ISSN: 2641-1784

Research Article

Advance in Environmental Waste Management & Recycling

Evaluating plant micronutrient retention using an electric potential around the root zone in Rice (*Oryza sativa L.*)

Gayathree I. Senevirathne[1]*, J.A.S. Chathurika[1], Manju Gunawardana[1], Asitha S. Siriwardhana[1], Kosala Purasinhala[1]

[1]Sri Lanka Institute of Nanotechnology, Nanotechnology and Science Park, Mahenwatta, Pitipana North, Homagama.

***Corresponding author**

Gayathree I. Senevirathne, Sri Lanka Institute of Nanotechnology, Nanotechnology and Science Park, Mahenwatta, Pitipana North, Homagama, Sri Lanka, Email: gayathreeS@slintec.lk.

Submitted: 31 Jul 2022; **Accepted**: 28 Aug 2022: **Published**: 05 Sep 2022

Citation: *Gayathree I. Senevirathne, J.A.S. Chathurika, Manju Gunawardana, Asitha S. Siriwardhana, Kosala Purasinhala,. (2022). Evaluating plant micronutrient retention using an electric potential around the root zone in Rice (Oryza sativa L.). Adn Envi Was Mana Rec, 5(3),263-268.*

Abstract

Deficiency in micronutrients lead to poor health and performance in plants and hidden hunger in many developing countries. This could be inherited by unavailability micronutrients around the root zone especially, in rice, where water logged conditions are maintained. Hence, adding electric potential around the root zone to retain micronutrients would be a beneficial. Therefore, this study was designed to evaluate the effect of direct electric potential (EP) in retaining soil nutrient around the root zone using iron as an index ion. The experimental setup consisted of two concentric iron mesh pots, inner pot connected to the negative end and outer pot connected to the positive end. An electric potential of 5.0 V was supplied with the direct current of 0.1 A for 8 hours per day. Soil was characterized for available iron (Fe) content around three zones at the time of panicle initiation and time of harvest using ICPMS plant growth and performance was measured. At the time of panicle initiation soil-available Fe content was higher around the negative electrode than the positive electrode in plants supplied with EP (WEP).Plant height, above ground biomass, and paddy yield were significantly lower in WEP plants than the contol plants ($P<0.05$). WEP plants showed a 45% reduction in paddy yield compared to the NEP plants. Results confirms that Fe provided in the presence of an electric potential increases the Fe concentration around the root zone and enhances the Fe absorption. This underpins the use of electric potential to retain micronutrients especially, cations around the root zone ultimately enhancing their availability for plants.

Keywords: Rice, Electric Potential, Retention, Iron

Introduction

Supplying balance nutrients in sufficient level is a key aspect in increasing crop production in the modern agricultural systems. As same as macro nutrients, micro nutrienst also account for huge impact on growth and performance of plants as well as human nutrition. Micronutrient deficiencies in plants lead to poor growth, disease susceptibility, vulnerability to stress and eventually low yield [1-3].

Major staple grains such as rice, wheat are calorie-rich but levels of several micronutrients are insufficient to meet human minimum daily requirements [4]. Micronutrient deficiencies account for hidden hunger in developing countries leading to many health risks. Enzymes, proteins, and other biological compounds that perform important metabolic functions in humans do not function well without micronutrients [5]. Even for plants the same rule applies as if one of the essential plant nutrients is deficient, plant growth will be retarted even when all other essential nutrients are abundant. Therefore, to get the maximum yield both macro and micro nutrients should be supplied in optimum. Hence, improving retention of micronutrients in the root zone will enhance the absorption of nutrients to the crops and thereby increase the crop yield and the quality.

During past decades different approaches have been adopted to overcome the poor retention of micronutrients in soil to facilitate the better absorption to plants. Use of organic fertilizer like compost amendments and biochar increase the availability of micronutrients [6]. Slow-release fertilizers have low solubility and can provide a gradual nutrient supply for a long period of time which improves the nutrient uptake efficiency of fertilizer and reduces leaching [7, 8]. Foliar application of micronutrients is proved to be effective in crop growth and performance but the efficacy in high rainfall areas can be insufficient [9].

