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Capping Fertilizer use while Enhancing Food and Nutrition Security inChina

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Abstract: Despite concerns about the ability of China to be self-sufficient in food, it has increased the per capita availability of food for its 1.4 billion people and dramatically reduced food insecurity over the past decades. However, China's self-sufficiency in food production came with dramatic environmental trade-offs due to excessive use of fertilizers. In response, the government of China imposed a policy of zero growth in the use of chemical fertilizers by 2020, with a challenge to the agricultural and fertilizer community to improve the nutrient use efficiency (NUE) of crops. These objectives have to be met while still ensuring food and nutrition security, and sustaining ecosystem health. In this paper we make a case for revisiting the functioning of fertilizers, in order to achieve a more effective and multifaceted impact on ecology and society. This leads to the notion of adopting a range of strategies with the potential for addressing the low NUE. These include identification of currently most effective fertilizer products and improved nutrient management practices for the immediate term, while designing innovative fertilizers based on plant nutrient physiology, developing ''smart'' fertilizers that recognize plant cues, deploying bio-nano-technology, and fortifying basic fertilizers with micronutrients.

Key Words: Revisiting fertilizer functioning, appropriate and innovative fertilizers,micronutrients, bio-nano-technology, nutrient use efficiency

Introduction

Fertilizers in agricultural production

The use of NPK fertilizers has allowed China to achieve food security for its teeming population, defying contrary predictions such as by Brown (1995). With only about 0.1 hectares available per person, about 5% of the planet's water resources and 7% of its arable land, fertilizer use has been a major driver for the increase in agricultural productivity. However, while grain production increased by 71% between 1977 and 2005, N fertilizer application increased by 271%, with an average national N fertilizer use efficiency of about 20 kg grain kg N, compared to over 40-50 in other countries. Under optimized N application, the excess N application, without penalty on China's cereal yield, was estimated at 11.8M tonnes (Ju et al., 2009). To better understand the magnitude of the challenge, this amount equals an average annual N fertilization rate of 68 kg N ha -1 over the 174 million ha of cropland in sub-Saharan Africa, and has the potential to double cereal production in the continent (Twomlow et al., 2008). Sattari et al. (2012) revealed a process of hysteresis in P uptake vs. P application in Western Europe from 1965 and 2007, wherein the increasing application rates of P were reverted from the mid-1980s, due to nvironmental policies, while crop yields continued to increase. These authors projected a continuing decline to 10 kg P ha -1 by 2050, still with no compromise in yield levels. The fertilizer industry indeed advocates the pursuit of a 4R Nutrient Stewardship principle, i.e. the use of fertilizer from the right source, at the right rate and at the right time, with the right placement, to increase nutrient uptake efficiency (IPNI, 2014). Along this line, good agricultural practices, such as deep placement of fertilizers demonstrated by the improvements gained from urea deep placement (UDP; Bandaogo et al. 2015; Khalil et al., 2011), and similar sub-surface fertilizer practices could push NUE even higher, while reducing extra fertilizer inputs. Additionally, ecological synergies achieved through integrated management practices with judicious and balanced use of inputs including water and fertilizers, can boost resource use efficiency (e.g., Glendining et al., 2009; Keating et al., 2010; Rockstrom, 2013), in line with the production ecological principles suggesting that "most production resources are used more efficiently under improving conditions of resource endowment" (De Wit, 1992). Clearly, agricultural practices pursuing these integrated production ecological principles can contribute to addressing China's fertilizer challenges.

Strategies for amplifying the role of fertilizers

In addition to generic agronomic measures, we make a case for revisiting the functioning of fertilizers, in order to achieve a more effective and multifaceted impact on ecology and society. Our reflection suggest that some of current fertilizer products are suitable from this renewed perspective and can be used for immediate impact, while we should continue to improve on fertilizer products. Here we plea for developing novel ways of packaging and delivering nutrients to plants, based on a better integration of plant physiological and ecological processes of nutrient mobilization in soil, and uptake, transport and metabolism in planta, as a basis for the design and development of mineral fertilizers (Bindraban et al., 2015). This paradigm shift in fertilizer packaging and delivery entails 1) plant biology to drive fertilizer design; 2) advancing physico-chemical production processes to include bio-nano-chemical processes; 3) moving from bulk fertilizer production to agrosystem-specific fertilizer products; 4) changing from macro (quantity) products to composite (quality) products; 5) assessing application needs from point source to spatial dimensions; 6) combining single testing with meta analyses; 7) going from resource mining to resource recycling, and 8) devising fertilization strategies that go from mono- disciplinary to trans-disciplinary approaches.

