Better Crops South Asia

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Inside: Micronutrient, Sulfur and Magnesium Issues for South Asian Agriculture

Better Crops
South Asia

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Our cover: Sulfur deficiency in groundnut shown as yellowing of the younger leaves.

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BETTER CROPS–SOUTH ASIA is a publication of the International Plant Nutrition Institute (IPNI). The mission of IPNI is to develop and promote scientific information about the responsible management of plant nutrition for the benefit of the human family.

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IPNI Scholar Award Recipients - 2018

IPNI recently selected the winners of its Scholar Award Program. In 2018, 31 graduate students representing 11 countries were chosen.

"Every year we have assembled a very impressive group of scholars from across the globe," said Dr. Terry L. Roberts, IPNI President. "Each individual selected should be very proud of this accomplishment. They are already contributing greatly to the field of plant nutrition," added Roberts.

Regional committees of IPNI scientific staff select the recipients of the IPNI Scholar Award. The awards are presented directly to the students at a preferred location and no specific duties are required of them. Each scholar receives the equivalent of US$2,000.

Short biographies for the six Scholar Award winners from South Asia are provided below. Brief details about the 25 other scholars follow and are organized according to IPNI Program. **BCSA**


Mr. Didal
India


Mr. Praharaj
India


Ms. Rani
India


Mr. Sarkar
India


Ms. Thakur
India


Mr. Ishfaq
Pakistan

Mr. Vijay Kumar Didal, the Professor Jayashankar Telangana State Agricultural University, Hyderabad, Telangana, India, is working towards his Ph.D. in agronomy. His dissertation title is *"Enhancing nitrogen use efficiency in different establishment methods of rice (Oryza sativa L.)."* Mr. Didal's research work focused on the application of the right dose of nutrients, as per the guidance of Nutrient Expert and recommended dose of fertilizer, with neem-coated urea and vermicompost in different establishment methods of rice (normal transplanting and mechanized system of rice intensification). Following his Ph.D., he wants to pursue postdoctoral research and continue research in the areas of enhancing nutrient use efficiency and biofortification for producing nutrient-enriched crops through the adoption of 4R practices.

Mr. Subhashisa Praharaj, Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, Uttarakhand, India, is working towards his Ph.D. in agronomy. His dissertation title is *"Agronomic biofortification of bread wheat (Triticum aestivum L.) with zinc."* His research is focused on alleviating the malnutrition problem (induced by zinc deficiency) through the agronomic biofortification approach. Mr. Praharaj would like to be actively engaged in research to further find solutions for addressing micronutrient malnutrition problems, especially in developing countries.

Ms. Sarita Rani, CCS Haryana Agricultural University, Hisar, Haryana, India, is earning her Ph.D. in agronomy. Her dissertation title is *"Integrated nutrient management for pearl millet-wheat cropping system under saline conditions."* One of the objectives of her research is to study the effect of different integrated nutrient management treatments on growth, yield attributes, yield, and quality parameters of pearl millet-wheat cropping system under saline conditions. After completing her Ph.D., she would like to join Agriculture Research Services and assist her country in developing new technologies.

Mr. Sukamal Sarkar, Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, West Bengal, India, is working towards his Ph.D. in crop husbandry. His dissertation title is *"Cropping system intensification through inclusion of pulses in rice-based system in the salt-affected coastal zone of West Bengal."* One of the major themes of his Ph.D. is optimizing the sowing date of rice for escaping inundation during initial growth. Mr. Sarkar's continued interest is in developing climate resistant rice based cropping systems, through the reorientation of the crop calendar and inclusion of pulses in coastal saline zone of West Bengal.

Ms. Jagriti Thakur, Dr. YS Parmar University of Horticulture & Forestry, Solan, Himachal Pradesh, India, is earning her Ph.D. in soil science. Her dissertation title is *"Standardization of irrigation and fertigation schedules for apple under high density plantation."* One of the objectives of Ms. Thakur's research is to determine the optimum irrigation schedule and fertilizer level for fertigation of high-density apple. Following her Ph.D., she would like to render her services as a global competent soil conservationist and help people to think about environmental stewardship and ecosystem sustainability.

Mr. Muhammad Ishfaq, Institute of Soil and Environmental Sciences, University of Agriculture, Faisalabad, Pakistan, is earning his Ph.D. in soil science. His dissertation title is *"Soil-potassium dynamics-based fertilizer recommendations in three alluvial soils differing in clay content."* One of Mr. Ishfaq's research objectives is to develop precise and site-specific potassium recommendation for different regions of Pakistan. He plans to develop himself as a productive researcher, who can contribute to soil sustainability and food security related challenges.

NORTH & WEST AFRICA


Ms. Boughanem
Algeria


Mr. Agbodan
Togo

Ms. Wassila Boughanem, Djilali Bounaama University, Khemiss Meliana, Algeria, is earning her Ph.D. in crop improvement.

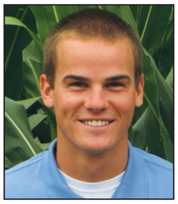
Mr. Kodjovi Mawuégnigan Léonard Agbodan, University of Lomé, Lomé, Togo, is working towards his Ph.D. in plant conservation biology.

EAST & SOUTHERN AFRICA

Ms. Moreblessing Chimweta, Bindura University of Science Education, Bindura, Zimbabwe, is earning her Ph.D. in flood-recession cropping.


Ms. Chimweta
Zimbabwe

NORTH AMERICA


Mr. Bernhard
United States


Ms. Croat
United States


Ms. de Oliveira Silva
United States


Ms. Olmedo Pico
United States


Mr. Ortez
United States

Mr. Brad Bernhard, University of Illinois at Urbana-Champaign, United States, is working towards his Ph.D. in crop sciences.

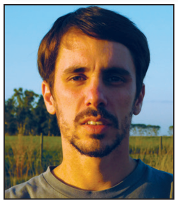
Ms. Samantha Croat, North Dakota State University, United States, is earning her M.Sc. in soil science.

Ms. Amanda de Oliveira Silva, Kansas State University, United States, is earning her Ph.D. in Agronomy with emphasis on crop physiology, plant nutrition, and soil fertility.

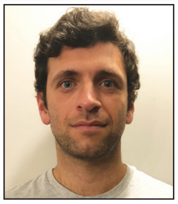
Ms. Lia Belen Olmedo Pico, Purdue University, United States, is working towards her Ph.D. in crop physiology.

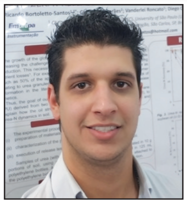
Mr. Osler Ortez, University of Nebraska-Lincoln, United States, completed his Master's degree in agronomy at Kansas State University.

SOUTH AMERICA


Mr. Arata
Argentina


Ms. Girón
Argentina


Mr. Romero
Argentina


Mr. Bortoletto-Santos
Brazil


Mr. Sarfaraz
Brazil


Mr. Saturnino-Pinto
Brazil


Mr. Sattolo
Brazil


Mr. González-Osario
Colombia

Mr. Agustín Francisco Arata, National University of the Center of Buenos Aires Province, Argentina, is working towards his Ph.D. in agricultural sciences at the University of Buenos Aires.

Ms. Paula Girón, University of Buenos Aires, Argentina, is working towards her M.Sc. in soil science.

Mr. Juan Ignacio Romero, University of Tucuman, Argentina, is working towards his M.Sc. in agricultural sciences.

SOUTH AMERICA continued

Mr. Ricardo Bortoletto-Santos, University of São Paulo, Brazil, is working towards his Ph.D. in chemistry with the Brazilian Agricultural Research Corporation (Embrapa Instrumentation).

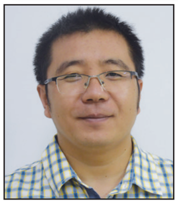
Mr. Qamar Sarfaraz, Federal University of Santa Maria, Santa Maria, Rio Grande do Sul, Brazil, is working towards his Ph.D. in soil fertility and plant nutrition.

Mr. Webert Saturnino-Pinto, the Federal University of Viçosa, Brazil, is working towards his D.Sc. in soils and plant nutrition.

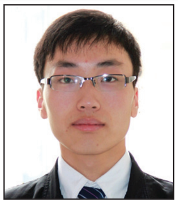
Mr. Thales Sattolo, University of São Paulo, Brazil, is working on a Ph.D. in soil fertility. Mr. Sattolo obtained his M.Sc. at the College of Agriculture "Luiz de Queiroz", University of São Paulo (ESALQ/USP).

Mr. Hernán González-Osario, Universidad Nacional de Colombia, Colombia, is working on a Ph.D. in biotechnology.

CHINA


Mr. Cai
China

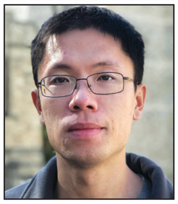

Mr. Guo
China


Mr. Ma
China


Mr. Riaz
China


Mr. Tang
China


Mr. Yang
China


Mr. Yao
China


Ms. Zhang
China

Mr. Zejiang Cai, Chinese Academy of Agricultural Sciences, China, is earning his Ph.D. in soil science.

Mr. Junjie Guo, Nanjing Agricultural University, China, is earning his Ph.D. in plant nutrition.

Mr. Qingxu Ma, Zhejiang University, China, is completing his Ph.D. in plant nutrition.

Mr. Muhammad Riaz, Huazhong Agricultural University, China, is working towards his Ph.D. in plant nutrition.

Mr. Zheren Tang, Fudan University, China, is earning his Ph.D. in environmental engineering.

Mr. Xiao Yang, Shanghai Jiao Tong University, China, is working towards his Ph.D. in horticulture.

Mr. Zhiyuan Yao, Northwest Agriculture and Forestry University, China, is earning his Ph.D. in plant nutrition.

Ms. Jiajia Zhang, Chinese Academy of Agricultural Sciences, China, is working towards her Ph.D. in plant nutrition.

EASTERN EUROPE & CENTRAL ASIA


Mr. Timokhin
Russia

Mr. Artyom Timokhin, Omsk State Agrarian University, Russia, is working on his M.Sc. at the Faculty of Agrochemistry, Soil Science, Ecology and Environmental Engineering.

Importance of Micronutrients in Indian Agriculture

By Arvind K. Shukla, Sanjib K. Behera, T. Satyanarayana, and Kaushik Majumdar

Different Micronutrient Status of Indian Soils

The analysis of more than 2.0 lakhs soil samples, collected from 508 districts of the country during 2011-2017 under the leadership of ICAR – Indian Institute of Soil Science, Bhopal, revealed that on an average of 36.5, 12.8, 7.1, 4.2 and 23.2% soils are deficient in Zn, Fe, Mn, Cu and B, respectively (**Figure 1**). Maps of available micronutrients in soil help in understanding the level of micronutrient deficiency and toxicity and their judicious management for sustainable production, improvement in food quality, and animal/human health. Therefore, global positioning system (GPS) and geographical information system (GIS) based district-wise maps have been prepared for various states of India for formulating the remediation strategies for correcting micronutrients deficiencies in crops.

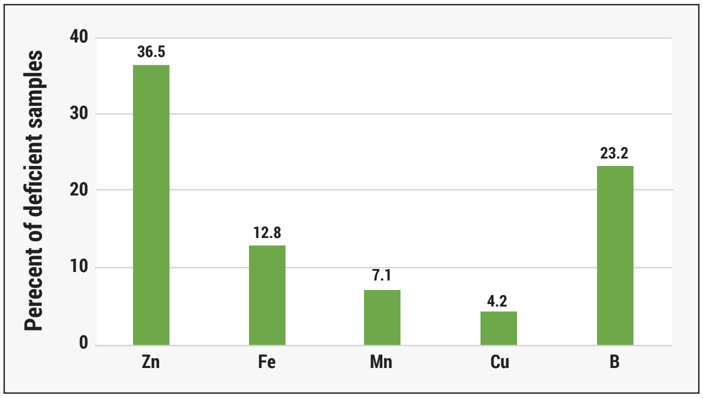


Figure 1. Micronutrient deficiency in Indian soils (2017).

Zinc deficiency varied among states with a minimum of 9.6% in Uttarakhand to as high as 75.3% in Rajasthan (**Figure 2**). Out of 508 districts delineated, 117, 100, 80, 63, 38 and 110 districts had deficiency in the range of 0-10, 10-20, 20-30, 30-40, 40-50 and > 50%, respectively. The most Zn deficient soils are the ones that are coarser in texture (sandy/loamy sand), high in pH (> 8.5 or alkali/sodic soils) and or low in organic carbon (< 0.4%), or calcareous/ high in $CaCO_3$ (> 0.5%) and intensively cultivated (Shukla et al., 2014). Initially, the incidence of Zn deficiency was observed more in cereals, particularly rice and wheat belts of the country, but with passage of time, distribution of Zn deficiency has covered the whole country across the crops and cropping systems (Shukla and Tiwari, 2016). In general, low Zn deficiency has been recorded in soils having acidic pH as compared to soils having high pH; however, soils of northern India, except Rajasthan, also displayed medium deficiency range as compared to previous studies due to regular use of $ZnSO_4$ fertilizer (Sadana et al., 2010). On the other hand, increase in Zn deficiency in areas where low deficiency was recorded earlier has resulted from intensification of agricultural systems, faster depletion rate of available Zn pools (Shukla et al., 2016).

Out of 508 districts, 290 districts were having very high Fe content (**Figure 2**), especially in acidic soil areas. In India, the problem of iron deficiency is mainly in calcareous and other alkaline soils having pH > 7.5. The availability of Fe gets reduced under drought or moisture stress condition due to conversion of Fe^{2+} iron to less available Fe^{3+} iron. On the other hand, the soils of north-eastern districts, Odisha and Kerala are reported to have Fe toxicity problem in rice paddies. Manganese deficiency in Indian soils is relatively low. Similar to Fe, Mn availability is also influenced by soil moisture, and affect the incidence and severity of Mn deficiency in crops grown with low moisture content.

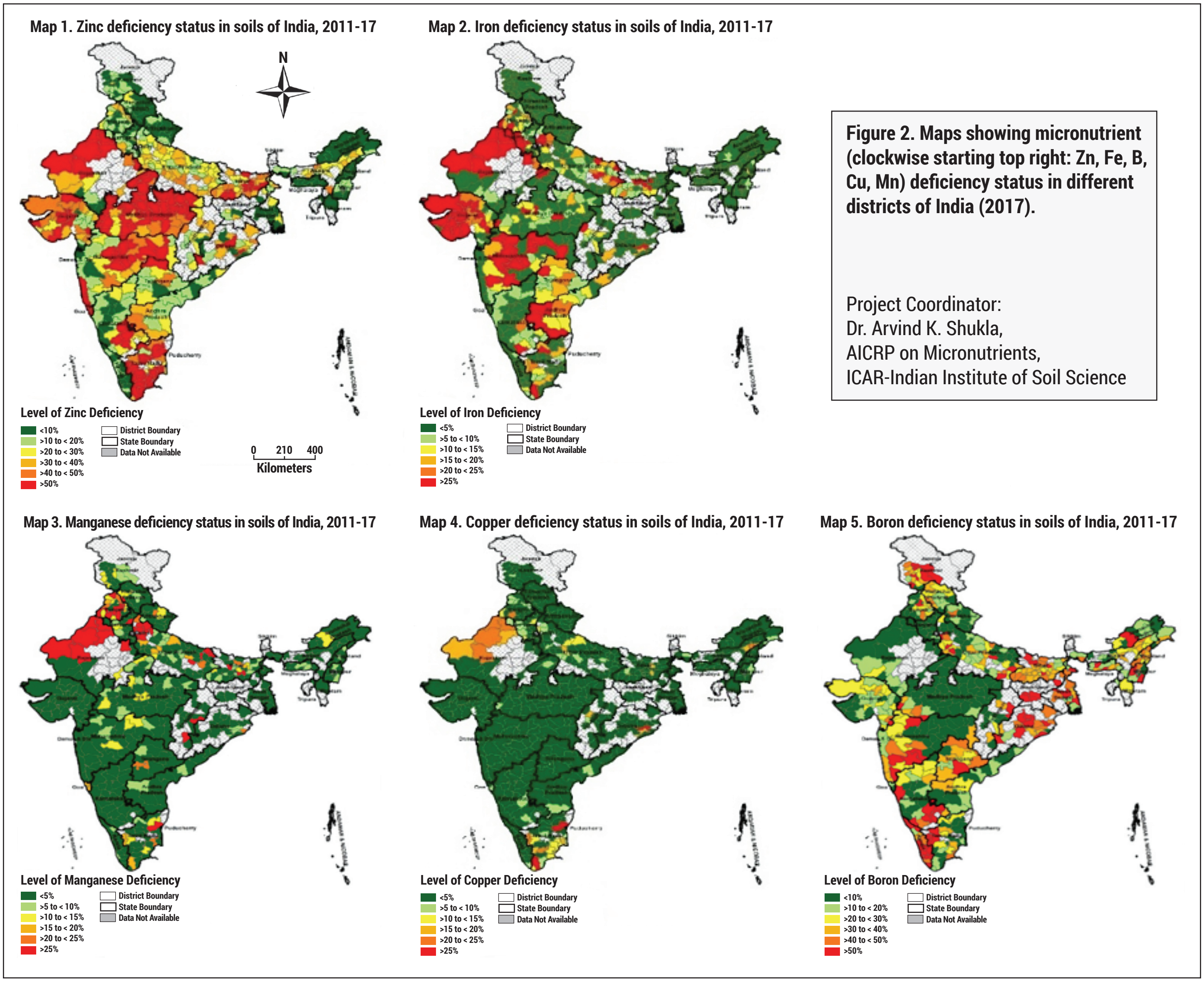
On the other hand, Mn is more mobile in imperfect-

SUMMARY

Micronutrients play important role in Indian agriculture towards sustainable crop production. The importance of micronutrients need to be viewed in food systems context, as their inclusion in balanced fertilization schedule would optimize micronutrient supply and availability in the entire food consumption cycle. Indian soils are generally poor in fertility especially in micronutrients as these have consistently been mined away from their finite soil source due to continuous cultivation for a very long time without addition of micronutrient fertilizer resulting in emerging micronutrient deficiency. In addition, green revolution led-increased demand of micronutrients by the high-yielding crop cultivars (especially rice and wheat) as well as adoption of intensive cropping practices, use of high-analysis fertilizers with low micronutrient content, decreased use of organic manures and crop residues, growing of crops in soils with low micronutrient reserves and other natural and anthropogenic factors adversely affecting phyto-availability of micronutrients aggravated the situation (Takkar and Shukla, 2015).