Breazeale & McGeorge demonstrated that cation uptake could be stimulated by the application of controlled direct voltage and suggested that cation uptake by plants is an electrical phenomenon [10, 11]. The application of electricity is also known to stimulate plant growth [12, 13]. Majority of previously reported studies have been conducted making the plant to act as one electrode [14]. At present, studies are more concentrated on creating an electrical field/potential around the plant [15, 16]. In the present study we evaluated the micronutrient retention in the root zone and absorption to plants by giving direct electric potential (EP). Therefore, we selected iron (Fe) as the test micronutrient. Although Fe is considered as a micronutrient, its toxicity or deficiency symptoms become more apparent and it will be easier to draw a conclusion about how providing an electric potential would affect nutrient retention especially, the cation around the root zone. Therefore, the objective of this study is to determine the effect of direct electric potential in retention of soil Fe around the root zone and thereby increase the iron uptake of rice.

Materials and methods

Experimental setup

This study was conducted in a greenhouse at Sri Lanka Institute of Nanotechnology, Homagama, Sri Lanka using local rice variety: BW 367. Treatments used for the pot study were; plants without EP around the root zone (NEP) and with EP around the root zone (WEP). 5.0 V of EP with maximum direct current of 0.1 A was supplied for 8 hours until the end of the growing season. The iron mesh was purposely selected to prepare the electrodes to provide excess iron (Fe) to the root zone as rice shows visible symptoms in growth and yield when subjected to Fe toxicity. The inner pot assigned as negative electrode while the outer pot was considered as the positive electrode (Figure 01-A). Five plants were used for each treatment

Soil sampling, characterization and extraction of Fe

Representative initial soil sample was collected, air-dried, sieved (2-mm) and was analysed for basic soil properties and available nutrients. Soil pH (1:2.5 soil: solution) were measured using pH meter (PL-700 PV). Available Nitrogen was measured by extracting using Potassium chloride (KCl) and extract was distilled and the distillate was titrated against 0.01 M HCl. Soil available phosphorus (P) was extracted by sodium bicarbonate and P concentration in extracts was determined by the Molybdate blue method [17] Soil organic carbon content was determined by Walkley and Black method [18].

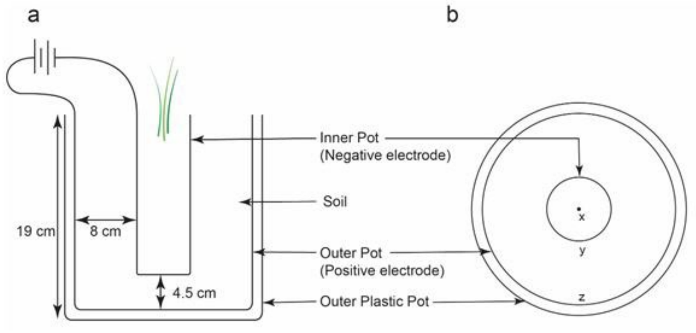

Figure 1: Schematic diagram of the experimental setup; a: longitudinal section of the experimental set up containing inner pot connected to negative end and outer mesh pot connected to positive end, b: soil sample collection points x= near the root of the plant, y= near negative electrode, z= near positive electrode.

Soil samples were collected from three zones: near root region (x), near negative electrode (y) near positive electrode (z) (Figure 01-b) from both control and treatment pots at the time of panicle initiation (40 days) and the end of the harvesting season (120 days). 2.5 g of air-dried soil were extracted with 0.1 M HCl (1:10 w/w) and filtrate [37] was analysed for plant available Fe content using Inductive coupled plasma mass spectrophotometry (ICP-MS-Agilent 7900). Plant height was measured weekly. Above and below ground biomass, paddy yield, number of seeds per panicle and unfilled grains per panicle were measured at the end of the growing season.

