Events
August 2017

Photo 1. The Andersen Parade, a musical performance of the famous children's stories by Hans Christian Andersen, at the opening ceremony of the 18th IPNC 2017 (Tivoli Centre in Copenhagen, Denmark). Photo by M. Nikolic.

International Plant Nutrition Colloquium 2017, Copenhagen, Denmark: A Conference Report

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Introduction

The 18th International Plant Nutrition Colloquium (IPNC) took place from 21-24 August 2017, at the magnificent Tivoli Centre in Copenhagen under the capable direction of Professor Jan Schjøerring and colleagues from the University of Copenhagen's Department of Plant and Environmental Sciences. The conference opened on the morning of 21 August 2017 with welcoming speeches from Professor Schjøerring and Thomas Bjørnholm, the University's Pro-rector for research, which was followed by the Hans C. Andersen Parade (Photo 1).

From its inception in the early 1950s, the IPNC, held every four years at a different venue, has become the most important international meeting on fundamental and applied plant nutrition. The main theme of the 18th IPNC was *Plant Nutrition for*

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Global Green Growth with this theme chosen to highlight the fundamental role of plant nutrients for successful intensification of global crop production.

The event was attended by close to 600 participants from more than 50 countries and was held in conjunction with two satellite meetings on Boron and Manganese, which took place prior to the colloquium itself with around 150 delegates. The colloquium, which was attended by many world authorities, provided an excellent forum for the exchange of knowledge and ideas leading to future collaboration in the fields of plant mineral nutrition, plant molecular biology, plant genetics, agronomy, horticulture, ecology, environmental sciences and fertilizer use. It was also, of course, an opportunity to meet up with old plant nutritionist friends and make new ones.

One of the most attractive features of the colloquium was the Marschner session: *Nurturing the Future* and the award ceremony in which winning young scientists presented their achievements in plant nutrition. Award winners included: Muneta Grace Manzeke from Zimbabwe, who presented on "Role of soil micronutrients and fertilizer management in crop nutrition under variable smallholder cropping"; Kengo Yokosho from Japan, "Identification of transporters involved in metal stress tolerance in plants"; Patrick E. Hayes from Australia, "Proteaceae from severely impoverished habitats preferentially allocate phosphorus to photosynthetic cells"; and Kristian Holst Lauren from Denmark, "Multi-dimensional stable isotope analysis - A novel tool in plant nutrition".

The large and ever increasing number of papers published on various aspects of plant nutrition means that a wide range of topics were included in the colloquium oral and poster presentations, which were divided into ten main themes:

1) Plant-microbe interactions and nutrient acquisition
2) Nutrient functions in plants
3) Nutrient management and fertilizers
4) Nutrient uptake, transport and homeostasis
5) Nutrient availability in soils, toxicity and remediation
6) Roots and genetics of crop nutrient uptake
7) Plant nutrition and food quality
8) Nutrient cycling, ecosystems and climate change
9) New analytical techniques in plant nutrition
10) Novel technologies for fertilizers

The colloquium proceedings of oral and poster presentations, together with those of the Boron and Manganese satellite meetings total just under 1,000 pages of text. Professor Schjøerring and his local organizing committee are to be congratulated for producing the publication in an electronic form, which can be accessed by readers at www.ipnc2017.org. Additionally, the organizers developed an innovative and very useful IPNC application available in the *App Store* and *Google Play*, which resulted in a significant reduction in paper and contributed to the environmental credentials of the colloquium.

To produce a publication relevant for the International Fertilizer Correspondent (*e-ifc*) from the IPNC text of over a 1,000 pages has inevitably meant it is necessary to omit certain sections completely and to be highly selective with the rest. We have only been able to scratch the surface but hope that our short contribution will, at least, provide a flavor of the meeting to whet our readers' appetites to consult the original proceedings and, particularly, the plenary keynote papers which can be accessed as described above. In citing the publications in the *e-ifc* text, plenary papers are denoted simply by the year 2017, whereas the addition of 'O' and 'P' indicates an oral or poster presentation, respectively.

