Fondation pour l'agriculture et la ruralité dans le monde
RECONNUE D'UTILITE PUBLIQUE

Charlotte Hebebrand

Responsible Plant Nutrition

Point of view n°4 - December 2015

Foreword

The *Point of view* collection presents the views of an external expert on a given topic. His opinion is not necessarily shared by the foundation, but is sufficiently reasoned and stimulating to be debated.

Edition 2015

Foundation for World Agriculture and Rurality

Préface

On redécouvre les sols. Longtemps négligés, ils apparaissent aujourd'hui comme la clé d'une agriculture productive et durable et sont l'objet de toutes les attentions. L'Organisation des Nations unies pour l'alimentation et l'agriculture (FAO) sonne l'alarme. Elle souligne, dans un rapport récent[1], qu'un tiers des terres dans le monde sont *« modérément ou fortement dégradées »*, ce qui compromet la sécurité alimentaire de la planète. Or, précise-t-elle, *« le manque de nutriments dans le sol est le premier obstacle à l'amélioration de la production vivrière et des fonctions du sol dans maints paysages dégradés. En Afrique, tous les pays – sauf trois – extraient plus de nutriments du sol chaque année que n'en sont restitués par les engrais, les résidus de récolte, le fumier et autres matières organiques »*. Il faut donc trouver la voie d'une fertilisation efficace, permettant de relever les défis alimentaire et écologique du XXIème siècle.

Reste à en définir les modalités. Sur ce point, il n'y a pas consensus. Schématiquement, deux camps s'opposent. Selon les uns, les engrais minéraux ont été un ingrédient essentiel de l'augmentation de la production agricole dans les pays développés, ainsi que dans ceux, en Asie et en Amérique latine, qui ont bénéficié de la Révolution verte. La priorité est donc d'accroître l'usage de ces engrais dans les régions où les agriculteurs, en particulier les petits paysans, n'y ont pas accès. Les autres pointent les dommages environnementaux, y compris les émissions de gaz à effet de serre, liés à un recours excessif aux engrais de synthèse. Ils prônent des pratiques agricoles visant à l'enrichissement des terres cultivées en matière organique, grâce notamment à la simplification du travail du sol et la généralisation des rotations culturales.

La Fondation pour l'agriculture et la ruralité dans le monde verse une pièce au débat en donnant la parole à Charlotte Hebebrand, directrice générale de l'International Fertilizer Industry Association (IFA). Les opinions exprimées dans la collection *Point de vue* ne reflètent pas nécessairement l'avis de FARM, mais elles fournissent des éléments de réflexion pour éclairer la complexité du sujet. Le titre de la présente publication, « Pour une nutrition des plantes responsable », est un appel à échanger et croiser les analyses pour orienter l'action des décideurs.

Jean-Christophe Debar

directeur, Fondation pour l'agriculture et la ruralité dans le monde.

[1] FAO and ITPS, Status of the World's Soil Resources, Rome, 2015.

Summary

Introduction

Global, aggregate (mineral) fertilizer demand is expected to reach 200 million metric tonnes of nutrients per year at the end of the decade[2], which represents a ten-fold increase since 1950, when some 20 million nutrient tons were applied.[3] This is proof of the world's farmers' desire to ensure and increase their agricultural productivity by providing nutrients to their crops, and stave off nutrient depletion in their soils. At the same time, this increase in consumption signals the need for ever more efficient fertilizer application, in particular since most of the fertilizer demand expansion since 1950 has been driven by nitrogen fertilizers, with underuse in many regions of phosphate and potash fertilizers raising concerns in some geographical areas of unbalanced nutrition. The Green Revolution of the 1970s provided a big boost to agricultural yields, primarily due to improved seed varieties and increased fertilizer use. Ongoing productivity gains are required in order to feed the world's burgeoning population. It is equally, if not more, important to ensure that the Green Revolution finally spreads to regions of the world that have not yet benefitted from its impact, if we are to successfully provide food security to a population of over 9 billion in 2050. However, an exclusive focus on productivity advances is clearly no longer sufficient. A new green revolution requires that productivity advances go hand in hand with a more efficient use of both natural resources, such as water and land, and agricultural inputs. "Responsible fertilization" requires that fertilizers be applied in a more efficient and effective way so as to maximize nutrient uptake by plants in the objective of bridging the yield gap[4] *and* staving off nutrient losses to the soil, water and air.

This paper will provide a brief overview of plant nutrients and their contribution to food security, outline how nutrients can be lost to the environment, and then put forth key elements of "responsible" plant nutrition. The final section of the paper will address both the challenges and opportunities in advancing such responsible plant nutrition.