At the end of the growing season plants were up rooted and air dried. Total Fe amount in plant material was determined by dry ash method with slight modification. Samples were ashed at 600°C in the muffle furnace and residue was then dissolved in Aqua Regia and diluted with distilled water [19]. Finally, the total iron concentration was determined using ICPMS.

Statistical Analysis

Data were analyzed using t-tests for the comparison of two samples, by SAS (ver. 9.4). The level of significance for all statistical analyses was set at P=0.05. Non normal data was transferred to its log value and then subjected to statistical analysis. For pot experiments 5 replicates were done for each treatment. All chemical analysis were done in triplicate.

Results and Discussion

The pH of initial soil was slightly acidic and organic matter content was 2.43 %. Available nitrogen content was 2.21 mg/100 g of soil and available phosphorus content was 6.75 mg/kg of soil (Table 01).

Table 01: Soil Chemical Parameters

pH	5.46 ± 0.47
Available nitrogen in soil (mg/100 g soil)	2.21 ± 0.03
Available prosperous in soil (mg/kg soil)	6.75 ± 1.96
Organic carbon content (%)	1.41 ± 0.07

The errors represent the standard error of measurements for 3 replicates (n = 3)

Fe was chosen as the target cation as toxicity symptoms could be much related to the hypothesis under study. Lower Fe doses can lead to deficiency symptoms while higher concentrations may result in toxicity symptoms. Fe can be absorbed as Fe^{2+}, Fe^{3+} and as Fe-chelate, and its absorption is metabolically controlled by plant [20]. The occurrence of Fe toxicity is associated with a high concentration of Fe^{2+} in soil solution [21]. Rice plants usually maintain 60–300 ppm of Fe, while iron-deficient plants may have 10–30 ppm of Fe. Under toxic conditions the plant iron concentration may rise to 400–1000 ppm [22]. At the time of panicle initiation, Fe^{2+}concentration in soil was higher than the optimum concentration of 30 ppm reported by Portch & Hunter [23]. Available Fe^{2+} concentration was high in WEP pots than NEP pots at the panicle initiation time (Figure 02-a) and it has shown a steep increase towards the negative electrode (as Fe ions are positively charged) whereas in NEP pots all regions showed more or less similar concentrations (500-620 mg/kg soil).

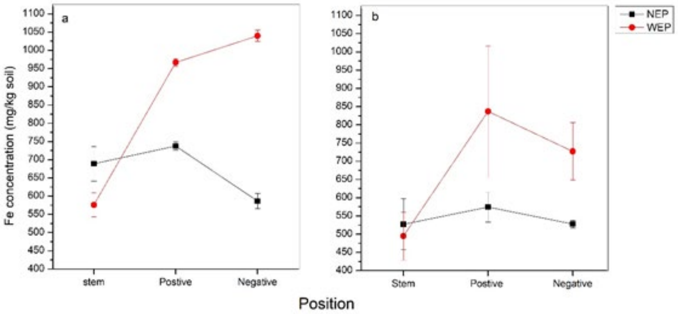

Figure 2: Iron concentration in soil a: at the time panicle initiation, b: at the end of the life cycle. The error bars represent the standard error of measurements for 3 replicates (n = 3). NEP= without electric potential, WEP= with electric potential

Fe concentration around the plant stem region was quite similar in both WEP and NEP pots (524.0, 585.3 mg/kg soil respectively). However, it was visible that among the two treatments, the concentration was higher in WEP plants (Figure 02-a). Ions like Fe and Manganese (Mn) are reduced in waterlogged soil to the well water-soluble Fe^{2+} and Mn^{2+} ions increasing the concentration of these two elements in the soil solution [24]. As rice is grown in waterlogged conditions, availability of Fe and Mn become high. However, at the end of the experiment, Fe concentration has decreased in both WEP and NEP soil but WEP soil concentration remained high (680 mg/kg soil) (Figure 02-b). Fe concentration reduction can be described with the increase absorption of Fe by the plant and absorption is significant when an electric potential is applied.