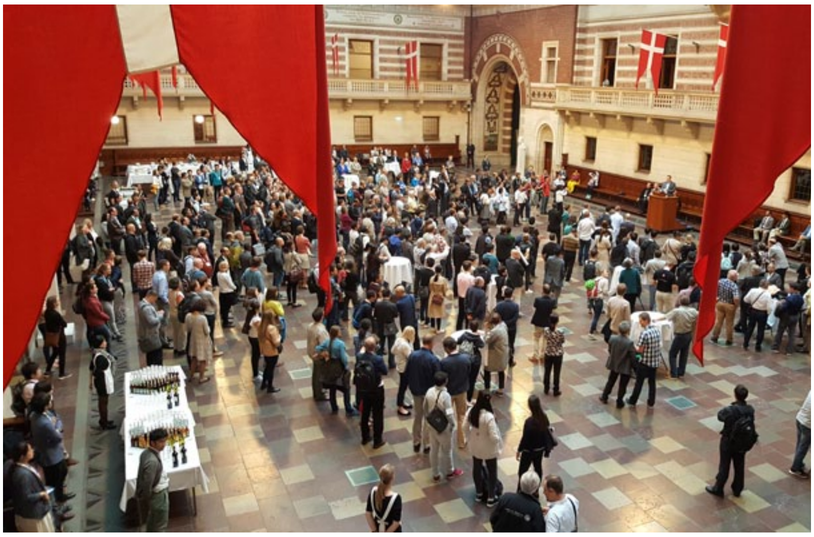

Photo 2. Welcome reception in the City Hall hosted by the City Council of Copenhagen. Photo courtesy of J.K. Schjøerring.

The IPNC organizers are to be congratulated on providing an excellent social program, which included a reception in the City Hall hosted by the City Council of Copenhagen on 21 August 2017 (Photo 2) and a canal boat trip via the famous Little Mermaid (Photo 3) to the conference dinner at the Langelinie Pavillonen on 23 August 2017.

Plant-microbe interactions and nutrient acquisition

Plant roots co-exist in association with microorganisms that constitute the soil-plant microbiome. The plenary keynote of Richardson *et al.* (2017) focused on exploitation of the plant-root microbiome in enhancing the availability of key macro- and micronutrients to plants. The authors presented some examples of successful interactions between roots and microorganisms, such as rhizobia's symbiotic association with legumes for N fixation and P acquisition through mycorrhizal associations. The authors highlighted the importance of microbiome-based approaches that allow comprehensive functional assessment of soil, rhizosphere and root-associated communities using high throughput sequencing techniques. Development of management practices to promote more beneficial microbiomes, such as crop rotation, selection of favorable microbial consortia, or even selection of crop germplasm more readily able to associate with beneficial microbiomes, are of great importance, in particular for low-input agriculture.

Neumann (2017, O1-1) presented the main results of the EU-integrated BIOFECTOR project (www.biofector.org) aiming to reduce the application of mineral fertilizers in European agriculture using microbial and non-microbial bio-effectors (BEs).

Photo 3. The Little Mermaid sculpture at the Langelinie promenade in Copenhagen, Denmark. Photo by E.A. Kirkby.

According to the large data set analyzed, high soil fertility was frequently considered a limiting factor for efficient application of BE on agriculture soils (Lekfeldt *et al.*, 2017, O1-7; Neumann, 2017, O1-1). The challenge therefore is to define the soil conditions and identify the management practice for improved integration of BE into agricultural practice.

The current increase in crop yields mainly depends on nitrogen (N) and phosphorus (P) fertilizer application, whereas sustainable approaches require high yields with lower environmental cost. In this regard, the plenary keynote paper of Chen and Liao (2017) introduces the importance of nodule P status for biological N_2 fixation in soybean with a pivotal role of high-affinity inorganic P (Pi) transporters (GmPT5 and GmPT7) for controlling Pi transfer from host roots to nodules. The molecular study of de Bang *et al.* (2017, O1-5) provided novel information on the role of small-secreted peptides (SSP) in legume nodulation and adaptation to macronutrient - N, P, potassium (K), sulfur (S) - stress, highlighting the diversity of SSP genes in legumes and their impact on legume-rhizobia symbiosis.

Root exudation of organic anions and phosphatases are the important mechanisms for soil P acquisition in many plant species. However, the benefits of these two exudates are often limited due to their interactions with soil, so it is important to consider space and time close to the P uptake zone (Giles *et al.*, 2017, O1-6). Therefore, strategies that enhance both the distribution and concentration of exudates will be needed, which require spatial and temporal orchestration to achieve their positive complementarity through selection or transgenic approaches, or by close intercropping of plants with a strong expression of traits.