KEYWORDS:
soil fertility status; soil survey; nutrient interactions

ABBREVIATIONS AND NOTES:
B = boron; Cu = copper; Fe = iron; Mn = manganese; Zinc = zinc



Map 1. Zinc deficiency status in soils of India, 2011-17

Map 2. Iron deficiency status in soils of India, 2011-17

Map 3. Manganese deficiency status in soils of India, 2011-17

Map 4. Copper deficiency status in soils of India, 2011-17

Map 5. Boron deficiency status in soils of India, 2011-17

Figure 2. Maps showing micronutrient (clockwise starting top right: Zn, Fe, B, Cu, Mn) deficiency status in different districts of India (2017).

Project Coordinator:
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AICRP on Micronutrients,
ICAR-Indian Institute of Soil Science

ly drained soils (water logged) and sometime exhibited Mn toxicity in rice grown in paddy fields under continuous submerged conditions. Out of the soil samples analysed from 508 districts, more than 376 districts exhibited very high Mn content (**Figure 2**) and soils of 36 districts showed Mn deficiency > 25%. In India, Cu deficiency is not a such major concern showing deficiency in 4.2% soils only. Boron deficiency is more common in highly calcareous soils of Bihar and Gujarat and acid soils of West Bengal, Odisha and Jharkhand. In India, B deficiency has been recognised next to Zn. Availability of B to plants is governed by soil pH, $CaCO_3$ and organic matter contents, interactions of B with other nutrients, plant type and variety, and environmental factors. The concentrations of total B content ranges from 2.6 to 630 mg/kg (Takkar, 2011) and available (hot water soluble – HWS) B in Indian soils ranged from 0.04 to 250 mg B/kg with an average of 22 mg/kg soil. In general, B deficiency was higher in eastern region of the country and has resulted due to its excess leaching in sandy loam soils, alluvial and loess deposits. Molybdenum is least studied micronutrient in India. Molybdate anions (MoO_4^{2-}) are strongly adsorbed by soil minerals and colloids (at $pH < 6.0$) and sometimes also trapped due to formation of secondary minerals. Hydrous aluminium silicates may also fix Mo strongly. Soils formed from shale and granite parent materials had high Mo concentrations; whereas, those derived from sandstone, basalt and limestone had low Mo contents. Most of the soils are adequate in Mo but its deficiency is noticed in some acidic, sandy and leached soils. Molybdenum is most readily taken up by plants in soils with a pH above 7 and is relatively unavailable in acid soils. Thus, Mo deficiencies are most likely to occur on acid and severely leached soils and severely affecting mainly legumes, crucifer vegetables and oilseeds.

With due course of time, multi-micro and secondary nutrients deficiencies have emerged in different areas of the country. Currently, an average of 9.9, 8.3, 6.2, 5.8, 3.7, 3.3, 2.8 and 2.4% samples were found to be deficient in S+Zn,

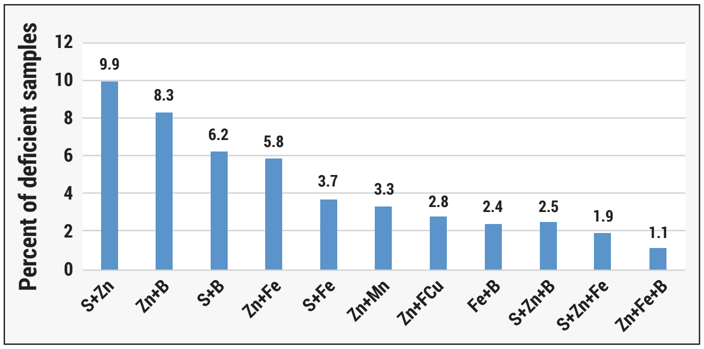

Figure 3. Multi- micro and secondary nutrient deficiency in soil (2017).

Zn+B, S+B, Zn+Fe, S+Fe, Zn+Mn, Zn+Cu and Fe+B nutrient combinations, respectively (**Figure 3**). Three nutrient deficiencies like S+Zn+B, S+Zn+Fe and Zn+Fe+B were recorded in about 2.5, 1.9 and 1.1% soils, respectively. Four or more than four nutrient deficiencies were very less (less than 0.5%) in most of the states. The results clearly reveal that deficiency of single micronutrient is most predominant as compared to the combination of two or three or four or more than four elements simultaneously. In the light of this, use of multi-micronutrient mixtures should be avoided as their use would be uneconomical. Only the deficient micronutrient as revealed by the soil tests should be used to mitigate the deficiency and minimize environment pollution.

Crop Response to Micronutrient Application

Crop responses to micronutrient application vary widely depending upon soil and crop type (Takkar et al., 1989). Crop responses to Zn application in large number of crops has been reported across the country based on more than 15,000 trials conducted at cultivator's field from 1967 to 2016. Depending upon the level of increase in relative economic yield (REY) of different crops, a soil is classified as marginal or non-responsive, responsive, very responsive, and highly responsive to Zn when incremental REY was <200, 200-500, 500-1000, > 1000 kg/ha, respectively. Out of 4,144 trials conducted on farmers' fields during 1967-84, 58 and 42% exhibited response and no response to Zn application, respectively (Takkar et al., 1989). The number of responsive trials increased over the years to 63% during 1985-2000, 72% during 2000-2010, and 80% during 2011-2016 (**Figure 4**; Shukla and Behera, 2011). On average, crop responses to soil and foliar application of Fe ranges from 0.45 to 0.89 t/ha for cereals, 0.3 to 0.68 t/ha for millet, 0.34 to 0.58 t/ha for pulses, 0.16 to 0.55 t/ha for oilseeds, 0.20 to 1.53 t/ha for vegetables, and 0.39 to 9.68 t/ha for cash and other crops. Soil and or foliage application of Mn resulted in marked response of crops on Mn-deficient soils. The responses ranged from trace to 3.78 t/ha for wheat, trace to 1.78 t/ha for rice, 0.03 to 1.02 t/ha for soybean, 0.40 to 0.70 t/ha for sunflower, 3.63 to 4.30 t/ha for onion, 0.30 to 0.80 t/ha for tomato. Crop responses to Cu application ranged from trace to 1.78 t/ha of cereals, 0.20 to 0.30 t/ha of millets, trace to 0.80 t/ha of oilseeds, 4.43 to 6.18 t/ha of onion, and 0.30 to 0.50 t/ha of sugarcane. Soil application of 0.5 to 2.5 kg B/ha gave a response of 108 to 684 kg grain/kg of B or 10 to 44% over NPK and helped in sustaining the high productivity of cereals, pulses, oilseeds and cash crops in B-deficient soils of Bihar, Orissa, West Bengal, Assam and Punjab. Response of crops to Mo application ranged from 0.24 to 1.01 t/ha for rice, 0 to 0.47 t/ha for wheat, 0.08 to 0.19 t/ha for soybean, and 0.10 to 0.40 t/ha for green gram.

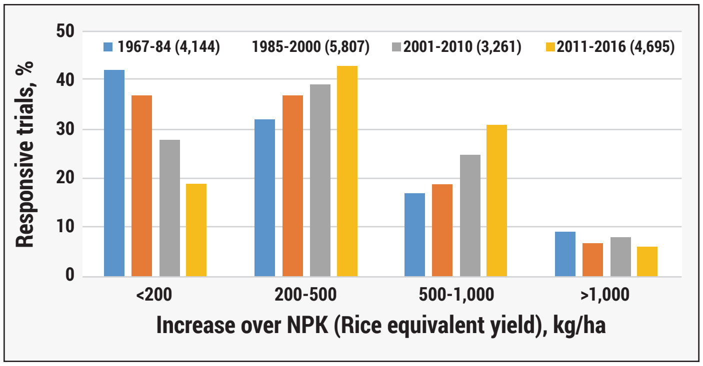

Figure 4. Changes in crop responses to Zn with time in trials at farmers' field.

Role of Micronutrients in Food Grain Production

The increasing trend in consumption of micronutrients fertilizer vs food grain production of the country over the years (**Figure 5**) shows the importance of micronutrients in sustainable food production. According to an estimate, the contribution of Zn and B fertilizer to present food crop production comes around 29 M t rice equivalent yields (Shukla and Behera, 2011). The contribution from other micronutrients should not be underestimated as their use has been increasing consistently and enhancing crop productivity. As per recent estimate of micronutrients consumption, the use of $ZnSO_4$ fertilizer was the highest (1,88,305 t) followed by iron sulphate (21,188 t), boric acid/borax (19,976 t), manganese sulphate (2,740 t) and copper sulphate (1,369 t) during 2015-16 (FAI, 2016). Of the total Zn used, 70% goes to the field crops and remaining 30% to vegetable and fruit crops,

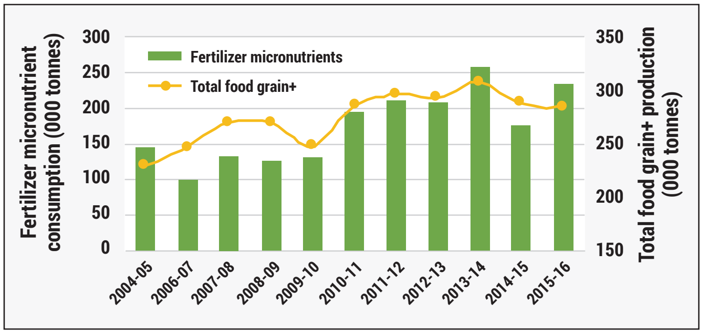

Figure 5. Micronutrient fertilizer consumption vis-a-vis food grain production in the country during last decade.

while the reverse is true for Mn, Fe and Cu.

Role of Micronutrients in Enhancing Use Efficiency of Macronutrients

The partial factor productivity of macronutrients (NPK) fertilizer has declined over the years. One of the reasons for this decline is emerging deficiency of micronutrients. Although needed in trace amounts, micronutrients play a macro role in enhancing the use efficiency of NPK as recorded in several studies (Shukla et al., 2009). Decline in system productivity of rice-wheat sequence has been recorded in different parts of the country due to omission of micronutrient from the balanced fertilization schedule (**Table 1**). The results obtained in long-term experiments at PDCSR, Modipuram, Meerut showed 16.7% cumulative increase in productivity of rice-wheat system with Zn application over NPK treatments after 15 years. The productivity loss due to omission of Zn from balanced fertilization schedule ranged between 3.5 and 17.5% at nine sites across the country. Another study conducted in rice-rice system revealed that the highest increase in P use efficiency was recorded with addition of Zn (35.4%) followed by B (28.7%) and Mn (15.6%) in balanced fertilization schedule. On an average, the agronomic efficiency of fertilizer K was enhanced by 35.1, 32.4, 33.7 and 10.3% with addition of S, Zn, B and Mn in balanced fertilization schedule, respectively. Addition of micronutrients in balanced fertilization schedule increased internal utilization efficiency of NPK (Tiwari, 2008).

Table 1. Loss in system productivity (kg/ha) due to omission of micronutrients from balanced fertilization schedule in rice-wheat cropping system.

Location	System productivity with NPK fertilization (REY*)	Loss in system productivity (kg/ha) due to omission of micronutrients from balanced fertilization schedule			
		Zn	B	Mn	Cu
Modipuram	17,574	2,057 (11.7)	1,738 (9.9)	1,440 (8.2)	-
Kanpur	15,371	1,619 (10.5)	-	-	-
Faizabad	12,992	2,279 (17.5)	1,499 (11.5)	1,061 (8.2)	-
Varanasi	12,823	1,096 (8.5)	486 (3.8)	494 (3.9)	665 (5.2)
Pantnagar	13,305	1,230 (9.2)	567 (4.6)	-	-
Sabour	14,301	-	-	-	-
Ranchi	11,664	489 (4.2)	528 (4.5)	-	-
Palampur	10,037	354 (33.5)	795 (7.9)	-	-
R. S. Pura	13,493	804 (6.0)	-	248 (1.8)	344 (2.5)

Values in parenthesis depict percentage loss; *Rice equivalent yield.

Micronutrient Management for Higher Crop Production

Micronutrient management needs to be carried out based on the demand and supply of micronutrient in soil-plant system. It varies with crops, soil types, severity of deficiency, source, method, time, rates and frequency of application. While planning for replenishment of the micronutrients removed by the crop and/or depleted from soil through micronutrient management, important aspects like micronutrient requirements of the crops and cropping systems, ranges between their deficiencies and toxicities, low use efficiency of micronutrients, and residual availability etc. need to be considered (Shukla et al., 2014).

Out of the several Zn sources evaluated for their efficacy under different soil-crop situations, $ZnSO_4 \cdot 7H_2O$ proved better or equal with other sources in correcting the Zn deficiency (Takkar et al., 1989; Shukla et al., 2009; Shukla and Behera, 2012). However, in some studies, chelated Zn proved more effective than $ZnSO_4 \cdot 7H_2O$ for maize and rice. The optimum rates of Zn application varied with severity of Zn deficiency, soil types and nature of crops. Results emanated from large number of field studies indicated that 2.5 to 10 kg Zn/ha as $ZnSO_4 \cdot 7H_2O$ proved most effective in mitigating its deficiency and in sustaining high soil productivity in most of the crops grown on diverse Zn-deficient soils. As the efficiency of soil applied Zn is very low (2-5%), efforts have been made to develop efficient and inexpensive methods of Zn application. Application of Zn to soil through broadcast and mixed or its band placement below the seed proved superior to top dressinzg. Other Zn application methods are side-dressing or side-banding, foliar application of 0.5 to 2.0% $ZnSO_4 \cdot 7H_2O$ solution and soaking or coating of seeds in Zn solution. The results of seedling root dip with ZnO are contradictory in sustaining high agricultural productivity of rice, sugarcane and vegetables. Seed soaking, rice seedling root dip in ZnO slurry and even foliar application could not catch up with the farmers so far because of certain constraints and limitations.

Iron chlorosis is generally observed in upland crops especially rice, sorghum, groundnut, sugarcane, chickpea grown in highly calcareous soils, compact soil with restricted aeration, soils with low in Fe and high in P and bicarbonate. Ferrous sulphate, (19-20.5% Fe) is the major source used for managing Fe deficiency in the country. However, Fe-EDTA (9-12% Fe), Fe-EDDHA (10.0% Fe), pyrite, biotite, and organic manures (FYM 0.15% Fe), poultry and pig manure (0.16% Fe), sewage sludge have also been used as sources of Fe to correct its deficiency in crops. By and large foliar application of 10-12 kg $FeSO_4$/ha or soil application of 50-150 kg/ha $FeSO_4$ alleviated Fe deficiency in most of the crops (Takkar et al., 1989). The rates of soil application of Fe were very high, because of rapid rate of oxidation of Fe^{+2} to Fe^{+3} and as such were uneconomical. Similarly high cost of Fe-chelates discourages farmers to use it as Fe fertilizer source. For horticultural crops foliar spray of $FeSO_4$ is recommended, which have beenmore effective and efficient than soil application in correcting Fe-chlorosis in tomato, chilli, groundnut and sugarcane.

Severe Mn deficiency is difficult to manage with soil application due to oxidation of soil-applied Mn, especially in high pH soils. Foliar application of $MnSO_4 \cdot H_2O$ is an immediate effective measure to combat Mn deficiency in wheat though it has to be applied every year. The fertilizer $MnSO_4 \cdot H_2O$ proved 1.5 and 10 times more effective than that of Mn-frits and MnO_2, respectively in increasing significantly the wheat grain yield. Both soil and foliar application of Mn helped to mitigate its deficiency and sustained the high productivity of wheat. However, foliar spray of 0.5% $MnSO_4$ solution was found more effective and economical than soil application of 50 kg $MnSO_4$/ha.

Copper deficiency in Indian soils is very less. Either soil or foliar application of Cu to soybean-wheat cropping system, on Typic Ustipsamments of Ludhiana, proved equally effective in correcting its deficiency and gave significant response of 0.2 t/ha with soil application of 5.0 kg Cu/ha to the first crop. Foliar spray of 0.2% $CuSO_4$ solution increased soybean grain yield from 2.18 to 2.35 t/ha. Residual effect of soil applied Cu on the following wheat was non-significant.