Plant height was (Table 02) significantly ($p<0.05$) higher in NEP plants (nearly 19% increase) compared to WEP plants. Although below ground biomass did not show a significant decrease in WEP plants, it is comparatively low compared to the NEP plants suggesting iron toxicity in the WEP plants. NEP plants showed a 44.5% increase in yield compared to WEP plants. Besides, the stunted growth and poor yield could be attributed to iron toxicity in the WEP plants. Both treatments may have not given the higher yield due to iron toxicity but the severity is high in WEP plants. All these results confirm that the EP around the root zone enhances the Fe uptake to the plant where plant shows toxicity symptoms. High concentrations of Fe in soil solution also decrease the absorption of other plant nutrients, especially due to chelating effect [25, 26]. Therefore, poor growth and performance can be attributed by poor availability of essential nutrients.

Table 02: Biometric measurements of WEP and NEP rice plants at the time of harvest

Parameter	NEP	WEP
Plant height ($\times10^{-2}$ m)	64.3 ± 1.5 a	54.1 ± 1.8 b
Above ground biomass ($\times10^{-3}$ kg)	3.62 ± 0.09 a	2.34 ± 0.07 b
Below ground biomass ($\times10^{-3}$ kg)	2.71 ±0.62 a	1.71 ± 0.32 a
Paddy yield kg/ha	156.13± 19.04 a	86.12± 10.85 b
The errors represent the standard error of measurements for 3 replicates (n = 3). Different letters indicate a significant difference ($p<0.05$) between treatments. NEP=without electric potential, WEP=with electric potential		

Fe translocation was higher in vegetative parts compared to the seeds in both WEP and NEP plants (Figure 03). Especially rice roots showed highest translocation of Fe. This observation was analogous to what observed with winter wheat and rice [27, 28]. Winter wheat showed high translocation of Fe and Mn in vegetative parts and glums compared to seeds and rice showed high translocation of Cd [27, 28]. These findings confirm that the control of redistribution processes via the phloem is important for the composition of harvested grains. Seeds in WEP plants showed a translocation of Fe in to seeds to a lesser extent compared to the seeds in NEP plants. This can be due to the same protective mechanism that the plant had undergone to overcome iron toxicity in edible portion. Elevated concentrations of metal ions such as Zn, Ni, Co or Cd cause increased content of ions in leaves and glums least affecting grains suggesting again a control of heavy metal delivery to the grains via the phloem. Retention of Fe in higher amounts in roots can also be to overcome oxidative stress in iron toxic conditions [29].

In the present study, it is confirmed that WEP plants showed toxicity symptoms of Fe due to high availability in soil (Figure 02) and high absorption (table 02) thus it is evident that the 5 V potential or the current (100 mA) provided was not the reason for poor growth of rice plants supplied with electric potential.