Arbuscular mycorrhizal fungi (AMF) form a symbiotic association with approximately 80% of all known terrestrial plant species including many important agricultural crop species. AMF's role is most remarkable under low P conditions. However, microbes and their metabolites responsible for AMF suppression are unknown. Cruz-Paredes *et al.* (2017, O1-3) presented preliminary results of their ongoing work on AMF suppression by unsterile soil and isolation of AMF suppressive microorganisms and identification of the metabolites responsible for this suppression. Furthermore, using tomato mutant reduced mycorrhizal colonization unable to form associations with AMF, Watts-Williams *et al.* (2017, O1-4) demonstrated the importance of AMF symbiosis for increased zinc (Zn) content in tomato grown on low Zn soil, but with less benefit as soil Zn concentration increased. The acquisition of Zn essential for symbiotic N_2 fixation was investigated by Abreu *et al.* (2017, P1-1) in the legume, *Medicago truncatulata*. The authors provided evidence that Zn is transported through vascular bundles to the apoplast of the nodule's apical zone and proposed a model of Zn acquisition by rhizobia-infected legume cells mediated by a Zn-iron (Fe) permease (MtZIP6). The beneficial influence of a plant nutrient in stimulating SNF may not only be a direct one. In fact, Peng *et al.* (2017, P1-22) investigated soybean nodulation in water culture experiments comparing increasing magnesium (Mg) supply from extremely low to adequate values. Nodulation was greatly retarded by low supply but neither the Mg concentration nor nitrogenase activity of the nodules was affected. The authors suggest that nodule growth was probably depressed because Mg deficiency decreased carbohydrate transport from shoots to roots.

Nutrient functions in plants

White *et al.* (2017) discussed the plant ionome defined as the elemental composition of a subcellular structure, cell, tissue or organism, which includes all mineral elements, whether essential or non-essential for life, in whatever chemical form they occur. The functional ionome - and this forms the basis of plant nutrition - comprises the subset of these mineral elements that are essential for plants, which includes the macronutrients N, P, K, calcium (Ca), Mg and S, and the micronutrients chlorine (Cl), boron (B), Fe, manganese (Mn), copper (Cu), Zn, nickel (Ni) and molybdenum (Mo). Additionally there is interest in some elements including cadmium (Cd) and arsenic (As), which can accumulate in plants but are toxic to man.

Potassium is a major plant nutrient involved in the crop metabolism, growth, development, yield and quality. It activates numerous enzymes in the cytoplasmic pool including those that control carbohydrate and protein metabolism; the fixation of carbon dioxide (CO_2) in photosynthesis; and nitrate assimilation by plants. Potassium in the vacuole plays a key role in water relations in the maintenance of turgor and control of stomatal movement. It is also essential in the regulation of cell growth. In the process of photosynthesis, K functions directly or indirectly at various stages including light interception, CO_2 availability and chlorophyll synthesis. K^+ is the predominant cation in plants and functions in ionic form in nitrate transport from root to shoot, as well as the loading of assimilates (sucrose and amino acids) into the phloem and their transport to fruit and storage organs. Crops well supplied with K are more resistant to stresses, both biotic (e.g. pest attack) and abiotic (e.g. drought, cold and salt stress). K and N interact in the physiological and biochemical processes described above and are taken up by crops in relatively similar amounts. Appropriate nutrient balanced fertilizers should be applied in order to obtain high quality yields.

Valuable new findings were reported at the colloquium including the need to increase K application to prevent frost damage in wheat in the West Australian grain belt, which was discussed by Bell and Ma (2017, O2-4). Low K in topsoils and subsoils is common and frost is increasing in frequency and severity during spring coinciding with the young microspore stage of pollen development. Current K fertilizer rates on these low K soils are generally too low to meet the various demands for replacing K removal, i.e. increasing soil K to safe levels, meeting demand for high yield crops and achieving ongoing crop protection against stress. Tavakol *et al.* (2017, O2-1) concluded that K supply under osmotic stress in barley mitigated photo-oxidative damage mainly via improved photosynthesis and avoiding reactive oxygen species generation rather than high antioxidant activity. Optimizing K nutrient status under osmotic stress recovered most of the pathway changes back to control conditions.