Boron deficiency is one of the serious nutritional problems limiting crop production in acid and calcareous soils. Soil application of borax or sodium tetra-borate decahydrate ($Na_2B_4O_7 \cdot 10H_2O$, fertilizer grade, 10.5% B) is commonly used to correct its deficiency. Boric acid (H_3BO_3, 17% B), solubor ($Na_2B_4O_7 \cdot 5H_2O$+ $Na_2B_4O_7 \cdot 10H_2O$ fertilizer grade, 19% B) are mostly used as foliar spray. However, rates of B application for achieving sustainable optimum productivity varied with crop, season and type of soil. In a B-deficient sandy loam calcareous soil of Bihar, the optimum rates for chickpea and winter maize were 2.08 and 1.68 kg B/ha, respectively. Application of 1.5 kg B/ha gave optimum yields of *Rabi* (winter) crops such as mustard, maize, sunflower, onion and lentil and the rates were higher 2.0-2.5 kg B/ha for *kharif* (summer) crops: groundnut, maize, onion, yam, bean and black gram (Sakal and Singh, 1995). The rates of B were relatively low (0.5-0.75 kg B/ha) for sesame and linseed in coarse-textured Entisols; more moderate (0.75 and 1.5 kg B/ha) for maize, wheat and rice; 1-2 kg B/ha for chickpea, pigeon pea, groundnut, sunflower and mustard in calcareous and clay textured Vertisols (Dangarwala et al., 1994); and 2.0 kg B/ha for potato in acid soils (Inceptisol) of Garhwal. It was also superior to foliar spray (0.2% + lime twice) or potato tuber soaking. But both soil and foliar application of B proved equally effective for soybean. By and large, soil application of B is a better method of its management than the foliar and seed soaking.

Conclusion

Adoption of intensive and modern cropping practices with high-yielding crop cultivars and unbalanced fertilizer application resulted in emergence of widespread micronutrient deficiency in soils and crops of India leading to reduced crop yield and low micronutrient concentration in agricultural produce. According to results from the analysis of more than 2.0 lakh soil samples collected from 508 districts of the country, on average 36.5, 12.8, 7.1, 4.2 and 23.2% soils are deficient in Zn, Fe, Mn, Cu and B respectively. More than 50% samples are found deficient in Zn and B in 110 and 63 districts of the country, respectively. Over the years, Zn deficiency has declined in soils of the country because of regular and more use of Zn fertilizer whereas deficiency of Fe and Mn increased slightly. In addition, multi-micro and secondary nutrient deficiencies like S+Zn, Zn+B, S+B, Zn+Fe, S+Fe, Zn+Mn, Zn+Cu and Fe+B, S+Zn+B, S+Zn+Fe and Zn+Fe+B have emerged in different parts of the country. Responses of different crops to micronutrient application have been recorded in different micronutrient deficient soils. Inclusion of micronutrients in balanced fertilization schedule increased internal use efficiency of NPK. Therefore, micronutrient management depending upon crops, soil types, severity of deficiency, source, method, time, rates and frequency of application needs to be undertaken for sustainable agricultural production and maintenance of human health. **BCSA**

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Zinc Deficiency in Indian Soils is Associated with Low Crop Productivity and Crop Quality

By Soumitra Das, Andrew Green, and Ming Xian Fan

Zinc deficiency in plants delays photosynthesis and N metabolism, reduces flowering and fruit development, and prolongs growth periods. All of these factors result in delayed maturity, lower yield, poor produce quality, and sub-optimal nutrient use efficiency. Some of the common deficiency symptoms of Zn in plants appear as light green, yellow, or bleached spots in interveinal areas of older leaves; small size of the emerging leaves, often termed as "little leaf"; and in case of severe deficiency, small inter-nodal distances so that all the leaves appear to come out from the same point, termed as "rosetting." It is estimated that almost half of the soils in the world are deficient in Zn (Alloway, 2008). Since cereal grains have inherently low concentrations of Zn, growing these crops on potentially Zn-deficient soils further decreases grain Zn concentration.

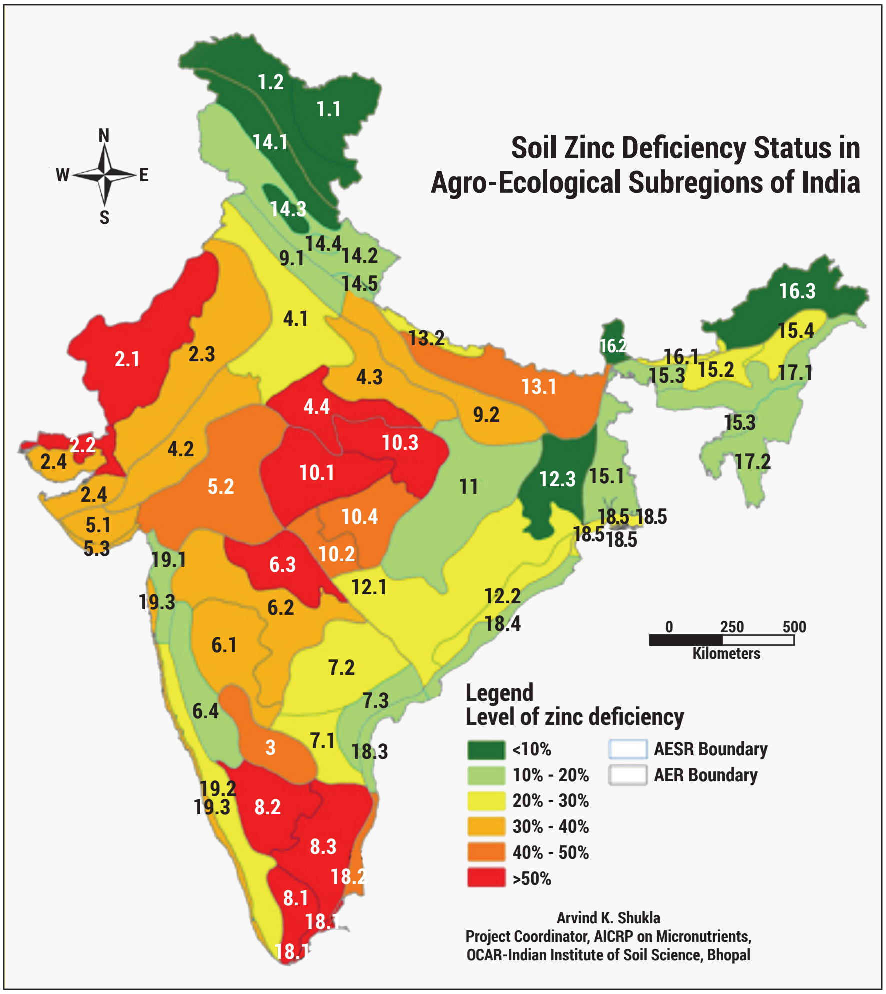

Figure 1. Soil zinc deficiency status in India (Shukla and Tiwari, 2016).

Zinc is considered the fifth most important yield-limiting nutrient (following N, P, K, and S) in India's upland crops, and in lowland crops like rice, it is second only to N. About 40% of soil samples analysed for available Zn in India were found to be deficient (**Figure 1**). Zinc plays a key role in plants as both a structural constituent and a regulatory co-factor for a wide range of different enzymes and proteins in various biochemical pathways. These pathways include carbohydrate metabolism, photosynthesis, conversion of sugars to starch, protein metabolism, auxin (growth regulator) metabolism, pollen formation, maintenance of the integrity of biological membranes, and resistance to infection by certain pathogens.

There are multiple reasons for the increasing incidences of Zn deficiency in India, including large Zn removals due to high crop yields and intensive cropping systems, lesser application of organic manures, use of high analysis fertilizers, increased use of phosphatic fertilizers resulting in P-induced Zn deficiency, and the use of poor quality irrigation water with high calcium carbonate content.

The critical level of Zn in Indian soils is 0.6 ppm and there is a growing concern that it should be increased to 1.2 ppm, or higher, as the intensity of crop production increas-

SUMMARY

Zinc deficiency is widespread in soils and crops worldwide. Almost half of the soils in the world are deficient in Zn and India is no exception. About 40% of soil samples analysed for available Zn were found deficient in India. Significant improvement in crop yield and quality through balanced application of Zn has been reported across India. Adequate Zn application to crops is important for the food and nutritional security of India.

KEYWORDS:

human health; crop quality; micronutrients

ABBREVIATIONS AND NOTES:

Zn = zinc; N = nitrogen; P = phosphorus; K = potassium; S = sulphur

Table 1. Refined critical limit of Zn for some soils and crops at different locations.

		----- Zn, mg/kg -----	
Location	Crop	Soil	Plant
Akola, Maharashtra	Soybean	0.65	24.3
Coimbatore. Tamil Nadu	Maize	0.90	24.8
Pantnagar, Uttarakhand	Lentil	1.20	9.6
Pantnagar, Uttarakhand	Chickpea	1.20	19.2
Nainital, Uttarakhand	Soybean	1.24	22.3

Shukla and Tiwari, 2016.

Table 2. Response of different crops to Zn application.

			Grain yield, t/ha		% Response
Crop	Location	On-farm trials	Zn 0	Zn 5 / Zn 10*	Zn 5 / Zn 10
Rice	Assam	43	5.1	5.6	12
Rice	Jharkhand	46	3.8	4.0	9.3
Rice	West Bengal	6	4.8	5.3	10
Chickpea	Maharashtra	5	1.0	1.1	9.4
Cotton	Maharashtra	25	1.3	1.5	9.8
Maize	Maharashtra	5	2.6	2.9	10
Soybean	Maharashtra	36	1.1	1.2	8.8
Wheat	Maharashtra	16	3.9	4.2	8.8
Cabbage	Tamil Nadu	2	39.5	42.5	7.3

*Zn application of 5 or 10 kg/ha. Shukla and Tiwari, 2016.

Table 3. Effect of different sources and mode of Zn application on grain yield (t/ha) and grain Zn content (mg/kg) in rice.

Treatment	Grain yield, t/ha	Grain Zn content, mg/kg
No Zn	6.3	19
2.5 kg Zn/ha ($ZnSO_4$)	7.2	21
5.0 kg Zn/ha ($ZnSO_4$)	7.4	22
2 Foliar Spray (0.5% $ZnSO_4$)	6.5	25
2 Foliar Spray (0.5% Zn-EDTA)	8.0	24
2.5 kg Zn/ha ($ZnSO_4$) + 1 Foliar Spray (0.5% $ZnSO_4$)	6.7	26
5.0 kg Zn/ha ($ZnSO_4$) + 1 Foliar Spray (0.5% $ZnSO_4$)	8.5	27
2.5 kg Zn/ha ($ZnSO_4$) + 1 Foliar Spray (0.5% Zn-EDTA)	7.7	24
5.0 kg Zn/ha ($ZnSO_4$) + 1 Foliar Spray (0.5% Zn-EDTA)	6.7	26

Shukla and Tiwari, 2016.

es. At present, about 40% of soils in India are classified as Zn deficient on the basis of the existing critical Zn limit. However, crop response to applied Zn has been observed in soils above the critical limit and it is generally believed that critical concentrations of Zn are site specific and one critical limit may not represent every soil type or crop. Shukla and Tiwari (2016) suggested that the critical limit of Zn may vary widely depending upon the soil types and crops grown, and it could be as high as 1.24 mg Zn/kg for soybean in Uttarakhand (**Table 1**).

Crop Response to Zinc Fertilizers

Crop response to Zn has been observed in most crops in almost all types of soils and agro-climatic conditions. While the response was found to be higher in grain crops like rice and maize, fruit and vegetable crops also responded well to applied Zn. Singh (2008) summarized the range of crop response to Zn based on over 15,000 on-station field trials in India:

Cereals: 420 to 550 kg/ha (16 to 23%)
Pulses: 170 to 460 kg/ha (7.3 to 28%)
Oilseeds: 110 to 360 kg/ha (11 to 40%)
Fodders: 90 to 4620 kg/ha (5 to 34%)

Shukla and Tiwari (2016) reported the response of Zn application on cereals (rice, wheat, and maize), pulses (chickpea), oilseeds (soybean), fiber crops (cotton), and vegetable (cabbage) based on a large number of experiments and on-farms trials in different states of India. Zinc application resulted in a 9 to 12% increase in rice yield at different locations. A similar range of responses were also observed for chickpea, cotton, maize, soybean, wheat, and cabbage at different locations (**Table 2**).

A field trial on source and method of Zn application in kharif rice in Nadia, West Bengal, showed that basal application of 5 kg Zn/ha through zinc sulfate solution ($ZnSO_4 \cdot 7H_2O$), along with one foliar spray of 0.5% $ZnSO_4$ at the time of maximum tillering, increased the grain yield of rice to 8.5 t/ha and increased the grain Zn content by 47% (27 mg/kg) over no Zn application (**Table 3**). Field experiments on rice and wheat in India showed that application of Zn-enriched urea (up to 3% Zn) significantly enhanced both grain Zn concentration and grain yield in rice and wheat (Shivay et al., 2008).

Application of Zn not only increases the crop yield, but also improves its quality. For potato it increased ascorbic acid in tubers, reduced phenol content and enhanced reducing sugars, sucrose, and total sugar. Zinc was also found to increase the phenol tannin content of leaves, kernels, and seed coat of cotton. An increase in the energy value, as well as total lipids, crude protein, and carbohydrate content in rice, maize, wheat, mustard, chickpea, and blackgram were attributed to Zn application. Improvement in amino acids in cereals and sucrose recovery and juice quality in sugarcane were also reported (Kalwe et al., 2001).

A recent study (Myers et al., 2014) highlighted reduction in nutritional quality of grains due to climate change impact. Field trials in wheat, rice, maize, and soybean showed that high ambient CO_2 concentration significantly reduced Zn concentration in wheat grains by as much as 9.3%. Similarly, foliar Zn application increased water use efficiency

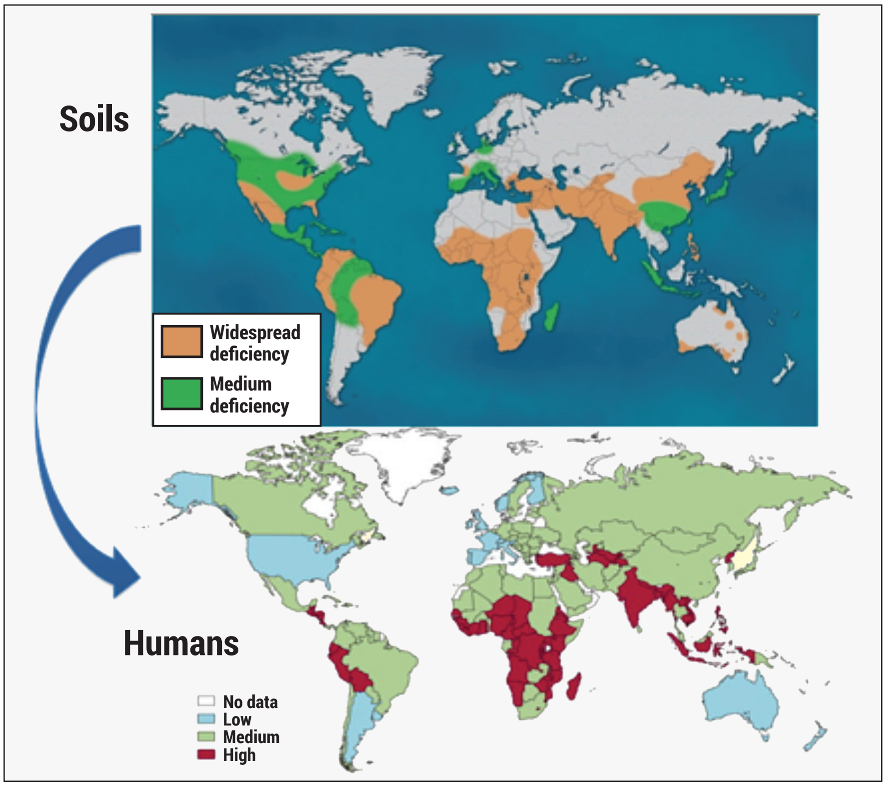

Figure 2. Worldwide Zn deficiency in soils and humans (Alloway, 2008).

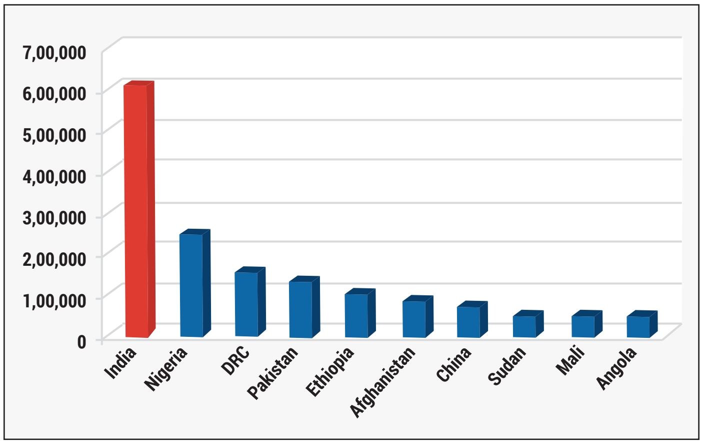

Figure 3. Deaths from diarrhoea and pneumonia in children under 5 (UNICEF, 2012).

and thereby reduced the negative effects of drought stress. Results support that appropriate Zn application could improve wheat growth under drought stress (Yavas and Unay, 2016). Therefore, adequate Zn application in crops would be necessary to alleviate climate change impacts on crop yield and nutritional quality.