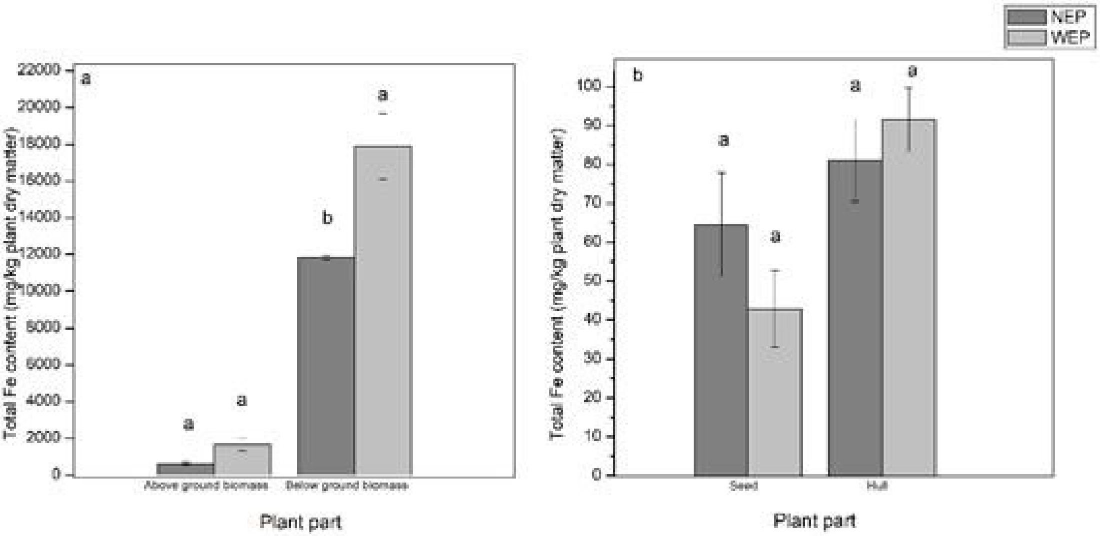

Figure 3: Total iron content in plant parts: a: above ground biomass and below ground biomass of WEP and NEP plants, b: in seed and hull of WEP and NEP plants. The error bars represent the standard error of measurements for 3 replicates (n = 3). (Different letters indicate a significant difference ($p<0.05$) between treatments) NEP= without electric potential, WEP= with electric potential

Previous studies showed radish plants supplied with electric current up to 1000 mA were healthy and had not shown any visible damage [16].

Table 03: Cationic Element Concentration around Positive and Negative Electrode Regions in WEP Plants

Element	Positive electrode mg/kg soil	Negative electrode mg/kg soil
Ca	79.35 ± 28.36 a	318.48 ± 114.48 a
Mn	8.25 ± 1.54 b	21.95± 5.92 a
Cu	2.12 ± 0.16 a	2.12 ± 0.04 a
Zn	53.51 ± 6.48 b	77.99 ± 2.50 a
Co	0.11 ± 0.01 b	0.30 ± 0.03 a
Ni	0.28 ± 0.03 a	0.32 ± 0.05 a
Mg	10.02 ± 1.02 a	27.92 ± 8.71 a

The errors represent the standard error of measurements for 3 replicates (n = 3). Different letters indicate a significant difference (p<0.05) between treatments. WEP= with electric potential

Even the time duration for the supply of potential and current is not the reason for poor growth as Black et al. [13] has conducted studies employing 4 and 12 hours per day with two splits and 24 hours.

Not only Fe (Fe^{2+} / Fe^{3+}), other cations such as Calcium (Ca), Magnesium (Mg), Manganese (Mn), Zinc (Zn), Nickel (Ni), Cobalt (Co) and Copper (Cu) determined by ICPMS were higher near the negative electrode (Table 03) in the WEP pots. Meaning that cation is retained near the root zone making them available to the plants (Table 03). These cations play a major role in the plant life cycle. Therefore, this approach is useful in retaining micronutrients along the root zone for better absorption. Many cations are micronutrients which are essential for plant growth and development. Plants need Ca2+ provide structural support, provide stress protection and also act as a messenger molecule [30]. Mg is particularly important to plants, with some 75% of leaf Mg involved in protein synthesis and 15–20% of total Mg associated with chlorophyll pigments [31]. Zinc deficiency in plants retards photosynthesis and nitrogen metabolism [32].

Ni is essential for viable seed production [33]. Mn^{2+} and Cu^{2+} acts as an essential element in enzyme activity and accounts for reduced yield in deficient conditions [34, 35]. Co has been recently found be essential micronutrient which enhances enzyme activity especially in legumes [36].