Root uptake of K is affected by various soil and plant factors. Plasma membrane bound H^+-ATPase activity is required for effective K uptake by roots; the enzyme generates a membrane potential gradient across the plasma membranes which contributes greatly to root uptake. On the other hand, B plays an essential role in maintaining membrane integrity. In keeping with these concepts, Ceylan *et al.* (2017, P4-9) reported impaired root growth of canola (oilseed rape) at low B supply. By contrast, plants grown with adequate B had higher root and shoot concentrations of K compared to plants with low B. The authors stress the need to maintain an adequate B supply to ensure a better response to K fertilization and suggest the use of K fertilizer containing B as an agronomic approach to avoid B deficiency.

Magnesium deficiency symptoms are commonly observed in agricultural crops with inadequate Mg fertilization leading to yield depression. It is well established that Mg deficiency induces a reduction in sucrose transport from source leaves to roots. In a study of Mg deficiency in maize, however, Jung *et al.* (2017, O2-5) demonstrate for the first time that reduced apoplastic acidification, brought about by changes in the plasma membrane H^+-ATPase, is the primary cause of limited plant growth. Macronutrient cations K, Ca and ammonium (NH_4^+) compete for uptake with Mg, their effectiveness depending mainly on their concentrations in the root vicinity. In the volcanic ash soils (Andisols) of the southern Chilean grasslands, high winter rainfall solubilizes bases which increases soil acidity. This in turn releases toxic amounts of Mn, while simultaneously decreasing the availability of Mg, which favors the competitive uptake of Mn (Reyes Diaz *et al.*, 2017, P2-20).

Sulfur interaction with N and the negative effect of S starvation on N use efficiency (NUE) was studied by Garcia-Mina *et al.* (2017, O2-7) in wheat plants. Shoot nitrate transport was depressed and consequently so too further N metabolism in the leaves leading to a decrease in leaf concentration of active cytokinins. S deficiency led to substantial accumulation of molybdate in both roots and shoots as might be expected to compensate for the anion deficit as has been previously reported. This example of imbalanced fertilization between N and S is also frequently seen between N and K, where inadequate K supply inhibits N uptake and metabolism, and is of very practical importance in limiting crop production.

Silicon (Si) is the second most abundant mineral element in the soil and, although not yet generally accepted as an essential element for higher plants, its beneficial effects in the alleviation of various abiotic and biotic stresses have been extensively demonstrated. In addition to two plenary keynote presentations on recent progress in Si transport in rice (Ma and Yamaji, 2017) and Si-mediated transport of other mineral elements (Nikolic *et al.*, 2017), Si pre-treatment was shown to delay N mobilization and senescence processes in the mature leaf of N-deprived canola plants (Arkoun *et al.*, 2017, P2-4). On the other hand, Si addition was effective in mitigation of NH_4^+ toxicity in passion fruit (*Passiflora edulis*), as demonstrated by increased NUE and greater plant growth responses (Prado *et al.*, 2017, P2-7). Also Si application was effective in mitigation chilling stress in maize which was mainly attributed to increased distribution of Zn and Mn to the leaf thereby enhancing antioxidant defense (Moradtalab *et al.*, 2017, P2-16). Hosseini *et al.* (2017, O2-6) highlighted the beneficial importance of Si nutrition in maintaining photosynthesis activity under concomitant drought and K deficiency in barley, a Si-accumulating species. In intact ryegrass plants, Si lowered aluminium (Al^{3+}) concentration and increased Si uptake by up-regulating root Si transporter genes (Lsi1 and Lsi2) (Pontigo *et al.*, 2017, P4-40). Moreover, Si supply enhanced shoot lignin accumulation in barley plants subjected to Al toxicity (Vega *et al.*, 2017, P7-25). Furthermore, Hinrichs *et al.* (2017, P2-12) demonstrated that Si addition increased the gene expression related to lignin metabolism in rice roots thereby promoting formation of the Casparian band and its barrier functions for radial oxygen loss and elevated Fe uptake. More practically, the use of stabilized monosilicic acid as a Si source for both foliar sprays and fertigation was superior in increasing stress tolerance, growth, yield and quality parameters of various crops such as wheat, cucumber, pepper, tomato, grapes and cardamom (Lanne, 2017, O5-4).

