahamud, N. U. and Hossain, M. M. (2014). Comparative performance of two magnesium source on yield and yield attributes of potato. Bangladesh Journal of Environmental Science, 27:98-101.

Gomez, A. K. and Gomez, A. A. (1984). Statistical Procedure for Agricultural Research, second edition, John Wiley and Sons, pp. 95-109.

Hänsch, R. and Mendel, R. R. (2009). Physiological functions of mineral micronutrients (Cu, Zn, Mn, Fe, Ni, Mo, B, Cl). Current Opinion in Plant Biology, 12:259-266.

Hossain, A. B. M. S., Hakim, M. A. and Onguso, J. M. (2003). Effect of manure and fertilizer on the growth and yield of potato. Pakistan Journal of Biological Science, 6:1243-246.

Islam, M. M., Akhter, S., Majid, N. M., Ferdous, J. and Alam, M. S. (2013). Integrated nutrient management for potato (*Solanum tuberosum*) in grey terrace soil. Australian Journal of Crop Science, 7:1235-1241.

Jackson, M. L. (1973). Soil Chemical Analysis. Prentice Hall of India Pvt. Ltd., New Delhi, pp.498.

Khoshgoftarmanesh, A. H., SanaeiOstovar, A., Sadrarhami, A. and Chaney, R. (2013). Effect of tire rubber ash and zinc sulfate on yield and grain zinc and cadmium concentrations of different zinc-deficiency tolerance wheat cultivars under field conditions. European Journal of Agronomy, 49:42-49.

Khoshgoftarmanesh, A. H., Schulin, R., Chaney, R. L., Daneshbakhsh, B. and Afyuni, M. (2010). Micronutrient-efficient genotypes for crop yield and nutritional quality in sustainable agriculture. A review. Agronomy for Sustainable Development, 30:83-107.

Mahmud, A. A., Sajeda, A., Hossain, M. J., Bhuiyan, M. K. R. and Haque, M. A. (2009). Effect of dehaulming on yield of seed potatoes. Bangladesh Journal of Agricultural Research, 34:443-448.

Petersen, L. (2002). Analytical methods - soil, water, plant material and fertilizer. Soil Resources Management and Analytical Services. Soil Resource Development Institute, Dhaka. pp.21-24.

Prasad, R. (2010). Zinc biofortification of food grains in relation to food security and alleviation of zinc malnutrition. Current Science, 98:1300-1304.

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

Stein, A. J. (2010). Global impacts of human mineral malnutrition. Plant &Soil, 335:133-154.

Walkley, A. C. and Black, T. A. (1935). Estimation of soil organic carbon by chromic acid titration method. Soil Science, 47:29-38.

Wang, J., Mao, H., Zhao, H., Huang, D. and Wang, Z. (2012). Different increases in maize and wheat grain zinc concentrations caused by soil and foliar applications of zinc in Loess Plateau, China. Field Crops Research, 135:89-96.

Welch, R. M. and Graham, R. D. (2004). Breeding for micronutrients in staple food crops from a human nutrition perspective. Journal of Experimental Botany, 55:353-364

White, P. J. and Broadley, M. R. (2009). Biofortification of crops with seven mineral elements often lacking in human diets – iron, zinc, copper, calcium, magnesium,selenium and iodine. New Phytologist, 182: 49-84.

White, P. J. and Broadley, M. R. (2011). Physiological limits to zinc biofortification of edible crops. Frontier in Plant Science, 80:1-11.

Zhang, Y. Q., Sun, Y. X., Ye, Y. L., Karim, M. R., Xue, Y. F., Yan, P., Yan, P., Meng, Q. F., Cui, Z. L., Cakmak, I., Zhang,F. S. and Zou, C. Q. (2012). Zinc biofortification of wheat through fertilizer applications in different locations of China. Field Crops Research, 125: 1-7.

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