Zinc in Human Health

It is estimated that about one third of the world's population suffers from Zn deficiency (Cakmak, 2008). Zinc deficiency, especially in infants and young children under five years of age, has received global attention. According to the World Health Organization, about 800,000 people die annually due to Zn deficiency including 450,000 that are children under the age of five. It is estimated that 60 to 70% of the population in Asia and sub-Saharan Africa could be at risk of low Zn intake. In absolute numbers, this translates into about 2 billion people in Asia and 400 million people in sub-Saharan Africa (Prasad, 2006). There is a high degree of correlation between Zn deficiency in soils and that in human beings (**Figure 2**).

Some of the reported symptoms of Zn deficiency in humans, specifically in infants and young children, are diarrhoea, pneumonia, stunted growth, weak immune system, delayed mental development, dwarfism, impaired cognitive function, behavioural problems, memory impairment, problems with spatial learning, and neuronal atrophy. Deaths due to diarrhoea and pneumonia in children under five is alarmingly high in India, higher than the sub-Saharan African countries or their neighbouring countries (**Figure 3**). This has drawn the attention from the government and policy makers in India and generated awareness on the critical role of Zn in human health. Consequently, Zn fertilizer consumption doubled over the last ten years in India (FAI, 2016).

Analysis of Zn content in soil, crop, animal, and human blood serum established a strong relationship and interdependence among the soil-plant-animal-human continuum, as depicted in **Table 4**.

Table 4. Soil Zn status vs Zn content in crops and its effect on serum Zn level in human blood.

Location	Soil Zn status	No. of people tested	Mean Zn status, ppm	
			Soil	Plant
Ranga Reddy (Andhra Pradesh)	Deficient	18	0.4	18
	Sufficient	44	0.7	27
East Godavari (Andhra Pradesh)	Deficient	16	0.4	14
	Sufficient	44	1.1	26

Singh, 2009.

Possible Solution to the Correction of Zinc Malnutrition

Ideally, cereal grains should contain 40 to 60 mg Zn/kg grain to meet the requirement of human nutrition and currently it is only 10 to 30 mg Zn/kg grain (Cakmak, 2008). Some possible solutions to the Zn malnutrition in the humans may be: i) Food supplementation, ii) Food fortification, or iii) Biofortification. The former two programmes require infrastructure, purchasing power, access to market and healthcare centres, and uninterrupted funding, which have their own constraints. Alternatively, biofortification (genetic or agronomic fortification of crops especially food crops with Zn) is the best option for alleviating Zn deficiency. This involves both the breeding of new varieties of crops with the genetic potential to accumulate a high density of Zn in cereal grains (genetic biofortification) and the use of Zn fertilizers to increase Zn density (agronomic biofortification). Although the plant breeding route is likely to be the most cost effective approach in the long run, the use of fertilizers is the fastest route to improve the Zn density in diets. In order to replenish the Zn taken up by the improved cultivars, higher and sustainable use of fertilizers is inevitable. Zinc fertilizer use efficiency is abysmally low and does not exceed 2 to 5% in crops, which continues to be a challenge. Therefore, sustained research initiatives are needed to enhance the uptake of Zn through development of innovative fertilizer sources. Nanoscale or nanostructured materials as fertilizer carriers or controlled-release products for the building of the so-called 'smart fertilizers' can enhance the nutrient use efficiency (Rai et al., 2015).

Economics of Zinc Fertilizer Use

Many reports show the significant cost-benefit effects of Zn fertilizers for resource poor farmers, especially in regions where soil Zn deficiency is of particular concern. **Table 5** shows that the benefit-to-cost ratio was as high as 38:1 at a lentil farm in India, revealing that Zn application was remunerative to the farmers.

Conclusions

Zinc deficiency in crops and humans is a critical issue and a global challenge. The sustainable solution is to apply an adequate and balanced quantity of Zn in crop production, so that the soil health and food and nutritional security are ensured. This could be achieved by ensuring: 1) availability of new and innovative Zn fertilizer products for higher use efficiency; 2) timely access to quality Zn fertilizers; 3) increased stakeholder awareness on Zn requirement in the soil-plant-animal-human continuum; and 4) a supportive and conducive policy environment for encouraging the balanced fertilizer use by the farmers in India. **BCSA**

Table 5. Yield increase and benefit-to-cost ratio on some key crops in India.

Crop	Zn rate, kg/ha	Yield increase, kg/ha	Value of increase, Rs	Benefit:Cost ratio
Wheat	5.25	1,430	20,735	24:1
Rice	8.40	1,102	14,987	11:1
Maize	6.30	1,521	19,925	19:1
Chickpea	10.00	855	32,063	18:1
Lentil	2.62	440	16,500	38:1
Groundnut	5.50	690	25,875	28:1
Mustard	6.30	230	8,625	8:1
Cotton	5.60	430	16,125	17:1

Rattan et al., 2008.

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Magnesium Fertilization is Essential for Tea Gardens of Southern India

By N. Palani

Mr. Palani, Deputy Director of UPASI Tea Research Foundation, observing the visual symptoms of Mg deficiency in tea gardens.

Magnesium is the third most important nutrient (after N and K) for tea plants and is a critical input for profitable tea production (Jayaganesh and Venkatesan, 2010). It is the only mineral constituent in the chlorophyll molecule that regulates photosynthesis. In addition, Mg activates many enzymes involved in carbohydrate metabolism, synthesis of nucleic acids, and translocation of sugar. Harvestable tea shoots contain about 0.20 to 0.30% Mg on a dry weight basis (Venkatesan, 2006). However, Mg availability in the predominant tea-growing soils of southern India is generally low. This article summarizes the research findings from the UPASI Tea Research Foundation on the reasons for low Mg availability in tea gardens of southern India, the importance of Mg nutrition for the biochemical and quality constituents of marketable tea, and it proposes 4R management strategies for Mg use.

Factors Affecting Mg Availability

Tea-growing areas in South India run parallel and close to the west coast of the peninsula. The six major tea districts vary in elevation from 300 to 2,500 m above sea level and rainfall varies from 900 to 7,500 mm/yr. Poor base saturation of soils, coupled with low binding energy for cations make these tea-growing soils vulnerable to Mg deficiency due to

SUMMARY
Attention should be given to Mg nutrition in the tea gardens of Southern India to enhance tea quality and to break yield barriers. The antagonistic relationship of Mg and K, strong Mg adsorption capacity of some tea soils, and emerging responses to Mg application all highlight the need for 4R management strategies for Mg.

KEYWORDS:
crop quality; nutrient interactions; foliar application

ABBREVIATIONS AND NOTES:
N = nitrogen; P = phosphorus; K = potassium;
Mg = magnesium; B = boron; Mn = manganese; Zn = zinc.

intense leaching, especially under high rainfall. Senthurpandian et al. (2009) reported low to medium Mg availability (33 to 126 mg/kg) in these soils, which is inadequate to maintain high productivity.

Soil Type and Antagonism between K and Mg

In recent years, considerable attention has been focused on Mg deficiency induced by K fertilizer application. Tea, being a foliage crop, requires high rates of K fertilizer application to produce high yields. Application of high rates of K, however, reduces Mg uptake due to the antagonism between K and Mg and results in a Mg deficiency in the crop. It is estimated that about 150 to 300 kg/ha K_2O is added on most plantations every year to overcome K deficiency and to obtain sustainable tea yields (Venkatesan, 2006). High application of K can increase the leaching of Mg by displacing it from cation exchange sites, leading to lower Mg availability in the root zone. Jayaganesh et al. (2011) reported severe deficiencies of Mg in many tea gardens of southern India, especially in the high-yielding tea plantations. Although Mg removal through leaf harvesting is 6 to 8 times lesser than that of K, the higher K input reduces Mg uptake and results in the appearance of Mg deficiency in tea leaves.

Magnesium is mobile within the plant and the deficiency symptoms first appear in mature tea leaves. The deficiency is expressed as an inverted 'V' shaped chlorosis, coupled with yellow zones on either side of main veins of the older leaves, and eventually results in the shedding of mature leaves.

High Mg Adsorption Capacity of Soils

A study in three tea-growing regions (i.e., Anamallais, High Ranges, and Central Travancore) has showed that 46 to 52% of applied Mg can be adsorbed by the plantations' soils within 24 hours of application. Adsorption of Mg progressively increased as Mg input was increased (**Table 1**). The study indicated that the quantity of adsorbed Mg, at any concentration, was highest in the Travancore soils followed by the soils of Anamallais, and High Ranges. Travancore soils have higher clay content (270 g/kg) compared to Anamallais (190 g/kg), and High Ranges (170 g/kg) soils. The equilibrium concentration of Mg was highest for the soils of High Ranges and the lowest for Travancore soils, which is attributed to higher organic matter content (i.e., 97 g/kg in the former and 66 g/kg in the latter). The Freundlich coefficients 'K', an index of nutrients sorbed from a solution having unit equilibrium concentration, were 1.567, 1.683, and 2.443 for the High Ranges, Anamallais and Travancore soils, respectively. Thus Mg adsorption followed the order: Travancore soils > Anamallais soils > High Ranges. All these observations indicate a need to prioritize Mg fertilization in Travancore soils, followed by Anamallais, and High Ranges.

Table 1. Magnesium (Mg) adsorption capacity in the major tea-growing soils of southern India.

	Adsorbed --------- Mg, mg/kg ---------			Equilibrium concentration of ----- Mg in solution, g/kg -----		
Added Mg, mg/kg	Anamallais	High Ranges	Central Travancore	Anamallais	High Ranges	Central Travancore
25	14	13	16	11	12	9
50	27	26	29	23	24	21
100	52	51	57	48	49	43
150	76	74	82	74	76	68
200	99	99	107	101	101	93
300	146	138	155	154	162	145
400	190	187	204	210	255	196
SEm±	-	-	-	0.81	1.77	0.63
C.D. (p = 0.05)	-	-	-	1.76	3.87	1.38

Adapted from Jayaganesh and Venkatesan, 2006.

Mg Release Pattern

Soil samples from 16 agro-climatic zones representing four predominant tea-growing zones of Southern India (i.e., Anamallais, High Ranges, Nilgiris, and Central Travancore) were collected to study the Mg release characteristics through repeated extraction by 1 N ammonium acetate (Hanway and Heidal, 1952). The Cobb-Douglas exponential function, $Y = ax^b$ (Meeusen and Van Den Broek, 1977), where Y = cumulative nutrient, a = degree of steepness of nutrient release, x = number of extractions, and b = exponential constant, was employed to study the Mg release pattern. The results indicated that the net cumulative Mg release varied from 112 to 138, 139 to 165, 87 to 217, and 32 to 82 mg/kg in the soils of Anamallais, High Ranges, Nilgiris, and Central Travancore, respectively. The 'a' values from Cobb-Douglas response equations (**Table 2**) indicated that tea grown on all of the analyzed samples should respond to Mg application, except for the Coonoor region of Nilgiris (Venkatesan, 2006; Jayaganesh and Venkatesan, 2006; Senthurpandian et al., 2009).

Role of Mg on Biochemical Activity and Quality of Tea

Amino acids are important chemical constituents influencing the quality and freshness of marketable tea. Magnesium activates several enzymes involved in carbohydrate and N metabolism that are reported to improve the free amino acid content and quality of tea (Ruan et al., 1999; Ma et al., 2005). Amino transferease enzymes play a major role in the synthesis of amino acids. Alanine and aspartate amino transferease are important enzymes in the amino acid synthesis pathway, and are mainly responsible for the conversion of amides into plant-available amino acids. Foliar application of 1% magnesium sulphate ($MgSO_4$) in various tea cultivars increased the alanine amino and aspartate amino transferease activities of tea shoots by 22 to 63 and 20 to 68%, respectively (**Table 3**). The total amino acid content of marketable tea significantly increased when the plants were treated with either soil or foliar application of Mg fertilizer, confirming the Mg-induced, amino acid synthesis pathway (Ma et al., 2005).

Another study in Southern India on the influence of soil applied $MgSO_4$ (300 kg/ha) on biochemical constituents of green, tea leaves (Jayaganesh and Venkatesan, 2010) resulted in increased polyphenol, catechin, and carotenoid content (data not shown). Soil-applied Mg also influenced the chlo-

Table 2. Response of tea soils to Mg application.

Zone	Cobb-Douglas equation
Anamallais	
Eastern facing	$Y = 65.470X^{0.0619}$ ($R^2 = 0.915$)
Intermediate	$Y = 81.780X^{0.0460}$ ($R^2 = 0.932$)
Western facing	$Y = 72.430X^{0.0779}$ ($R^2 = 0.813$)
High Ranges	
Eastern end	$Y = 77.260X^{0.0724}$ ($R^2 = 0.872$)
Lower elevation	$Y = 92.080X^{0.0559}$ ($R^2 = 0.893$)
Plateau	$Y = 80.820X^{0.0635}$ ($R^2 = 0.913$)
Top station	$Y = 96.740X^{0.0583}$ ($R^2 = 0.820$)
Western end	$Y = 87.280X^{0.0782}$ ($R^2 = 0.783$)
Nilgiris	
Coonoor	$Y = 143.85X^{0.0487}$ ($R^2 = 0.834$)
Kotagiri	$Y = 80.850X^{0.1049}$ ($R^2 = 0.893$)
Kullakamby	$Y = 49.230X^{0.0715}$ ($R^2 = 0.888$)
Kundah	$Y = 42.000X^{0.0852}$ ($R^2 = 0.920$)
Ooty	$Y = 82.570X^{0.0823}$ ($R^2 = 0.895$)
Central Travancore	
Elappara	$Y = 40.370X^{0.0776}$ ($R^2 = 0.921$)
Peermade	$Y = 43.180X^{0.0700}$ ($R^2 = 0.892$)
Vandiperiyar	$Y = 38.710X^{0.0840}$ ($R^2 = 0.919$)

Senthurpandian et al., 2009

Table 3. Effect of foliar application of Mg on amino transferase activity in tea plants.

			Aspartate Activity*			Alanine Activity*		
S. No	Clone	Variety	Control	Foliar $MgSO_4$	% Increase	Control	Foliar $MgSO_4$	% Increase
1	UPASI 1	Assam	190 ± 2.1	272 ± 3.3	43	101 ± 1.2	142 ± 2.3	41
2	UPASI 2	Assam	248 ± 4.2	352 ± 4.5	42	164 ± 2.2	228 ± 3.1	39
3	UPASI 3	Assam	285 ± 3.7	479 ± 4.1	68	182 ± 2.1	310 ± 2.8	63
4	UPASI 7	Assam	252 ± 2.7	348 ± 2.2	38	115 ± 1.4	155 ± 3.3	35
5	UPASI 8	China	110 ± 1.9	132 ± 1.6	20	87 ± 0.9	106 ± 2.2	22
6	UPASI 9	Assam	271 ± 3.9	409 ± 3.8	51	190 ± 1.9	283 ± 1.9	55
7	UPASI 11	Assam	198 ± 4.9	289 ± 2.6	46	106 ± 1.3	158 ± 2.2	49
8	UPASI 12	Cambod	260 ± 3.6	374 ± 3.4	44	176 ± 1.9	257 ± 3.1	46
9	UPASI 13	Assam	245 ± 4.9	264 ± 1.7	56	109 ± 1.0	166 ± 1.6	52
10	UPASI 14	Cambod	91 ± 2.2	132 ± 1.9	45	70 ± 0.5	99 ± 1.9	41
11	UPASI 15	China	155 ± 4.1	211 ± 2.6	36	38 ± 0.6	52 ± 2.2	38
12	UPASI 17	Cambod	230 ± 4.0	311 ± 3.3	35	55 ± 0.5	76 ± 1.1	39
13	UPASI 22	Assam	220 ± 2.5	293 ± 1.8	33	122 ± 1.1	171 ± 2.4	40

*micromole of pyruvate formed (min/g) of fresh weight of leaf.
Adapted from Venkatesan and Jayaganesh, 2010.

Table 4. Quality constituents and yield of made tea as influenced by application of Mg.

Treatment details	TF, %	TR, %	HPS, %	TLC	FI	AA,%	PP, %	MTY, kg/ha
T_1 - Control	1.07	11.99	10.32	3.52	1.58	1.3	15.9	3,820
T_2 - Recommended NPK	1.3	14.35	10.42	4.01	1.75	1.42	17.43	4,231*
T_3 - T2 + 200 kg Mg	1.38	15.41	10.77	4.15	2.42	1.51	17.33	4,344**
T_4 - T2 + 300 kg Mg	1.4	15.55	10.78	4.25	2.52	1.53	17.23	4,495**
T_5 - T2 + 200 kg Mg minus 50% K_2O	1.35	14.75	10.55	3.75	2.18	1.45	16.21	4,245*
T_6 - T2 + 300 kg Mg minus 50% K_2O	1.34	14.85	10.56	3.68	2.08	1.46	16.45	4,250*
T_7 - T2 + 1% Mg as foliar + micros	1.33	15.21	10.78	4.37	1.76	1.69	17.92	4,355**
T_8 - T2 + 2% Mg as foliar + micros	1.36	15.33	10.78	4.45	1.56	1.72	18.21	4,568**
SEm±	0.04	0.26	0.12	0.06	0.4	0.05	0.19	155
C.D. at $p = 0.05$	0.08	0.56	0.25	0.13	0.86	0.11	0.41	333
C.D. at $p = 0.01$	0.11	0.78	0.35	0.18	1.19	0.15	0.57	462

TF = Theaflavins; TR = Thearubigins; HPS = Highly polymerized substances; TLC = Total liquor colour; AA = Amino acids; PP = Polyphenols; FI = Flavour index; MTY = Made tea yield.