Nutrient management and fertilizers

In the plenary presentation, McLaughlin *et al.* (2017) highlighted the markedly different patterns of nutrient usage over the past 50 years on a global scale as measured by P consumption from data from the International Fertilizer Industry Association. In developed countries, usage has decreased greatly, whereas in developing countries, such as Latin America, usage continues to increase. Continued increases in fertilizer use are required to close yield gaps. Almost 75% of global areas are not achieving potential yields of staple crops of maize, wheat and rice so fertilizers must be used more efficiently. By marked contrast, Africa has had very low fertilizer usage over the same period. In terms of responses to mineral fertilizer application, Giller (2017) refers to Africa as the plant nutritionist`s paradise because, on these old highly weathered soils, deficiencies of virtually all essential plant nutrients can be found and studied in the field.

One of the major challenges facing *Plant Nutrition for Global Green Growth* as discussed by McLaughlin *et al.* (2017) and Fixen (2017) is the exponential growth of world population. Currently at about 7.6 billion, the global population is expected to reach almost 10 billion by 2050, which means that global green growth must be sufficient to produce more food in the next 50 years than in all human history (Fixen, 2017). This author also draws attention to the difficulties in achieving this aim because of the added pressures of climate change, water insecurity, land use changes and soil degradation. The impact of human conflict may also be added to this list. From lifetime experience in the fertilizer industry, Fixen (2017) also points out that available guidance and nutrient recommendations to farmers are still largely empirical rather than mechanistic.

The use of mineral fertilizers, especially N, are essential for the increase in crop production necessary to meet future food demands. While N is not a limiting nutrient, as it can be fixed from the atmosphere either chemically or biologically, its use has to be carefully monitored because that which is not utilized by the crop can act as a major pollutant by inducing nitrate leaching from the soil, releasing nitrous oxide (N_2O) into the atmosphere contributing to greenhouse gas emissions, as well as the release of ammonia (NH_3) into the atmosphere. These polluting, well-known effects associated with high N fertilizer usage have been observed in China for example since the 1980s. The world also has large reserves of K which is required by crops in similar amounts to N, but unlike N is harmless to the environment. Phosphorus is the most limiting of the three major plant nutrients in terms of world reserves and the need for its efficient recycled use has long been recognized.

Fertilizer efficiency may be measured in various ways (McLaughlin *et al.*, 2017) but, in terms of nutrient removal by crops over a single growth season, the values for N, P and K are generally <50% with micronutrients much lower at <5%. Following application, residual effects benefiting crops in subsequent years may be long-lasting, but not in the case of N, S and B which are easily lost from the soil. Aguirre *et al.* (2017, P3-22) in Germany reported field trial experiments with winter wheat in which the efficiency of urea, the dominant form of N used worldwide, was substantially improved by the addition of the new urease inhibitor (2-NPT) to urea fertilizer. This treatment successfully inhibited urea hydrolysis as shown by soil analysis and, due to lower NH_3 losses, significantly increased crude protein content and N uptake compared to urea alone. Less spectacular but positive results were obtained by Syed Shah *et al.* (2017, P3-68) in field experiments in the UK, which compared the effects of urea treated with a nitrification inhibitor and urease (UTr) with urea and ammonium nitrate (AN). With a single application of 120 kg ha^{-1}, UTr outperformed urea and AN in yield of spring barley averaged over two years and lower yields were obtained for three growing seasons by urea compared to plots treated with UTr. The absence of any significant differences between treatments for winter wheat was attributed to differences in the rooting systems, and growth stages of the two crops at the time of fertilizer application and effects of high rainfall intensity. Other than inhibitors, coatings and less soluble matrices can be used to slow down the rate of release of N from granules.

How much N to apply and when to apply it to benefit the crop without detriment to the environment has long concerned farmers. A valuable and sophisticated contribution to the colloquium in this respect was presented by Leibisch *et al.* (2017, O3-4). These researchers set up a randomized field trial on a commercial sugar beet field with treatments with increasing N supply taking into account soil available N. At harvest, sugar beets were sampled and yield and quality parameters established. Spectral reflectance on ground (proximal) was measured and aerial image spectroscopy was realized. The results obtained confirmed the applicability of spectral proximal and remote sensing techniques to allow the quantification of N fertilizer demand in sugar beet.