Conclusion

The present study confirms that a plant provided with an EP having a minimum current has increased the iron concentration around the negative electrode region making them more available for plants while in an plants without any electric potential all regions showed more or less similar concentrations of Fe. Plants provided with an EP showed higher iron translocation in all parts except the seed and a decrease in growth and performance due to iron toxicity. However, absorbed total Fe concentration in WEP plants was higher than NEP plants except in the seeds. This confirms that this approach can be used to increase retention of micronutrients around the root zone and thereby increase plant uptake to overcome the nutrient losses. Further studies should be carried out involving macronutrients instead of targeting a micro nutrient.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Conflicts of interest

The authors declare that they have no conflicts of interest pertaining to this study

Acknowledgement

Authors like to acknowledge Ms. Pivini Gunasekara from Sri Lanka Institute of Nanotechnology, Sri Lanka on her contribution to graphical illustrations.

References

1. Ali, N., Farooq, M., Hassan, M. A., Arshad, M. S., Saleem, M. K., & Faran, M. (2018). Micronutrient seed priming improves stand establishment, grain yield and biofortification of bread wheat. Crop and Pasture Science, 69(5), 479-487.
2. Hajiboland, R. (2012). Effect of micronutrient deficiencies on plants stress responses. In Abiotic stress responses in plants (pp. 283-329). Springer, New York, NY.
3. Grusak, M. A. (2001). Plant Macro-and Micronutrient Minerals. e LS.
4. Hirschi, K. D. (2009). Nutrient biofortification of food crops. Annual review of nutrition, 29, 401-421.
5. WHO-Micronutrient deficiencies (2020). (Accessed 05 July, 2020).
6. Adejumo, S. A., Owolabi, M. O., & Odesola, I. F. (2016). Agro-physiologic effects of compost and biochar produced at different temperatures on growth, photosynthetic pigment and micronutrients uptake of maize crop. African Journal of Agricultural Research, 11(8), 661-673.
7. Fernández-Escobar, R., Benlloch, M., Herrera, E., & Garcıa-Novelo, J. M. (2004). Effect of traditional and slow-release N fertilizers on growth of olive nursery plants and N losses by leaching. Scientia horticulturae, 101(1-2), 39-49.
8. Trenkel, M. E. (1997). Controlled-release and stabilized fertilizers in agriculture (Vol. 11). Paris: International fertilizer

industry association. (Accessed 12 April, 2020)