*, ** Denotes significantly superior over control at $p = 0.05$ and $p = 0.01$, respectively.

Jayaganesh and Venkatesan, 2010.

rophyll content in tea leaves. A similar study on the influence of Mg application on made tea quality (**Table 4**) revealed an increase in theaflavin and thearubigin content due to soil application of $MgSO_4$ at 300 kg/ha, but this effect decreased when K was reduced by 50%. Improved theaflavin content can play a major role in determining price premiums for South Indian black teas (Jayaganesh and Venkatesan, 2010). The increase in theaflavin could be attributed to increased content of polyphenol, which is the precursor for theaflavin and thearubigin. Highly polymerized substances, which are believed to be part of thearubigin, responsible for imparting strength, richness, and colour of the liquor, increased due to both the soil and foliar application of Mg. Magnesium application improved the total liquor color, responsible for increasing the cuppage and flavor index of made tea (**Table 4**). The presence of higher flavor compounds in made tea due to field application of $MgSO_4$ has resulted in higher amino acid content, which are precursors of flavour components.

4R Magnesium Management in Tea Gardens

Applying the right source of Mg at the right rate, time, and place following the 4R Nutrient Stewardship Principles (IPNI, 2016) may help in achieving the economic, social, and environmental sustainability in South Indian tea gardens. Application of dolomitic lime (12.6% $MgCO_3$) once or twice in a pruning cycle is a regular practice in tea plantations and can partially manage Mg deficiency in acidic tea soils. Supplying Mg through dolomitic lime is not a feasible practice; however, $MgSO_4$ could be used as a standard source depending on the age of plantation, yield level, physiological stage, or the pruning cycle. The right rate of Mg application is site-specific and nutrient requirement is based on yield target, available nutrient status in the soil, and the synergistic (Mg x P) and antagonistic (Mg x K) relationship of Mg with other nutrients. At high levels of K application, the available soil Mg may not be adequate to meet the Mg requirement of tea plants, particularly in high-yielding plantations. Hence, in addition to meeting the Mg requirement through liming with dolomitic lime, it is recommended to apply the right rate of $MgSO_4$ at right time through a right method, either by soil broadcast or foliar application, following the guidelines provided in **Table 5**. Foliar spray of $MgSO_4$ (1 to 2%) may be carried out using a spray volume of 200 L/ha. Mixing other limiting micronutrients and growth regulators (such as Zn, Mn, B, and naphthalene

Table 5. Guidelines for 4R management of Mg in tea gardens of Southern India.

Yield, kg/ha	Right Rate, kg $MgSO_4$/ha/yr	Right Time
Soil application		
< 2,000	100	During May/June
2,000 to 3,000	200	Twice; During May/June and October/November
3,000 to 4,000	250	Twice; During May/June and October/November
4,000 to 5,000	300	Twice; During May/June and October/November
> 5000	350	Twice; During May/June and October/November
Foliar application		
< 3000	8	4 splits, after plucking
3,000 to 4,000	10	4 to 5 splits, after plucking
4,000 to 5,000	12	4 to 6 splits, after plucking
> 5,000	14	6 splits, after plucking

Palani et al., 2015.

acetic acid) along with Mg in the spray tank, economizes the application of Mg in tea gardens (Palani et al., 2015). Foliar application of $MgSO_4$ on the day after plucking helps in effectively covering the maintenance foliage for better absorption. Visual symptoms of Mg deficiency, coupled with yield stagnation of tea gardens may require combined soil and foliar application of $MgSO_4$. Soil application of $MgSO_4$ in tea gardens may be carried out by broadcasting method, alone or in combination with the NK fertilizers. When applied together, urea should be mixed with $MgSO_4$ on the day of application due to the hygroscopic nature of urea.

Conclusion

Magnesium is an essential nutrient responsible for increasing the photosynthetic efficiency of tea that reflects directly on the yield. A large quantity of K fertilizer is generally applied to maintain good tea foliage. However, the antagonistic relationship between K and Mg often leads to Mg deficiency in both the soil and plant, especially in the high-yielding tea gardens of southern India. On one hand application of fertilizer K increases the yield of tea and thereby the Mg requirement of the plant, but K also has an antagonistic effect on Mg uptake.

Availability of Mg in the tea plantations of southern India is also constrained by acidic and lateritic soils, and strong Mg adsorption capacity of some soils. This article highlighted the significant role of Mg nutrition in improving the biochemical activity and quality aspects of tea. Thus, it is important to use 4R principles of Mg management through soil and foliar application of Mg fertilizer as opposed to only resorting to the application of dolomitic lime to amend the acidic, tea plantations soils in southern India. **BCSA**

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2018 PHOTO CONTEST WINNERS

Congratulations to this year's crop of winning photo submissions! In addition to their cash award, each will receive our most recent USB flash drive collection featuring hundreds of images. More details on our image collection are available at: http://ipni.info/nutrientimagecollection.

Thanks to all for supporting our contest! **BCSA**

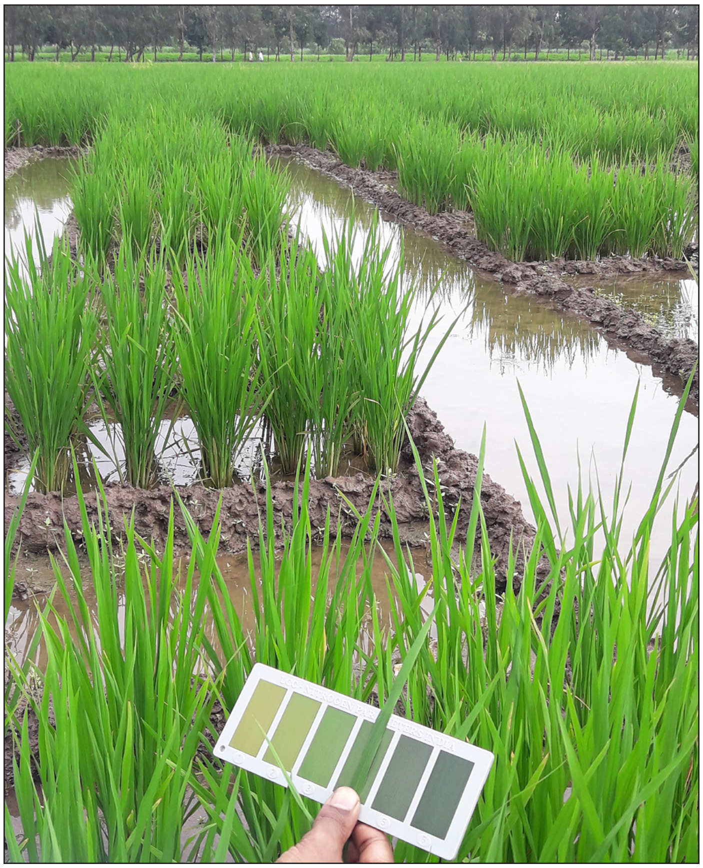
4R Nutrient Stewardship Category

FIRST PLACE:

Stabilized Urea in Maize

André Luis Vian, Experimental Agronomic Station of Universidade Federal do Rio Grande do Sul, Brazil.
e-mail: andreluisvian@hotmail.com

Mr. Vian submitted a close-up example of a topdress application of a stabilized nitrogen (N) source (urea with urease inhibitor) for a maize crop. Use efficiency for N was maximized given this right source applied at a right rate and time (i.e., 250 kg N/ha during V8 stage with eight completely formed leaves). Fertilizer placement near the root system provided for an opportunity for maximum response to N given the crop's productive potential.



SECOND PLACE:

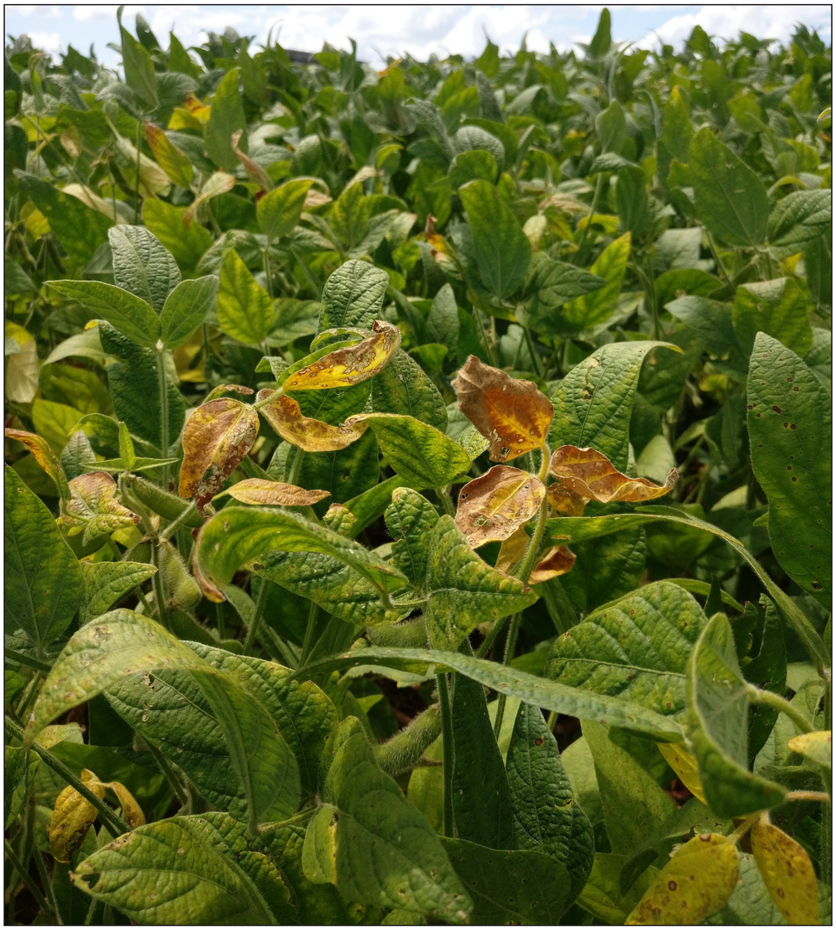
Real Time Nitrogen Management in Rice

Nitin Gudadhe, Navsari Agricultral University, Gujarat, India.
e-mail: nitbioworld@gmail.com

Real time N management is demonstrated at this Instructional Farm through the use of a leaf color chart (LCC) in rice. Leaf color chart panel number 4 was used to check the N fertilizer requirement of rice at tillering and panicle initiation stages. Ammonium sulfate was applied as a topdressing when the color of panel 4 matched the rice leaf color. Right timing of fertilizer application, guided through the use of a LCC, can increase rice crop yield by up to 10% over farmer's practice.

2018 PHOTO CONTEST WINNERS

Primary Nutrient Category



FIRST PLACE:

Potassium Deficiency in Soybean

Gustavo Dos Santos Cotrim, Londrina, Paraná, Brazil.
e-mail: gustavodscotrim@outlook.com

Selected for its sheer clarity, Mr. Cotrim captured this example of potassium (K) deficiency in a soybean field near Londrina, Brazil. The crop is in the midst of its seed production stage (i.e., R5.5).

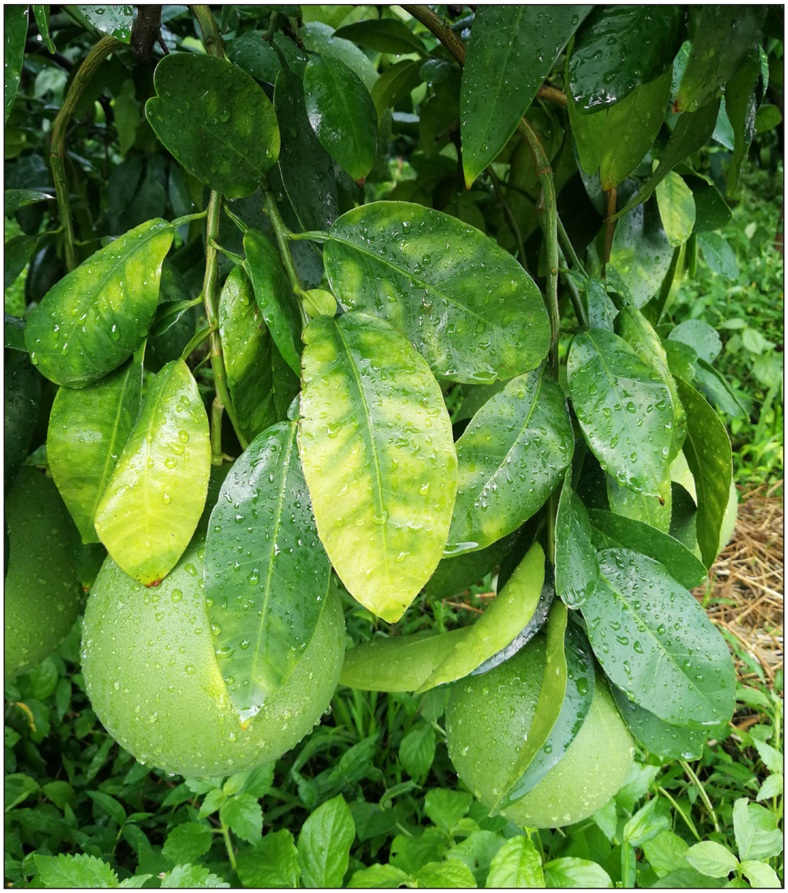
SECOND PLACE:

Potassium Deficiency in Wheat

Mark Reiter, Virginia Tech, Accomack County, Virginia, USA.
e-mail: mreiter@vt.edu

Dr. Reiter reported that this wheat field had an issue with poor growth down its center. The field history for the past seven years include poultry litter applications at 3 t/A prior to corn in a corn-wheat-double crop soybean rotation on sandy loam soil. Field soil potassium (K) values range from low (L+) to medium (M). This photo was taken where 127 lb/A K was sampled (M) using Mehlich-1 extract with soil water pH of 6.1. Plant flag leaf concentration was deficient at 1.31% K. The plant also exhibited poor root growth and a hardpan at 6 in. The farmer applied 100 lb N/A in two split applications in the Spring using 30% urea-ammonium nitrate solution. Phosphorus concentrations were very high (128 lb P/A). The farmer bales his straw each year to aid in soybean establishment.

Secondary Nutrient Category



FIRST PLACE:

Magnesium Deficiency in Pomelo

Guo Jiuxin, International Magnesium Institute, College of Resources and Environment, Fujian Agriculture and Forestry University, China.
e-mail: jiuxinguo@hotmail.com
Soils in this region are strongly acidic (pH 4.3), have low organic matter (1.5%), have high K concentrations (315 mg/kg), and are deficient in the available magnesium (58 mg Mg/kg). The Mg concentration for these chlorotic leaves was 0.23%. The smallholder farmers tend to use unbalanced fertilization strategies involving excessive NPK fertilizer (more than 2,500 kg/ha/yr), while neglecting secondary and micronutrient applications. This Mg deficiency was corrected by application of a Mg fertilizer, specifically $Mg(NO_3)_2$.

SECOND PLACE:

Magnesium Deficiency in Mango

K. Venkatesan, Horticultural College and Research Institute, Tamil Nadu Agricultural University, Periyakulam, India.
e-mail: venkat672003@gmail.com

This inverted 'V' shaped chlorosis of older leaves typical of magnesium (Mg) deficiency was observed in this 25-year-old mango orchard at harvesting stage. The orchard soil had low organic matter content and a pH of 7. In the deficient leaves, Mg content was very low at 0.17%.

2018 PHOTO CONTEST WINNERS

Micronutrient Category

FIRST PLACE:

Boron Deficiency in Sweet Potato

Susan John Kuzhivila, ICAR-Central Tuber Crops Research Institute, Kerala, India.
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The symptom of boron (B) deficiency was manifested as typical cracking and splitting of the tubers, which cannot be marketed. These crops were supplied with recommended NPK at 50-25-50 kg/ha through urea, rajphos, and MOP as basal and topdressings at 20 and 40 days after planting. Placement was at the bottom of the plant mounds. The soil analytical data indicated a B content of 0.5 ppm, which is the critical level. The plant analytical data on B content of the leaves bearing these tubers was 32 ppm, which is below the critical level of B for sweet potato (40 ppm) indicating that the deficiency of B in the plant might have affected tuber cracking.

SECOND PLACE:

Boron Deficiency in Sugarcane

Mr. Eduardo Cancellier, Compass Minerals South America, Brazil.
e-mail: educancellier@gmail.com

The picture demonstrates a classic boron (B) deficiency symptom in sugarcane 200 days after planting. Since B is not mobile in the plant, the more intense symptoms are found in the youngest leaves with little effect on older leaves. The soils in the area are derived from a sandstone parent rock known as Arenito Caiuá, hence the soil is very sandy. This type of soil is naturally poor in B and the element is prone to leaching, especially because of the intense rains in the area, usually amounting to 1,500 mm of precipitation per year. Soil tests indicated a very low level, 0.05 mg/dm³ of B in the top 20 cm of soil and 0.2 mg/dm³ in the 20 to 40 cm layer. The critical level is considered to be 0.6 mg/dm³. Leaf tests of the index leaf indicated 0.14% B. The lower limit of the B sufficiency range is 0.1 to 0.3%. This sugarcane cultivar (CTC 9001) was planted using 540 kg/ha of the NPK (10-26-26) without B.