The enormous benefits to practical agriculture in Turkey of the long-term research association between the International Potash Institute (IPI) and the University of Ege was discussed by Dilek Anaç (see Anaç 2017, O3-1). At the colloquium, Professor Anaç was deservedly presented with a Sulphate of Potash Information Board (SOPIB) award for her work on K which has featured at the centre of her research. This has included the establishment of rates of application of K for numerous crops, ensuring balanced fertilization and the role of K in NUE. More recently her work has extended to the benefits of K in relation to water and salt stress and the use of K salts in fertigation of outdoor and indoor crops and crop quality. Two most important features of her work should be acknowledged. The first is the stream of young research workers who over the years have benefited from her support and encouragement and finally her ability to communicate her findings to farmers for their practical application.

Giller (2017) suggests that balanced K nutrition plays a key role in adaption to drought and climate change, in citing the findings of Taulya (2013) who showed that alleviation of K deficiency in East African highland banana gave complete protection against the impact of drought on yield.

The marked reduction in S deposition from the atmosphere to soil due to the control of air pollution, together with increased crop removal, has meant that limitation of soil fertility by a lack of S has become a worldwide problem. S is an essential plant nutrient with functions including the formation of plant protein and chlorophyll so that increased application of S fertilizers will be required to avoid deficiency and crop failure. The problem has been exacerbated by the regular use of high grade NP fertilizers lacking in S (Chien and Gearhart, 2017, O3-7). These researchers have evaluated the agronomic effectiveness of ammonium sulfate (AS) in comparison to recent commercial grade granular bentonite type fertilizers for S availability and crop growth. In order to provide an effective source of S, bentonite fertilizers are dependent on the oxidative process of soil microbes to produce sulfate in the soil. From their evaluation, which included a laboratory incubation study, a greenhouse evaluation study and agronomic field trials, they concluded that oxidative activity was nil or virtually absent and that bentonite fertilizers were unable to provide crop growth during the season of application.

Photo 4. Prof. Dr. Dilek Anaç presenting her work on K application in the field. Photo courtesy of D. Anaç.

The efficiency of the fertilizer polyhalite, a hydrated sulfate of K, Ca and Mg with the formula $K_2Ca_2Mg(SO_4)_4 \cdot 2H_2O$, was investigated by Yermiyahu *et al.* (2017, O3-13). Several pot experiments were carried out with the fertilizer supplied at different application levels and uptake and yield production by wheat plants was measured. It was concluded that polyhalite is a more efficient fertilizer for supplying K, Ca, Mg and S relative to equivalent soluble salts. To meet the plant requirement ratios for Ca, Mg and K, polyhalite should be supplied to provide sufficient Ca and Mg and additional K fertilizers should be used as a source of K. Transport and leaching of Ca, Mg, K and S in soil following polyhalite application is lower than following the application of equivalent sulfate salts. The residual effect of polyhalite fertilizer on the subsequently grown crop is higher than the effect of the equivalent sulfate salts, especially regarding Ca, Mg and S. Irrigation management, as determined by the leaching fraction, has a strong impact on polyhalite efficiency as a source of K, Ca, Mg and S for plant nutrition. Polyhalite was also tested in comparison to KCl as a nutrient source for alfalfa growing on the highly weathered low-fertile and acid soils of tropical Brazil (de Campos Bernardi *et al.*, 2017, P3-8). It was shown to be an alternative source of K and S and polyhalite was able to meet the nutritional requirements of alfalfa for healthy growth and production.

Boron and S can readily be leached from light soils and crop deficiency of these nutrients is widespread. The possible benefit of applying these nutrients simultaneously as B and S granules 80% fortified with 1.2% B in supplying soybean and cotton in India was investigated by Singh and Goswami (2017, P3-18). Yields and quality of both crops were improved by BSG in comparison with B and S treatments alone.