9. Aziz, M. Z., Yaseen, M., Abbas, T., Naveed, M., Mustafa, A., Hamid, Y., ... & Xu, M. G. (2019). Foliar application of micronutrients enhances crop stand, yield and the biofortification essential for human health of different wheat cultivars. Journal of Integrative Agriculture, 18(6), 1369-1378.
10. Breazeale, E. L., McGeorge, W. T., & Breazeale, J. F. (1951). Nutrition of plants considered as an electrical phenomenon—a new approach. Soil Science, 71(5), 371-376.
11. Breazeale, E.L. & Mc George, W.T. (1953). Cation uptake by plants as affected by an applied potential. Soil Science 75: 443-448.
12. Costanzo, E. (2008). The influence of an electric field on the growth of soy seedlings. Journal of Electrostatics 66(7-8): 417-420.
13. Black, J. D., Forsyth, F. R., Fensom, D. S. & Ross, R. B. (1971). Electrical stimulation and its effects on growth and ion accumulation in tomato plants. Canadian Journal of Botany 49(10): 1809-1815.
14. Bratton, B. O. & Henry, E. W. (1977). Electrical stimulation and its effects on indoleacetic acid and peroxidase levels in tomato plants (Lycopersicon esculentum). Journal of Experimental Botany 28(2): 338-344.
15. Gogo, E. O., Huyskens-Keil, S., Krimlowski, A., Ulrichs, C., Schmidt, U., Opiyo, A. & Dannehl, D. (2016). Impact of direct-electric-current on growth and bioactive compounds of African nightshade (Solanum scabrum Mill.) plants. Journal of Applied Botany and Food Quality 89: 60-67.
16. Dannehl, D., Huyskens-Keil, S., Eichholz, I., Ulrichs, C., & Schmidt, U. (2009). Effects of intermittent-direct-electric-current (IDC) on polyphenols and antioxidant activity in radish (Raphanus sativus L.) during growth. J. Appl. Bot. Food Qual, 83, 54-59.
17. Olsen, S., Cole, C., Watanabe, F. & Dean, L., (1954). Estimation of available phosphorus in soils by extraction with sodium bicarbonate. USDA Circular Nr 939, US Gov. Print. Office, Washington,D.C.
18. Walkley, A. & Black, I.A. (1934). An examination of Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. Soil Science 37: 29-38.
19. Plank, O.C. (1992). Plant Analysis Reference. Procedure. For Southern. US (SCSB # 368). Page 5. (Accessed 10 August, 2020)
20. Kobayashi, T., Itai, R. N. & Nishizawa, N.K. (2014). Iron Deficiency Responses in Rice Roots. Rice 7: 27–38.
21. Ponnamperuma, F.N.; Bradfield, R. & Peech, M. (1955). Physiological disease of rice attributable to iron toxicity. Nature 175: 265.
22. Vose P.B. (1982). Iron nutrition in plants: A world overview. Journal of Plant Nutrition 5: 233-249.
23. Portch, S., & Hunter, A. (2002). A systematic approach to soil fertility evaluation and improvement. Special publication, 5, 30-44.
24. Page, V. & Feller, U. (2015). Heavy metals in crop plants: transport and redistribution processes on the whole plant level. Agronomy 5(3): 447-463.
25. Schmidt, W., Buckhout, T. J. & Thomine, S. (2019). Iron Nutrition and Interactions in Plants. Frontiers in Plant Science 10: 1670.
26. Olaleye, A.O., Tabi, A.O. Ogunkunle, A.O.,Singh, B.N. & Sahrawat, K.L. (2001). Effect of toxic iron concentrations on the growth of lowland rice. Journal of Plant Nutrition 24: 441–457.
27. Stieger, P. A. & Feller, U. (1994). Nutrient accumulation and translocation in maturing wheat plants grown on waterlogged soil. Plant and Soil 160(1): 87-95.
28. Rascio, N., Dalla Vecchia, F., La Rocca, N., Barbato, R., Pagliano, C., Raviolo, M. & Gabbrielli, R. (2008). Metal accumulation and damage in rice (cv. Vialone nano) seedlings exposed to cadmium. Environmental and Experimental Botany 62(3): 267-278.
29. Becker, M. & Asch F. (2005). Iron toxicity in rice—Conditions and management concepts. Journal of Plant Nutrition and Soil Science 168(4): 558–573.
30. Thor, K. (2019). Calcium—nutrient and messenger. Frontiers in plant science 10: 440.
31. White, P.J. & 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.
32. Das, S., & Green, A. (2016). Zinc in crops and human health. In Biofortification of food crops (pp. 31-40). Springer, New Delhi.
33. Brown, P. H., Welch, R. M. & Cary, E. E. (1987). Nickel: A micronutrient essential for higher plants. Plant Physiology 85(3): 801-803.
34. Manivasagaperumal, R., Vijayarengan, P., Balamurugan, S. & Thiyagarajan, G. (2011). Effect of copper on growth, dry matter yield and nutrient content of Vigna radiata (L.) Wilczek. Journal of Phytology 3(3): 53-62.
35. Hänsch, R. & Mendel, R. R. 2009. Physiological functions of mineral micronutrients (cu, Zn, Mn, Fe, Ni, Mo, B, Cl). Current opinion in Plant Biology 12(3): 259-266.
36. Akbar, F. M., Zafar, M., Hamid, A., Ahmed, M., Khaliq, A., Khan, M. R. & ur Rehman, Z. (2013). Interactive effect of cobalt and nitrogen on growth, nodulation, yield and protein content of field grown pea. Horticulture, Environment Biotechnology 54: 465–474.
37. Osiname, O. A., Schulte, E. E. & Corey, R. B. (1973). Soil tests for available copper and zinc in soils of Western Nigeria. Journal of the Science of Food and Agriculture 24(11): 1341-1349.