Influence of Boron on Productivity, Profitability and Quality of Processing-Grade Potato

By Sukamal Sarkar, Hirak Banerjee, and Sudarshan Dutta

Productivity of potato in India is currently low due to multi-nutrient deficiencies and other allied problems (Banerjee et al., 2016). Potato farmers of India largely apply only N, P, and K in potato. As a consequence, deficiencies of S, Fe, Mn, Zn, and B are increasing. Attainable yields of potato are often not achieved despite balanced use of NPK due to micronutrient deficiencies (Banerjee et al., 2016). Widespread B deficiency is one of the major emerging constraints to crop production next to Zn. About one-third of cultivated soils in India are deficient in B and the number is increasing due to lack of effective management strategies. Boron plays a significant role in improving tuber yield and quality of potato. Adverse effects of B omission on the yield can occur even though no deficiency symptoms are evident on the foliage. The 4R nutrient management guidelines (IPNI, 2015) for B fertilization in potato (i.e., B fertilization using the right source at the right rate, time, and place) is not yet standardized for the alluvial plains of West Bengal.

S. Sarkar

Potato tubers displaying boron deficiency symptoms.

An on-station experiment was carried out at Bidhan Chandra Krishi Viswavidyalaya, West Bengal (**Figure 1**) during the winter seasons (November to March) of 2014-15 and 2015-16 to determine the right rate of B application for improving yield and quality of processing grade potato in the sub-tropical agro-ecology of eastern India. The experiment was laid out in a randomized block design (RBD) with five treatments, four replications and an individual plot size of 5 m x 4 m. The experimental treatments were comprised of five fertilizer treatments:

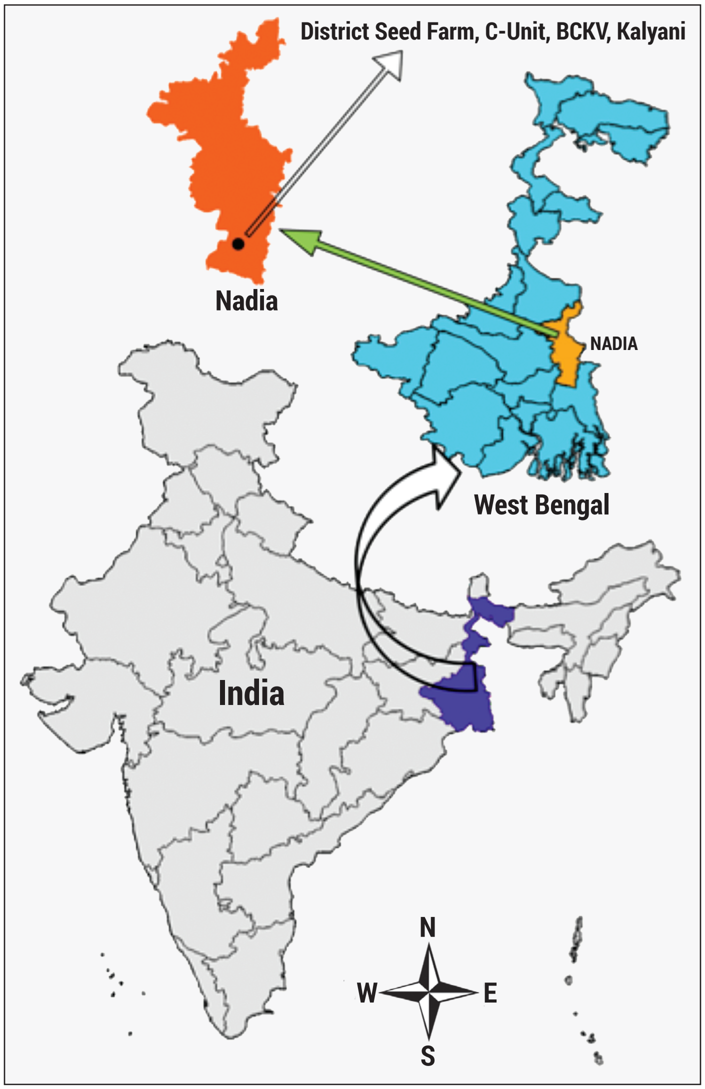

Figure 1. Location of the experimental site (22°58′ N latitude, 88°25′ E longitude, 9 m above mean sea level). (Map not in Scale.)

SUMMARY
Boron fertilization has a significant impact on tuber yield and quality of potato. Foliar spray of 0.1% Boric acid at 40, 50, and 60 days after planting, along with recommended doses of NPK, improved yield and processing quality of tubers.

KEYWORDS:
crop quality; foliar B; micronutrients

ABBREVIATIONS AND NOTES:
N = nitrogen; P = phosphorus; K = potassium; S = sulphur; Fe = iron; Mn = manganese; Zn = zinc; B = boron.

T_1: Recommended Doses (RD) of NPK (i.e., 200 kg N, 150 kg P_2O_5 and 150 kg K_2O/ha applied through urea, single super phosphate and muriate of potash) (Control);

T_2: RD of NPK + 2.0 kg B/ha as soil application as Granubor (containing 15% B);

T_3: RD of NPK + 0.1% boric acid as foliar application at 40 days after planting (DAP);

T_4: RD of NPK + 0.1% boric acid as foliar application at 40 and 60 DAP; and

T_5: RD of NPK + 0.1% boric acid as foliar application at 40, 50, and 60 DAP.

The test crop was a processing grade potato cultivar. The seed pieces of 30 to 40 g were planted at 20 cm distance at a depth of 15 cm in rows 60 cm apart. The crop was planted on November 20 and harvested on March 10 in both years. Boron uptake in tuber was estimated by dry-ashing following the azomethine-H colorimetric method. Quality parameters of potato tuber were determined following standard protocols (AOAC, 1995).

Impact of B Application on Yield and Economic Return

Boron fertilization had a significant positive impact on tuber number, yield of potato, net return, and Benefit:Cost (B:C) ratio (**Table 1**). Treatment T_5 produced a significantly ($p \le 0.05$) higher number of total tubers and improved processing grade tuber compared to the other B treatments (foliar and soil). The same treatment resulted in the highest yield of processing grade tuber (33.5 t/ha) as well as total tuber (35.1 t/ha) accounting for 35.5 and 34.7% increases over the control (RD of NPK only), respectively. Application of 0.1% boric acid spray (thrice at 40, 50, and 60 DAP) in combination with RD of NPK has been most effective, with the highest net return (US$ 2,383/ha) and best B:C ratio (2.40).

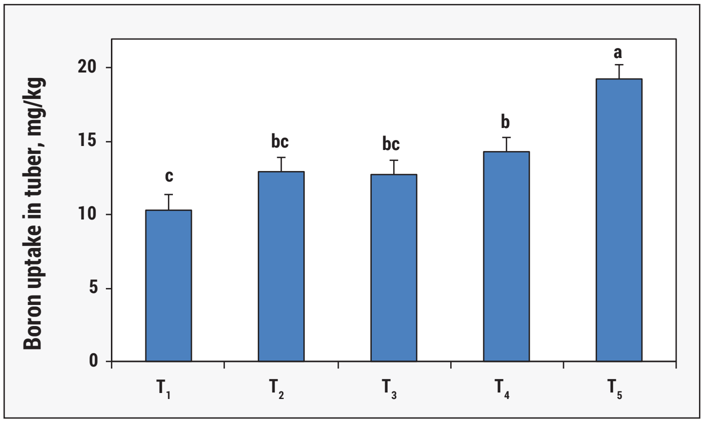

Figure 2. Effect of boron fertilization on tuber uptake in potato. (Bars indicates standard error.)

Uptake and B Application

Boron concentration in potato tuber increased significantly ($p \le 0.05$) as B application increased (**Figure 2**). Tuber B content was highest (85.8% higher than control) with T_5, which was significantly ($p \le 0.05$) higher than the other treatments. The same treatment recorded the highest N concentration (75% more than control), highlighting the importance of B in protein and other quality parameters of tuber potato.

Table 1. Effect of boron fertilization on tuber number, yield, net return, and B:C ratio. (Pooled data of two years.)

Fertilizer treatment	Tuber number, x10,000/ha Processing grade	 Total	- - - - Tuber yield, t/ha - - - - Processing grade	 Total	Net return, US$/ha	B:C ratio
T_1	2.71 d	3.33 b	24.72 d	26.02 d	1,353 d	1.80 d
T_2	3.23 bc	4.04 a	28.57 bc	30.24 bc	1,817 bc	2.06 bc
T_3	2.93 cd	3.61 b	26.88 cd	28.04 cd	1,580 cd	1.93 cd
T_4	3.44 ab	4.15 a	29.59 b	30.91 b	1,907 b	2.12 b
T_5	3.70 a	4.44 a	33.49 a	35.05 a	2,383 a	2.40 a

Numbers followed by different letters within columns indicate significant difference at $p \le 0.05$.

Tuber Quality and B Application

The quality parameters namely specific gravity, total soluble solids (TSS), tuber hardness, total acidity, and vitamin C content of potato tubers were significantly influenced by B application (**Table 2**). The tubers from the plants treated with foliar B had higher quality attributes than those harvested from the plants treated

Table 2. Quality parameters of potato cv. Kufri Chipsona-3 as influenced by boron fertilization. (Pooled data of two years.)

Fertilizer treatment	Specific gravity	Tuber dry matter content, %	TSS, °Brix	Tuber hardness, kg/cm	Total acidity, %	Vitamin C, mg/100 g of dry weight	Protein, %	Total starch, mg/100 g of dry weight	Total sugar, mg 100/g of dry weight	Total phenols, mg/100 g of fresh weight	Chip colour†
T_1	1.070 c	21.51 a	3.50 d	7.09 d	7.34 c	12.84 b	1.54 b	53.09 d	0.81 a	25.93 a	3.36 a
T_2	1.074 bc	21.83 a	4.08 cd	7.61 cd	7.42 c	13.31 b	2.08 a	55.14 c	0.77 ab	21.58 b	3.09 ab
T_3	1.078 b	21.06 a	4.40 bc	8.46 bc	7.99 b	13.23 b	2.01 a	55.98 c	0.78 ab	20.42 bc	2.74 b
T_4	1.080 b	22.37 a	4.84 ab	9.16 ab	8.64 a	13.70 b	2.17 a	61.10 b	0.73 b	17.14 dc	2.25 c
T_5	1.090 a	23.59 a	5.30 a	9.49 a	8.95 a	15.43 a	2.63 a	65.43 a	0.72 b	16.21 d	1.94 c

†On a 1-10 scale, where 1 is the lightest and 10 is the darkest chip colour; chip colour score up to 3 is acceptable, where Low score = Preferred colour; TSS, Total soluble solids.
Numbers followed by different letters indicate significant difference at $p \le 0.05$.

with soil applied B. Tubers harvested from the T_5 treatment plots exhibited significantly higher specific gravity, TSS, tuber hardness, total acidity, and vitamin C content that were 1.87, 51.4, 33.9, 21.9 and 20.2% higher in potatoes harvested from control plots (only NPK, without B), respectively. Statistical analysis in the present study did not show any significant variation in total dry matter content in tubers with B fertilization. The protein and total starch content in tubers in T_5 were 70.8 and 23.2% higher than the control (without B). Boron application reduced the phenolic concentration in tubers. Significantly low total phenol content (60% less than control) was recorded in potatoes harvested from the T_5 plot, as compared to other treatments. Potatoes harvested from the T_5 treatment plots recorded lighter chip colour (73.2% lighter than control) than those in the control plots. However, reduction of B application of up to two foliar sprays resulted in a non-significant ($p \geq 0.05$) decrease in chip colour of potato. Soil application of B was less effective in producing lighter chip colour than foliar sprays, and it was statistically at par with B omission treatment (Control).

Conclusion

Potato responded positively to foliar applied B, along with the recommended doses of NPK. Considering the yield, economics, tuber quality, and nutrient uptake it may be concluded that a B application of 0.1% boric acid at 40, 50, and 60 DAP, in combination with recommended doses of NPK (200 kg N, 150 K_2O, and 150 kg P_2O_5/ha) is beneficial to the development of processing grade potato in the alluvial Gangetic plains of West Bengal. **BCSA**

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Evaluation of Right Source of Boron and Sulphur for Enhancing Yield and Quality of Crops

By M.V. Singh, V. Goswami, and R.H. Wanjari

Sulphur is recognized as the fourth major essential nutrient severely limiting crop production in India. Indian soils have widespread S deficiency to an extent of 46% (Shukla and Tiwari, 2016) and proper S management is critical for higher crop yield and improved quality. In addition to S, increased deficiency of B in several crops (Singh and Goswami, 2014) is also of great concern for sustaining higher yields of modern crop varieties in many cultivated soils. Shrotriya and Phillips (2002) and Wani et al. (2011) reported B deficiency as the second most important micronutrient constraint next to Zn affecting crop production in India. Boron plays an important role in meristematic activities, cell division, root development, stimulation of root nodules, pollen germination, translocation of carbohydrates in plant tissues, and helps in increasing the yield of various crops (Malewar et al., 1992). Boron is relatively immobile in plants, which necessitates its availability in soil solution at all stages of growth, especially during fruit or seed development.

Combined deficiency of B and S within the same site is widely reported in soils, districts, states and agro-ecological regions in India (Singh, 2001a). All India Coordinated Research Projects (AICRP) of micronutrients have reported combined deficiencies of B and S in the soils of Odisha, adversely affecting yields of cereals, oilseeds, vegetables, and horticultural crops (Jena et al., 2008). Similarly, ICRISAT also reported coexistence of S and B deficiencies, where S deficiency ranged from 46 to 96% and B from 56 to 100% in various semi-arid tropical states of India (Rego et al., 2007 and Wani et al., 2011). Further information compiled on the extent of deficiency of S and B in 186 districts covering 14 states of India, revealed 48 and 70% deficiency of B and S (**Table 1**). This indicated that almost two thirds of cultivated soils would need combined application of S and B to ensure balanced nutrition of crops for maximizing crop productivity.

Table 1. Distribution of multinutrient (S plus B) deficiencies in 186 districts surveyed in 14 states of India (Singh, 2015).

Particular	Total no. of districts being surveyed	Distribution of districts in different categories High fertility < 20*	 Medium fertility 20-40*	 Low fertility > 40*
Boron	155	52.3	20.0	27.7
Sulphur	186	30.1	35.0	34.9

*Based on % deficiency of B and S

Sulphur and B, together, play a pivotal role in the growth and development of plants. Unlike S, which is required in quantities ranging from 20 to 45 kg/ha (Singh, 2001b), B requirement for crops is very small (250 to 300 g/ha). The established synergy between S and B allows the combined application of both nutrients through a single fertilizer source. This ensures uniform application of even a small dose of B, permitting easier blending with granular fertilizers like DAP (diammonium phosphate), Urea and NPK as per the farmers choice.

There is also a very narrow range between B deficiency and toxicity, as more than 5 ppm available B can be toxic to many agronomic crops. Therefore, combined application of B and S through a single fertilizer source should ensure the supply of optimum rate of B to crops, avoid physical mixing and minimize application cost through reduced cost of handling, transportation, and storage, while improving farmer income. Application of small doses of B along with S reduces deficiency of S and B in crops precisely, and helps in enhancing use efficiency of NPK and other micronutrients. Combined application also helps in overcoming toxicity due to uniform and optimum rate of application. Thus, the current study evaluated boronated sulphur granules (BSG) containing 80% S and 1.2% B with bentonite coating, as a right fertilizer source, for its agronomic efficiency in cotton, chilli, and soybean grown in soils deficient in B and S.

SUMMARY

Coexistence of deficiency of B and S in almost two-third of cultivated soils in India necessitates the need for combined application of B and S to crops. Considering a very narrow range between B deficiency and toxicity, a right fertilizer source consisting of B and S along with the other major essential nutrients should supply right rates of B and S. This helps to meet the balanced crop requirement while ensuring combined uniform application of deficient nutrients, minimized application cost and improved farm income.

KEYWORDS:
chilli; cotton; soybean; interaction

ABBREVIATIONS AND NOTES:
B = boron; S = sulphur; Zn = zinc

On-farm Trials

On-farm experiments were conducted on hybrid cotton (*Gossypium hirsutum*) and on chilli (*Capsicum annum*) on a mixed red and black clayey soil (Inceptisol) at a location 10 km away from Khargone, Madhya Pradesh (Latitude 21°50' N and Longitude 75°36'53.9" E) during the kharif season of 2015. Another experiment was conducted in soybean (*Glycine max* Merril.) in a black clayey soil at Parvalia Sani of Bhopal district (Latitude 23° 16' N and Longitude 77°36' E) in Madhya Pradesh. Soil pH in the experimental sites ranged from 6.8 to 8.7, while EC ranged from 0.14 to 0.24 dS/m. Soil texture was sandy loam to clay loam, classified as an Inceptisol. The experimental sites had low to marginal B and S fertility status, hot water-soluble B status in surface soil (0 to 15 cm depth) ranged between 0.26 to 0.38 mg/kg and available S (calcium chloride extractable) status ranged between 6.7 to 9.8 mg/kg soil, respectively.

Table 2. Effect of combined application of B and S through Boronated Super Granules on crop yield and farm profit.