Nutrient availability in soils, toxicity and remediation

The plenary keynote of Jensen (2017) critically reviewed the potential and challenges for producing and applying bio-based 'green' fertilizers, and the bias that farmers may have against using recycled materials for crop production. Recycling P from waste as P fertilizers in agriculture has become the ultimate option to overcome P scarcity in the future. Christiansen *et al.* (2017, P3-12), studied P release from struvite crystals ($NH_4MgPO_4{\cdot}6H_2O$; 12.6% P) obtained from sewage sludge. Fine struvite crystal size (powder) showed P release comparable to water-soluble mineral P fertilizer, while bigger crystals (>2 mm) functioned as a slow P release fertilizer. Another substantial nutrient provider for plant growth is Greenlandic rock flour. The work of de Neergaard (2017, O5-2) showed that this material released K, P, S and Mg immediately after addition to soil and, given the low cost of extraction and processing of the material, they suggested its potential use for agronomic application. Soltangheisi *et al.* (2017, O5-1), studied the long-term effect of cover crops in P mobilization for the subsequent crop. They found that none of the cover crops were effective in increasing available P in the soil compared to fallow, but they were important in recycling P and increasing soil organic matter.

Crop production on calcareous soils that occupy about 30% of global agriculture land is often limited due to Fe and P starvation. However, Ding *et al.* (2017, P5-3), suggested that the adverse effect of high pH on lateral root formation of various *Lupinus* species might be the main cause of their sensitivity to calcareous soils. Suzuki and Namba (2017, O5-3) tested the soil application of Fe complexed with deoxymugineic acid (DMA; plant-born phytosiderophore), as an Fe source for upland rice on calcareous soil. Although Fe-DMA was effective in remedying Fe deficiency chlorosis comparable to the synthetic chelate, Fe-EDDHA (ethylenediamine-N,N_bis(o-hydroxyphenyl)acetic acid), the lower stability of DMA in soil might not be appropriate for practical use. On the other hand, in a paddy environment, excess Fe might also limit rice production. Aung *et al.* (2017, P5-2), analyzed Fe distribution in various rice tissues under different excess Fe levels, which elucidated the relationships between excess Fe levels and plant damage, and revealed the molecular mechanism of Fe excess stress response in various rice tissues.

Paddy soils in Asia are often contaminated with As mainly due to irrigation with As-containing groundwater. Therefore, understanding As biogeochemistry in paddy soils, together with the mechanisms of As uptake, transport and detoxification in rice plants is important for both yield (food security) and human health (food safety). The plenary key note of Zhao (2017) gave a comprehensive overview of these processes, highlighting the importance of recently identified As(V) reductase genes (*OsHAC1;1, OsHAC1;2* and *OsHAC4*) that play a key role in As(V) tolerance and As accumulation in rice plants. In practical terms, the recent studies of Zhao's group have shown that the denitrification process is coupled with anaerobic oxidation As(III) to As(V) in anaerobic paddy soils, hence nitrate fertilizers enhanced the denitrifiers population and, in turn, attenuated As bioavailability in flooded paddy soil. Applications of high doses of P, Fe and Si fertilizers in rice ecosystems have shown promising results in many instances, including reducing As bioavailability and enhancing internal detoxification mechanisms and translocation of As to grains (Suriyagoda *et al.*, 2017, P5-17).

Changing the N source from nitrate to ammonium can effectively mitigate Mn toxicity in sugarcane due to decreased Mn-plaque formation in roots and subsequently lower Mn accumulation in the shoot (Ling *et al.*, 2017, P5-9). Lavres *et al.* (2017, P5-8), investigated the effect of S supply on the activity of antioxidant enzymes involved in Cd tolerance and biomass of Massai grass exposed to high Cd. The authors concluded that adequate S supply enhanced Cd phytoextraction potential and can potentially be used in contaminated substrates. Tanoi *et al.* (2017, P5-18) studied uptake of radioactive cesium (Cs) by rice following the Fukushima disaster in Japan. These authors showed that both uptake and grain accumulation of Cs in rice was lowered by high K supply, and they also found a genotypic difference in Cs distribution between husk and grain. The rapid growth of nanotechnology and the increasing applications of nanoparticles are raising environmental concerns as well as potential phytotoxicity risks. Fellmann and Eichert (2017, P5-4) demonstrated the negative effect of silver (Ag) nanoparticles on growth and physiological performance of both maize and canola.