The reflections also reveal that an important setback in qualitative food security has been the decline over the past decades in micronutrient contents of several crops, including grains and vegetables, presumably due to the use of high-yielding crop varieties and the continuous mining of soil micronutrients by crops (Jones et al., 2013). Moreover, there also are indications that the recent leveling of crop yields may in part be attributable to soil micronutrient deficiencies. Dimkpa and Bindraban (2016) opined that micronutrient fertilization of crops, in other words agronomic fortification, will increase crop nutritional quality, and thus is a promising addition to current interventions to address human malnutrition, including biofortification, food fortification, and use of mineral supplements. Furthermore, the authors provided evidence for multiple agro-ecological benefits of micronutrient fertilization, including increased crop yield, tolerance to drought, pest and diseases, increased biomass production that can also enhance soil health, and increased use efficiency of macronutrients and water. Taken together, these benefits have additional soil and environmental health ramifications, given their positive impact on soil biota.

In this paper, we therefore advocate for pursuing a continuous process of improving current products and designing novel fertilizers that meet the growing challenges of reducing input requirements; increasing nutrient uptake efficiency, and thus, mitigating adverse environmental side effects of fertilizers; and fighting both food insecurity and malnutrition, while reducing input costs and increasing farmers income.

To this end, upon the proof of their need in a soil-crop system, specific micronutrients can, for instance, be blended in, incorporated into, or coated onto, NPK granules. Micronutrients can also be applied foliarly to circumvent soil complications that reduce nutrient availability. These balanced micronutrient products can help to already reap the low hanging fruits to increase yield, NUE and nutrient content of the produce. Additionally, the fertilizer reverse engineering as proposed by Bindraban et al (2015) can leverage the fact that nutrients can also be taken up by plants in particulate forms and not solely as ions. We have coined such particulate nutrients as "micnobits", in recognition of their micro and nano-size nature. Upon uptake into plant, there is ample evidence that micnobit-type nutrients can release the active ingredient (i.e., ions) in planta for subsequent plant metabolism (reviewed in Dimkpa and Bindraban, 2016). "Corrective measures," such as coating of fertilizers or biosorbing nutrients in biomass, for slow release are among fertilizer strategies to prevent losses, and to better tune the timing and availability of nutrients to plant's need, thereby promoting yield (see for e.g. Chien et al., 2009; Michalak et al., 2015; Shivay et al., 2008). While coating for slow release typically responds to physical and chemical signals such as soil water and pH, it does not signal for plant demand of the nutrient. To this end, Monreal et al. (2015) proposed the integration of biosensors through nanopolymer technology, in the design of micronutrient fertilizers that would respond to specific nutrient-solubilizing root exudate signals that are cognate to the biosensors. Also, recovery and recycling of nutrient fertilizers should be encouraged because of the finite nature of mined nutrients and because of the essentiality of reducing the amount of new inert elements converted into reactive nutrients and released into the biosphere. While recycled products will be valuable, current extraction processes such as for producing struvite from wastewater, or burning of used vehicle tires to recover Zn in the ash (Ghiasi et al., 2015), need to be reconsidered, following the same logic as proposed by Bindraban et al. (2015), i.e., to take biological processes as a starting point in identifying chemical packaging modalities for recycled nutrients, rather than the extraction processes per se.

Conclusion

There is little doubt that reflections on the functioning of fertilizers will pave the way to identify currently most effective fertilizer products and towards the design and development of innovative fertilizer solutions. These will set the stage for the next leap in agricultural development not only in China, but also worldwide, and thus, will be a major contributor to ongoing efforts to feed the world's population sustainably. We suggest and provide options that fertilizer strategies should be more attuned to the crop's physiology, and leverage multiple pathways for nutrient interaction with crops to be more effective and efficient.

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