	--------- Cotton ---------		------- Chilli -------		------ Soybean ------	
Treatment	Seed cotton yield, kg/ha	Net income, Rs/ha	Yield, kg/ha	Net income, Rs/ha	Yield, kg/ha	Net income, Rs/ha
T_1 - *FFP alone	1,640	9,495	7,820	12,120	885	4,655
T_2 - FFP + B	1,870	9,930	9,080	14,700	1,040	5,005
T_3 - FFP + S	2,025	15,525	9,780	23,520	1,197	9,120
T_4 - FFP + B + S	2,220	23,880	10,640	31,620	1,310	12,655
LSD (P = 0.05)	211	-	1,010	-	133	-

*Farmer Fertilizer Practice

Prices used for net income calculation: B - Rs.700/kg; S - Rs. 45/kg (granular); Seed cotton - Rs.45/kg; Soybean - Rs.35/kg; Green chilli - Rs.12/kg pod

Treatments consisted of (T_1) Farmers' Fertilizer Practice (FFP, predominantly application of NP alone), (T_2) FFP + 0.6 kg B/ha, (T_3) FFP + 40 kg S/ha, (T_4) FFP + 0.6 kg B/ha + 40 kg S/ha. In T_2, B was applied through borax penta hydrate (14.6% B), and in T_3, S was applied using sulphur granular pastilles (90% S) coated with bentonite clay. In T_4, B and S were applied using boronated sulphur granules, consisting of 80% S and 1.2% B. At planting, DAP was applied to each treatment at 125 kg/ha along with $ZnSO_4 \cdot 7H_2O$ at 25 kg/ha to all the three crops. In chilli and cotton, urea was top dressed in each treatment at 125 kg/ha, applied in two equal splits at 30 and 50 days after planting (right time), following the right method of application at 6 to 8 cm apart from main shoot and mixed in through hoeing in moist conditions. In soybean, top dressing of urea was not done. Necessary weeding and plant protection measures were followed in all the three crops. Observations related to plant height, premature fruit/pod shedding, and yield were recorded.

Response with NP and B + granular S in chilli (top) vs. farmer's practice (without B and S; bottom) at Khargone, M.P.

Results

On-farm experiments conducted in cotton and chilli revealed that the yield of seed cotton (**Table 2**) varied between 1,640 and 2,220 kg/ha and chilli pod yield was between 7,820 and 10,640 kg/ha. Combined application of B+S through boronated S granules along with FFP (T_4), significantly increased seed cotton and chilli pod yield by 35 and 36%, respectively, compared to FFP alone (**Table 2**).

Application of FFP+B (T_2) or FFP+S (T_3) increased seed cotton yield by 14 and 24%, while that of chilli pod yield by 16 and 25%, compared to FFP alone. Visual observations revealed that plant height, number of sympodial branches, number of bolls per plant were higher in T_4, indicating that combined application of B+S together with FFP had better crop growth in terms of number and size of cotton bolls per plant. Similarly, plant height, number of branches and number of green pods of chilli were higher in T_4 with B+S, which resulted in a higher chilli pod yield (data not shown). In both crops the effect of combined application of B and S was evident, while S attributed to better growth and dark green foliage due to its role in formation of chlorophyll and

Response of cotton to boronated S in black cotton soils of Khargone, M.P.

the effect of B was visible on reduced flower and fruit drop and increased pod/boll setting. Results also showed that seed cotton yield was increased by 230, 385, and 580 kg/ha, due to application of FFP+B, FFP+S, and FFP+B+S over FFP alone. The corresponding increase of chilli pod yield was 1,260, 1,960, and 2,820 kg/ha, respectively. Application of FFP+B+S resulted in a higher net income of Rs.23,880 per ha in cotton and Rs.31,620 per ha in chilli, with a higher B:C ratio of 10.8:1 and 14.2:1, respectively (data not shown).

Another set of on-farm experiments conducted in soybean revealed that grain yield was significantly influenced by combined application of FFP+B+S (T_4). The soybean yield recorded in FFP+B+S (T_4) was 1,310 kg/ha, which was 48, 26, and 9% higher than FFP, FFP+B, and FFP+S, respectively. The results indicated that application of B+S together with FFP helped in better crop growth coupled with increased nodulation, number of branches and pods compared to soybean grown with the other treatments (data not shown). The combined application of B+S in soybean resulted in increased oil content in seed from 18.7 to 19.6%, and finally helped the farmer with a higher net income (Rs.12,655 per ha) and higher B:C ratio (5.7:1). These results agree with the findings of Rego et al. (2007), who showed positive response to the application of B+S to groundnut, finger millet, pigeon pea, soybean, chickpea, maize, and black gram compared to application of either B or S alone or over FFP in India.

Post-harvest soil available B and S at the on-farm experimental sites significantly improved over the initial levels at the time of planting due to combined application of B+S along with FFP over the other treatments. The experimental soils initially had hot water-soluble B concentrations ranging from 0.26 to 0.38 mg/kg, which increased at the time of harvest, ranging from 0.35 to 0.43 mg B/kg soil due to combined application of B+S. Similarly, the initial available S status of the experimental sites ranged from 6.8 to 8.7 mg/kg soil, which increased to 9.8 to 11.5 mg S/kg soil at harvest, indicating that application of B+S through boronated S granules helped in meeting the nutrient requirement of crops as well as enhancing the fertility status of soil, while increasing the productivity of crops. Earlier studies on combined application of B+S through boronated single super phosphate (BSSP, having 0.18% B+12% S+16% P_2O_5) in sugarcane reported taller canes, longer internodes, improved cane girth, and increased cane yield in the range of 12 to 19% over non-application B (Vaidya et al., 1984). Similarly, application of BSSP increased the onion bulb yield from 9.2 to 18% over S alone in Madhya Pradesh and Maharashtra (Deshmukh, 1985). Application of BSSP significantly increased the economic yield of peanut by 33%, and improved several quality parameters such as protein by 3.84%, oil by 4.09% and shelling by 2.87% (Patil and Patil, 1985). However, the authors feel that BSG seemed to be a better option to combat B and S deficiency compared to BSSP. The recommended rate of application of BSG did not leave any adverse effect on crop growth due to a lower rate of B (0.24 to 0.48 kg/ha) through addition of 20 to 40 kg/ha S granules as compared to 1.2 to 2 kg/ha B added through BSSP on account of its application of 60 to 100 kg/ha P_2O_5 even in soils with marginal to adequate B fertility status. Addition of higher rates of B through BSSP may pose adverse effect on a crop over the long run due to B sensitivity and the very narrow range between B deficiency and toxicity. BSG could be a better choice for regular application with the right rate of B to crops as it provides a crop-safe option for long-term improvement of crop yield, soil health, and the environment.

Summary

Coexistence of B and S deficiency is widely reported in several crops and agro-ecological zones of India. Almost half of the soils in India are tested to be deficient in B and S, which needs immediate attention through balanced fertilization. Application of right rate of BSG having 80% S and 1.2% B proved to be right source of B and S, as its application helped in maximizing crop growth, improved fruit/seed setting and in achieving higher crop productivity. BSG could be an alternative replacement to BSSP, and application of BSG at 25 and 50 kg/ha to different crops can give much higher yields and farm profits without any adverse effect on soil health. **BCSA**

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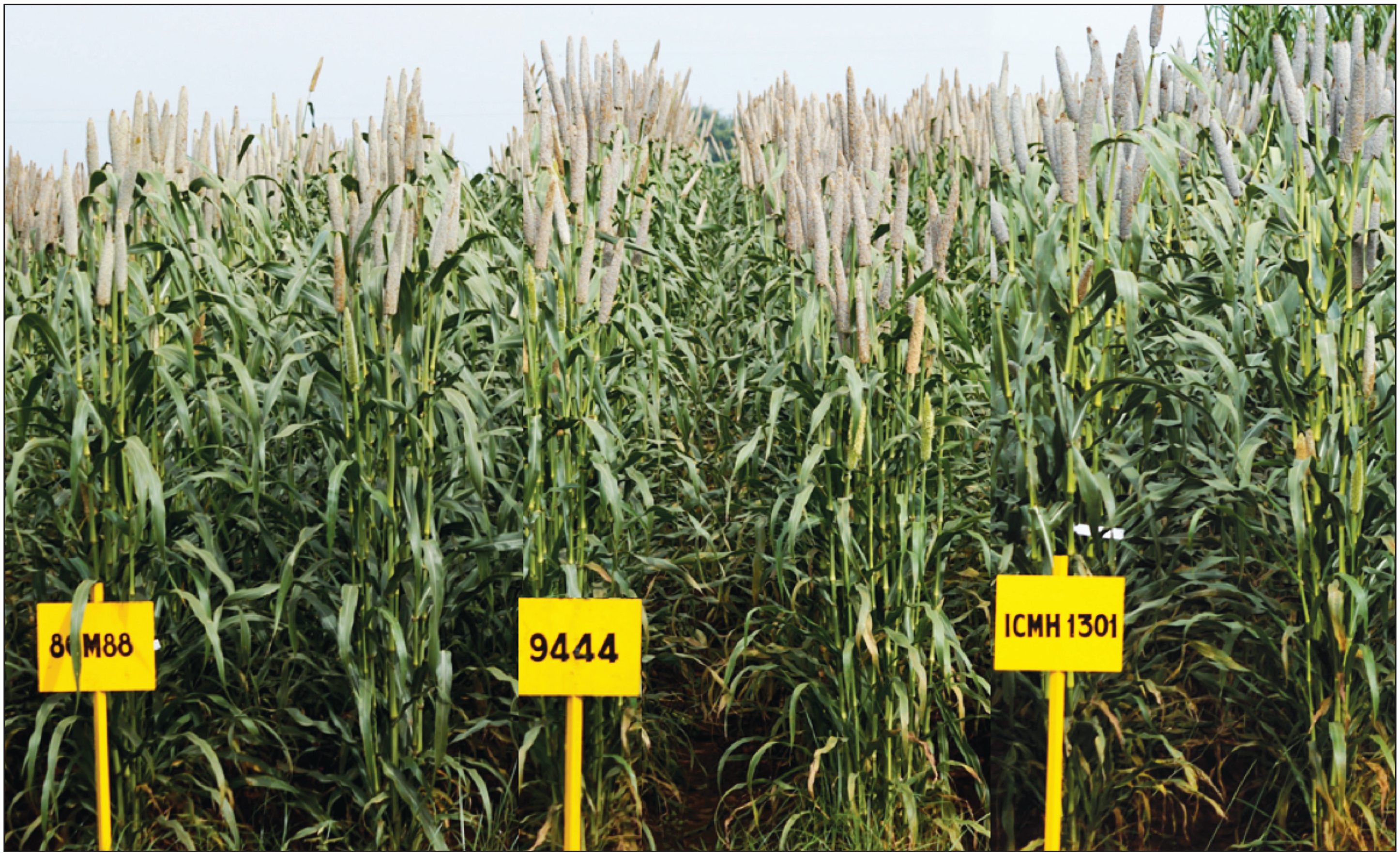
Does Soil Micronutrient Variability in Test Locations Influence Performance of Biofortified Pearl Millet in India?

By M. Govindaraj, A. Kanatti, K.N. Rai, and T. Satyanarayana



Field performance of biofortified pearl millet hybrid (ICMH 1301) compared to commercial hybrids (86M86 and Pro Agro 9444) in precision field at ICRISAT.

Dietary deficiency of essential micronutrients such as Fe and Zn has widely been reported to be a food-related global health problem, affecting more than 2 billion people across the world (WHO, 2012). This problem is particularly serious in the under developed and developing countries of Africa and Asia, where large segments of malnourished people depend on cereal and legume-based diet that comes from marginal and low fertility lands (Sandstead, 1991; Gibson, 1994). As a result, the cereal-based diets produced from such lands are generally low in micronutrients and proteins. Farmers in the past cultivated pearl millet varieties, which are potential sources of micronutrients and vitamins. However, in the last few decades, the varieties of pearl millet are replaced with high-yielding hybrids and are cultivated with inadequate use of NPK fertilizers, neglecting the application of micronutrients. This created an imbalance in the nutrition ecosystem and led to multi-micronutrient deficiencies in soil, which further resulted in production of less nutritious food for humans (Kumar et al., 2016).

In India, pearl millet is grown in an area of 8 million (M) ha with an annual production of 8 M t. The growing environment of pearl millet is challenged with low fertility soils, erratic rainfall and adverse climate, not conducive to

SUMMARY

Testing of biofortified hybrids across varying pearl millet-growing regions of India indicated the need for maintaining sufficient Fe and Zn levels in soil to express the crops's full genetic potential and ensure successful loading of micronutrients in the grain. The study suggested the need for practicing balanced fertilization while growing biofortified hybrids to increase grain yield and micronutrient accumulation in grains.

KEYWORDS:

biofortification; human health; enriched fertilizers

ABBREVIATIONS AND NOTES:

P = phosphorus; K = potassium; S = sulfur; B = boron; Fe = iron; Zn = zinc; OC = organic carbon

Table 1. Variability of different soil properties in pearl millet testing locations in India.

	pH		EC, dS/m		OC, %		Avail-P, mg/kg		Exch-K, mg/kg		Avail-B, mg/kg		Avail-S, mg/kg		Avail-Fe, mg/kg		Avail-Zn, mg/kg	
Location	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015
Durgapura	7.68	-	0.08	0.27	0.21	0.23	16.56	15.00	71	85	0.38	0.49	2.45	7.99	4.07	4.04	1.86	2.37
Hisar	7.82	7.83	0.20	0.14	0.35	0.32	8.08	9.13	115	145	0.86	0.79	9.62	9.95	7.69	6.25	4.00	2.02
Jamnagar	7.76		1.14	-	0.46	-	7.15	-	91	-	2.51	-	131.54	-	5.49	-	1.22	-
Ahmedabad	7.94		0.16	-	0.31	-	10.58	-	76	-	0.86	-	6.57	-	4.42	-	0.76	-
Nagour	8.26	-	1.84	-	0.30	-	10.96	-	105	-	3.32	-	88.40	-	2.90	-	0.71	-
Hisar	-	7.72	-	1.05	-	0.59	-	17.09	-	240	-	1.13	-	277.51	-	2.29	-	4.71
Akola	-	7.11	-	0.70	-	0.40	-	13.33	-	188	-	0.52	-	6.16	-	16.45	-	2.04
Aurangabad	8.68	8.28	0.27	0.40	0.36	0.57	4.04	8.16	211	488	1.45	1.77	6.33	15.85	1.60	7.11	0.92	1.02
Aurangabad	8.20		0.24	0.17	0.43	0.40	10.69	8.00	133	323	0.56	0.52	8.51	5.83	4.11	7.99	0.32	0.63
Aurangabad	7.97	8.23	0.20	0.47	0.52	0.48	8.87	13.77	254	398	1.46	1.89	8.83	49.54	12.00	4.35	0.55	0.51
Medchal	-	7.60	-	0.18	-	0.56	-	46.88	-	236	-	0.94	-	8.41	-	8.51	-	2.31
Aurangabad	-	8.36	-	0.22	-	0.31	-	6.38	-	318	-	1.05	-	5.39	-	4.20	-	0.61
Patancheru	7.84	7.40	0.17	0.26	0.31	0.32	10.60	14.02	121	158	0.65	0.81	5.62	27.72	12.47	5.22	1.20	1.25
SE	0.10	0.16	0.20	0.10	0.03	0.04	1.14	4.13	20.71	43.86	0.33	0.17	15.59	29.73	1.29	1.40	0.37	0.45
Min	7.68	7.11	0.08	0.14	0.21	0.23	4.04	6.38	70.89	85.13	0.38	0.49	2.45	5.39	1.60	2.29	0.32	0.51
Max	8.68	8.36	1.84	1.05	0.52	0.59	16.56	46.88	254.26	487.67	3.32	1.89	131.54	277.51	12.47	16.45	4.00	4.71

support sustainable production. About 50% soils in India are deficient in available Zn and 12% in available Fe, with largest deficiency reported in the millet-growing states of Haryana (26%) and Uttar Pradesh (10%) (Singh, 2009). Thus, Fe deficiency in soil is only second in importance after Zn (Singh, 2009; Nayyar et al., 2001), while in human nutrition, Fe is considered predominantly deficient (NFHS, 2016). This highlights the need to enrich our native food crops, especially pearl millet, with Fe and Zn for sustaining plant and human nutrition.

Increasing grain Fe and Zn concentration in pearl millet through biofortification could significantly increase the dietary intake of Fe and Zn in the areas where millets are primarily grown for human consumption. Great possibilities are open upfront for biofortification by exploring the effectiveness of micronutrient fertilization to improve crop productivity and nutritional quality, while enriching human nutrition. Therefore, the current study was established with an objective to determine the extent of variability of available soil micronutrients and determine its potential influence on grain micronutrient accumulation in the biofortified hybrids of pearl millet.

The study was initiated at 19 pearl millet-growing locations spread over five states, representing two different growing environments with respect to rainfall and temperature in 2014 and 2015. About 20 biofortified hybrids were evaluated for grain micronutrient accumulation in varying soil types represented by Vertisols (43%), Inceptisols (42%), Alfisols (10%), and Ultisols (5%). Soil samples were collected before planting from each location and analyzed for available nutrients. Each hybrid was planted in four rows of 4 m long with 3 replications at all the locations. Diammonium phosphate (100 kg/ha) was applied at field preparation and urea (100 kg/ha) was applied as side-dressing after thinning. Recommended agronomic practices were followed to ensure a good crop stand. Grain samples were collected from all the locations and analyzed for grain Fe and Zn concentration using Energy Dispersive X-ray Fluorescence (ED-XRF), a non-destructive quantitative method (Paltridge et al., 2012).