Plant nutrition and food quality

To a large extent, the quality of food crops is controlled by plant nutrition. In the developing world, in particular 'hidden hunger' for micronutrient deficiencies is a major health problem for human populations (Cakmak, 2017) with around 2 billion people affected. Children are especially prone to Fe, Zn and iodine (I) deficiencies resulting in chronic diseases. These micronutrient deficiencies are commonly associated with regions where soils are low in micronutrients and cereal-based foods of rice, wheat and maize make up the main diet. Despite intervention programs, including the use of iodised salt, inadequate iodine intake is still a growing health concern. Cereal grains are extremely low in I at about 10 µg kg^{-1} grain in comparison with human demand of about 150 µg per day and, for the major wheat consuming countries, grain Zn values commonly range between 15 and 25 mg kg^{-1} which is inadequate as a primary source of dietary Zn (Cakmak, 2017).

Biofortification of micronutrients is another means of increasing micronutrient supply. Cassava roots grown in tropical areas provide a rich source of starch but are naturally low in micronutrients. Under field conditions, Narayanan *et al.* (2017, O-1), using *Arabidopsis thaliana* iron transporter (IRT1) and ferritin (FER) transgenic cassava plants showed 6-12 times higher Fe and 3-9 times higher Zn concentrations compared to non-transgenic controls. The biofortified transgenic plants retained growth characteristics and storage root yields equivalent to the non-modified controls under field conditions. The biofortified plants contributed 45-50% of the estimated average requirement for Fe and 65-70% of the Zn requirement for 1-3 year old children.

Zou *et al.* (2017, O-2), attempted to increase Zn in wheat grains with the aim of raising it to 40 mg kg^{-1} in field grown wheat. Their objective was considered in a conceptual agronomic framework with an integrated strategy to harvest more grain Zn while ensuring high yield and protecting the environment. Genetic biofortification was achieved by using a new cultivar, agronomic biofortification by foliar application of Zn, N fertilizer was optimized, and excessive use of P fertilizer was avoided. Too high P applications, and too low N applications, especially depressed grain Zn concentration.

From preliminary experiments by Torun *et al.* (2017, P2-2), soaking maize seeds in solutions of 5 mM $ZnSO_4$ over increasing periods of time showed that Zn enriched seeds could be reliably used against Zn deficiency. The positive response of Zn seed enrichment of canola, a non-mycorrhizal crop, in improving growth under optimal and low root zone temperature conditions was reported by Mahmood and Neumann (2017, P2-14). These authors have introduced a very practical approach, whereby Zn seed dressing could be used in the canola seed industry.

Soil applications of most micronutrients are ineffective in increasing grain concentrations. Targeting by foliar application, however, provides a highly useful means of contributing to grain accumulation. An update on foliar fertilization was presented at the colloquium by Fernandez *et al.* (2017). During the reproductive stage, when foliar fertilization takes place, there is a need for maintenance of relatively large pools of Zn, selenium (Se), I, and other micronutrients in the leaf tissue during spraying (Cakmak, 2017) because this is the period when extensive assimilate transport to the grains is underway and required to meet the high micronutrient concentration desired for the human diet. The international HarvestPlus program (www.harvestzinc.org) delivered the first biofortified rice and wheat genotypes with an additional 8-12 mg Zn kg^{-1} grain by combining two strategies, genetic and foliar spraying, to allow the possibility of raising grain Zn above 45 mg kg^{-1} grain weight.

Food quality depends not only on the micronutrients but the macronutrients, particularly K. Several reports confirm this. The beneficial effect of an increasing supply of muriate of potash (KCl) on various quality and yield parameters of red delicious apples were reported from experiments from farmers' fields in India (Rather *et al.*, 2017, P3-5). Their results showed that 1,800-2,100 K_2O per tree applied in four-split doses provided the maximum increase in yield and quality of apple fruits. Similarly in grapes in India, the highest average bunch weight was combined with the highest percent fruiting canes confirming the essential role of K in the differentiation of the buds and the formation of the flower primordia in the grapes (Satisha *et al.*, 2017, P3-4). Potassium sulfate was found to be most beneficial in yield and quality for the grapes.

Reference

Taulya, G. 2013. East African Highland Bananas (*Musa* spp. AAA-EA) 'Worry' More about Potassium Deficiency than Drought Stress. Field Crops Research 151:45-55.

This report also appears on the IPI website at:

Papers and Presentations

Conference highlights and other information about the event are available on the IPNC 2017 website.