Performance of biofortified hybrids was assessed based on the grain yield, as well as grain Fe and Zn concentrations in comparison to commercial non-biofortified hybrids.

Results

The soils at the experimental sites were neutral to alkaline (pH 7.1 to 8.7) and non-saline to saline (EC 0.08 to 1.84) in nature (**Table 1**). Organic C was low (< 0.5%) in all locations except three sites (Aurangabad, Medchal, and Hisar), which reported medium organic C (0.5 to 0.75%). Available P and K were medium to high at the majority of the locations. Available B ranged from 0.4 to 3.3 mg/kg, while available S varied from 2.5 to 278 mg/kg. Available Fe and Zn in the experimental fields varied largely across locations. Available Fe varied from 1.6 mg/kg in Aurangabad to 12.5 mg/kg in Patancheru during 2014, while in 2015, it varied from 2.3 mg/kg in Hisar to 16.5 mg/kg in Akola, respectively. Aurangabad, Nagour, and Hisar reported available Fe less than 3.7 mg/kg, indicating deficiency of Fe in the soil at these locations (**Table 1**). Available Zn varied from 0.32 mg/kg in Aurangabad to 4.0 mg/kg in Hisar during 2014, while in 2015, it varied from 0.5 mg/kg in Aurangabad to

Table 2. Performance of biofortified hybrids at different testing locations in India.

	2014 trial data from 9 locations							2015 trial data from 8 locations					
	Grain Fe, mg/kg		Grain Zn, mg/kg		Grain yield, t/ha			Grain Fe, mg/kg		Grain Zn, mg/kg		Grain yield, t/ha	
Hybrid	Range	Average	Range	Average	Range	Average	Hybrid	Range	Average	Range	Average	Range	Average
1	66-104	86	27-56	41	1.68-3.81	2.84	1	93-108	101	37-76	51	2.04-4.58	3.26
2	61-107	84	24-57	38	1.94-4.17	2.85	2	67-84	75	31-58	42	1.56-4.66	3.42
3	66-116	91	26-54	39	1.85-4.05	3.04	3	64-92	76	30-68	44	1.67-4.61	3.50
4	53-101	80	19-69	39	1.98-4.28	3.25	4	70-109	84	28-49	37	1.28-4.35	3.53
5	45-90	68	21-53	37	1.73-4.05	3.19	5	73-122	87	32-61	45	1.59-4.16	3.28
6	60-93	70	23-43	32	1.95-4.01	2.86	6	77-134	99	34-71	46	1.78-4.3	3.37
7	61-100	78	24-59	40	2.07-4.19	2.87	7	85-123	100	36-81	51	2.09-4.41	3.26
8	72-110	89	28-74	46	1.73-4.53	3.26	8	77-112	91	36-68	46	1.79-4.17	2.99
9	43-80	66	17-48	34	1.58-4.34	3.01	9	68-111	86	35-60	44	1.81-4.61	3.35
10	61-104	80	20-59	38	1.96-4.11	3.03	10	59-83	74	29-52	39	1.65-4.09	3.32
11	63-87	73	27-50	39	1.70-3.88	2.83	11	71-98	86	35-54	45	1.63-4.28	3.17
12	57-85	68	26-46	37	1.77-3.46	2.80	12	79-106	92	34-60	43	1.78-3.67	3.05
13	60-97	77	24-48	38	2.18-4.07	3.16	13	75-96	84	35-54	45	1.78-4.02	3.13
14	56-92	70	14-51	35	1.70-4.91	3.15	14	65-108	86	32-60	41	1.25-4.27	3.23
15	56-88	72	21-49	36	1.43-4.56	3.25	15	85-131	101	37-68	48	1.71-4.22	3.14
16	57-89	72	22-51	36	2.08-4.45	3.18	16	71-109	92	38-69	46	2.25-4.51	3.36
17	59-105	82	26-60	41	1.90-4.29	3.07	17	42-61	48	26-43	33	1.6-4.98	3.84
18	57-93	74	24-51	35	1.89-4.32	3.26	18	60-83	68	32-54	41	2.11-5.07	3.82
19	63-109	80	23-53	36	1.97-4.81	3.28	19	81-113	92	34-65	44	2.27-4.45	3.56
20	70-105	84	24-56	38	2.28-4.00	2.77	20	48-78	60	29-58	41	1.29-4.25	2.98
21	47-78	61	19-43	34	2.38-5.36	3.54	21	49-69	60	27-55	38	1.65-5.02	3.94
22	67-95	83	26-55	39	2.22-4.28	3.09	22	91-119	102	36-72	52	1.24-4.02	2.48
23	41-76	56	23-45	36	1.50-4.56	2.82							
24	35-60	48	19-35	29	1.53-5.08	3.00							
25	39-63	54	19-44	33	0.68-2.46	1.70							
LSD		3.8		2.6		0.16	LSD		4.4		2.9		0.21
Min		48		29		1.70	Min		48		33		2.48
Max		91		46		3.54	Max		102		52		3.94

4.7 mg/kg in Hisar. All locations had sufficient Zn except two locations in Aurangabad, which exhibited Zn deficiency. Results of soil analysis in biofortification program helps to ensure ample levels of micronutrients at the test sites, so that the soils are not challenged with micronutrient deficiency while planting higher micronutrient-dense hybrids.

Yield and Grain Concentration of Fe and Zn in Pearl Millet

The grain yield of pearl millet in the biofortified hybrids varied from 0.7 to 5.4 t/ha, with an average of 3.0 t/ha in 2014, whereas, during 2015, the yield varied from 1.2 to 5.1 t/ha, with an average of 3.3 t/ha, indicating that the productivity of pearl millet varied across the growing environments similar to that of variability recorded in the available soil micronutrient status (**Table 2**). The grain Fe concentration varied from 35 to 116 mg/kg, with an average of 74 mg/kg in 2014, while in 2015, the corresponding grain Fe ranged from 42 to 134 mg/kg, with an average of 84 mg/kg, respectively. The grain Zn concentration varied from 14 to 69 mg/kg with an average of 37 mg/kg in 2014, while in 2015, it varied from 26 to 81 mg/kg, with an average of 44 mg/kg, respectively. The difference among the biofortified pearl millet hybrids for grain yield and accumulation of Fe and Zn in grain was significant in both the years (**Table 2**), indicating the need for evaluating biofortified hybrids for potential accumulation of Fe and Zn in the grain. The hybrids evaluated in 2015 had higher mean Fe (14%) and Zn (18%) content in the grain, and 11% higher mean grain yield over the entries tested in 2014, which could be due to higher availability of macro and micronutrients in test locations selected during 2015 (**Table 1**). In 2015, available P, K, S, Fe, and Zn levels of the test locations were 56, 97, 39, 9, and 36% higher than the locations that were selected

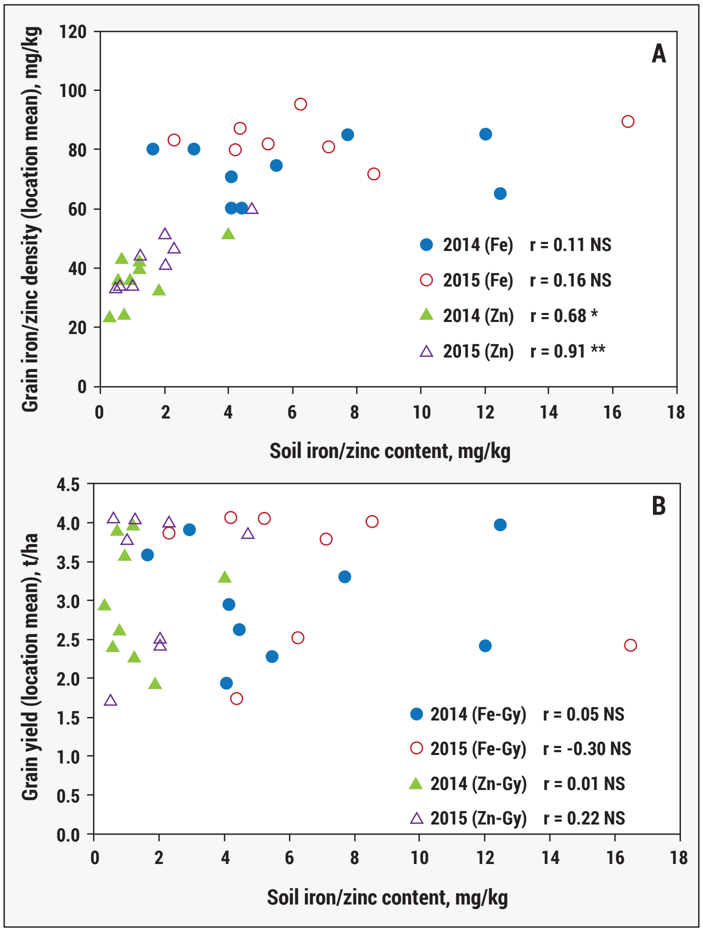


Figure 1. Relationship of soil micronutrient status with grain micronutrient content (A) and grain yield (B) of biofortified pearl millet hybrids.

in 2014, indicating the need for supplying adequate levels of macro and micronutrients in the soil for ensuring higher accumulation of essential micronutrients in the grain.

Relationship of Yield and Grain Micronutrient Concentration with Available Soil Micronutrients

The mean grain Fe content in the test entries was not significantly correlated with available Fe in both the years, whereas such relationship was significant between the grain and soil available Zn in both the years (**Figure 1**). Available Fe was high at 16 out of 19 locations, but its relationship with grain Fe was non-significant in both years. On the other hand, available Zn established a positive and significant relationship with grain Zn, in spite of being deficient in 12 out of 19 locations. The results even though failed to establish a positive linkage between the available soil and grain Fe content, however, indicated a significant relationship with the available Zn and grain Zn concentration, highlighting the need for ensuring adequate soil Zn levels for improving the Zn concentration in biofortified pearl millet hybrids. The mean grain yield also had no significant correlation with soil available Fe and Zn in both the years (**Figure 1**). This merit further strategic study in Fe/Zn deficient soils, which could give a better understanding of this relationship. This will support in a way that the seed mineral-dense cultivars are reported to grow well and produce more grains when grown under micronutrient deficient soils (Ruel and Bouis, 1998; Graham et al., 2001).

Although it is well established that plants absorb micronutrients from soil, optimum crop growth and yield depends not only on the available micronutrient status but also on the growing environment of the study locations. Soil factors, such as pH, moisture, organic matter and temperature, governs the micronutrient availability to any crop or its variety to express its full genetic potential in any given environment. Thus, the growing environment, especially soil and climate, seems to have strong influence on grain mineral content, and makes it imperative to test the stability of grain Fe and Zn content in the biofortified varieties over different geographical regions to make the most valid comparisons of the genetically controlled variation.

While the relationship between the available Fe with that of grain Fe density and grain yield was non-significant (**Figure 1**), the correlation between grain yield and grain Fe was also non-significant (**Figure 2**). On the other hand, available Zn showed significant correlation with grain Zn, whereas, the grain yield was non-significantly correlated with available Zn (**Figure 1**) and grain Zn (**Figure 2**), respectively.

The present study failed to explain the relationship of grain micronutrient concentration in the biofortified hybrids with soil micronutrient status at different pearl millet-growing locations in India. This gives an indication that the potential of biofortification could be explored not just by mere planting of biofortified entries across different locations but through ensuring adequate plant nutrition. The observations further gains support from the visual differences, which showed improved growth performance of biofortified hybrids over commercial hybrids recorded in the precision fields with high soil fertility (**See comparison in photo above**). Dwivedi et al. (2009) reported substantial yield responses to application of micronutrients in pearl millet and suggested that balanced fertilizer use in pearl millet no longer meant the application of NP or NPK alone, but should include all nutrients that are deficient at a particular site. Pearl millet hybrids, being exhaustive in nature, demand application of right rates of macro, secondary and micronutrients to optimize yields and profits. However, the nutrient management practice followed at each study location considered application of only N and P fertilizer, neglecting the application of deficient nutrients. Thus, the testing of biofortified entries need to be integrated with proper agronomic management with focus on balanced nutrient management.

The results of the present study suggested that significant micronutrient enhancement in pearl millet can be achieved through biofortification breeding. However, ensuring sustainable pearl millet yields and nutrient accumulation of grains through biofortification merits future research investigations on agronomic management, with special emphasis on balanced nutrient management in the study locations. Success of agronomic biofortification largely depends on the bioavailability of micronutrients in the soil-plant-human health continuum. This can be achieved through application of micronutrient-enriched fertilizers along with NPK through integrated soil fertility management. Genetic biofortification may thus be more cost-effective in the long run with the complementarity of agronomic and soil fertility management practices. **BCSA**

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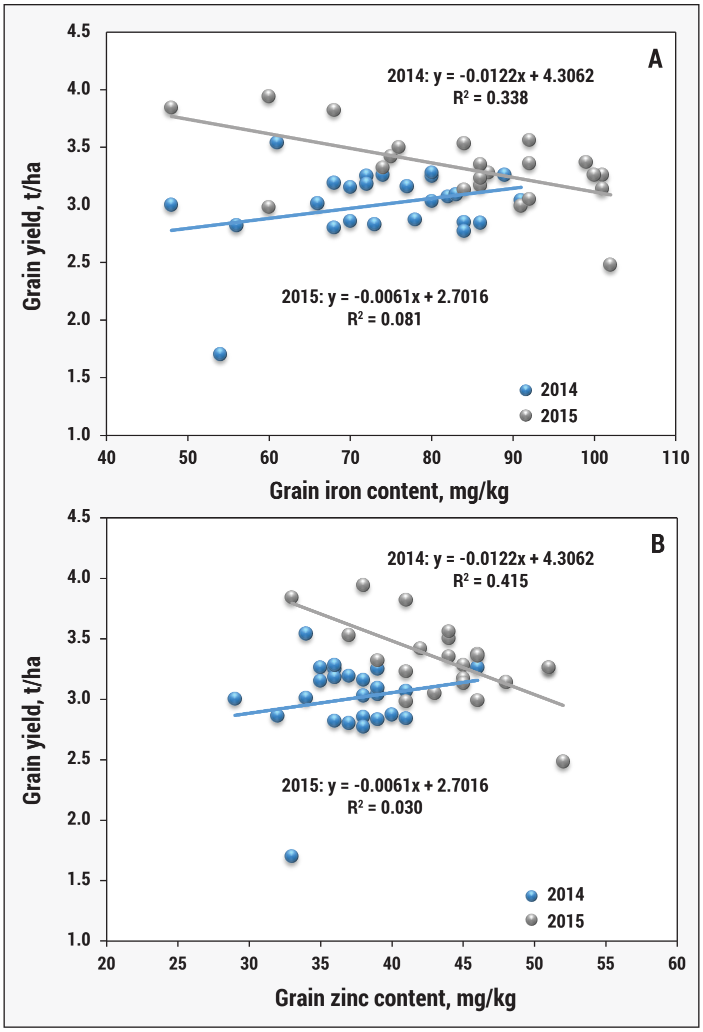

Figure 2. Relationship between grain yield and grain iron content (A) and grain zinc content (B) across locations in 2014 and 2015.

Secondary and Micronutrients are Important

Welcome to the 11th issue of *Better Crops-South Asia*, focused on the management of secondary and micronutrients in enhancing the productivity and quality of crops. Secondary and micronutrients are common missing elements in crop fertilization programs across South Asia. This is notwithstanding the fact that their inclusion is critical to improve crop productivity and quality, and to enhance the nutrient use efficiencies of the major nutrients. These essential plant nutrients have significant human health benefits associated with their adequate intakes. Improved awareness and better appreciation of their role in the food system and in the broader context of population health would benefit the society.

IPNI is in transition. The International Plant Nutrition Institute (IPNI), erstwhile Potash & Phosphate Institute of Canada-India Programme (PPIC-IP), started its operation in India in 1989. Since then, the Institute has remained steadfast in its commitment to appropriate management of plant nutrients through research and education for achieving food security and economic development in an environmentally sustainable manner. We have invested strongly in research, education and extension of improved plant nutrition over the last 30 years through our engagement with the SAUs and the ICAR Institutions, State Departments of Agriculture, the CGIAR and other International organizations, the Fertilizer Industry, other Non-Governmental Organizations, and most importantly with the farmers.

Recently, the Board of Directors of IPNI has decided to merge IPNI and transfer its operations to The Fertilizer Institute (TFI), Fertilizer Canada, and the International Fertilizer Association (IFA). This essentially means that IPNI will cease to exist as an independent organization by mid-2019. This would end our engagement in India and elsewhere in South Asia that produced tangible and impactful outputs and outcomes. I am sure our collaborators in the region would agree that together we have brought in transformational changes in how plant nutrition is discussed and implemented in South Asia. There are several examples, but I think popularizing the concept of site-specific nutrient management through research and education, and developing the Nutrient Expert® fertilizer decision support tools for on-farm implementation of SSNM are two bright ones. We have a long way to go in the plant nutrient management space to ensure safe, accessible and abundant nutritious food for the population, that is responsibly produced without harming the environment. And we believe that innovations in plant nutrition research and outreach will continue in South Asia to ensure that.

It has been a remarkable journey for us which would not have been possible without the active support of our peers. We convey our heartfelt gratitude and appreciation to our partners and collaborators who have been part of this journey to support our mission of promoting scientific information for the responsible management of plant nutrition for the benefit of the human family.

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