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[2] P. Heffer and M. Prud'homme, IFA Fertilizer Outlook 2015-2019, www.fertilizer.org/MarketOutlooks

[3] IFA Fertilizer Indicators, May 2013, www.fertilizer.org//En/Knowledge_Resources/Library/IFA_Selection_Fertilizers.aspx

[4] The 'yield gap' represents the difference between farmers' actual and attainable yields and is often caused by poor access to agricultural inputs and to knowledge.

What Are Plant Nutrients?

In addition to carbon (C), oxygen (O) and hydrogen (H), coming from the air and water, plants require a series of 13 essential plant nutrients, composed of primary, secondary and micronutrients. The three primary nutrients are nitrogen (N), an important component of many structural, genetic and metabolic compounds in plant cells, phosphorus (P), which is vital for root and plant development and helps build resistance to drought, and potassium (K), which is essential for facilitating photosynthesis and stress tolerance. The other 10 nutrients[5] are as important for plant growth but required in smaller quantities. It is the most limiting nutrient that will limit crop yield.

Fertilizers contribute to food and nutrition security by providing nutrients for plants, preventing soils from becoming depleted of nutrients, replenishing soils that have become nutrient depleted, and maximizing agricultural productivity without increasing land surface use.

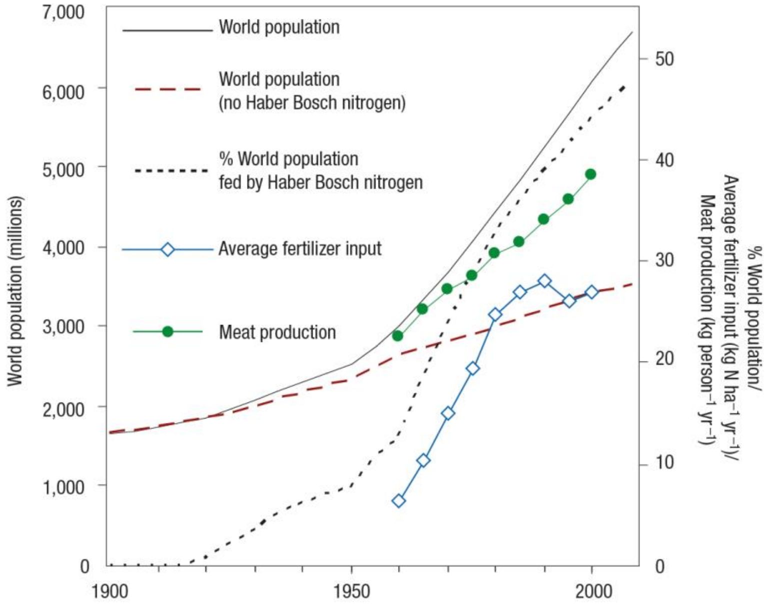
Any natural or manufactured material that contains at least 5% of one or more of the three primary nutrients - N, P or K - can be considered a fertilizer. Plants take up plant nutrients from the soil, those nutrients are removed from the soil with each harvest and must be replenished to ensure that subsequent crops can thrive. A recent study by Amy Bogaard, an archaeo-botanist at the University of Oxford, has shown that fertilizer use first started about 8000 years ago when Europe's first farmers began applying manure in order to enhance their crops.[6] While all 16 plant nutrients exist in nature, the quantities provided by organic sources (manure, crop residues and biological N fixation) are in many cases not sufficient to meet the needs of our growing, urbanized population. When manure, crop residues and biological N fixation are not sufficient, mineral fertilizers supply the outstanding nutrient balance needed for good crop yields. Mineral fertilizers have higher and more predictable nutrient level than organic sources, contain nutrients that are more immediately available to plants, and are more suitable for trade and commerce with respect to their higher nutrient content, which explains their rapid uptake by farmers. It is estimated that without manufactured nitrogen fertilizers alone, we could only feed half of today's global population (Figure 1).[7]

[5] 3 secondary nutrients: calcium (Ca), magnesium (Mg), sulphur (S) and 7 micronutrients: boron (B), chlorine (Cl), copper (Cu), iron (I), manganese (Mn), molybdenum (Mo), zinc (Zn).

[6] Balter, Michael. Researchers Discover First Use of Fertilizer. Sciencemag.org. Science, 15 July 2013. Web. 12 Nov. 2015

[7] Jan Willem Erisman, *et al.*. How a Century of Ammonia Synthesis Changed the World. Nature geoscience, Vol.1, October 2008.

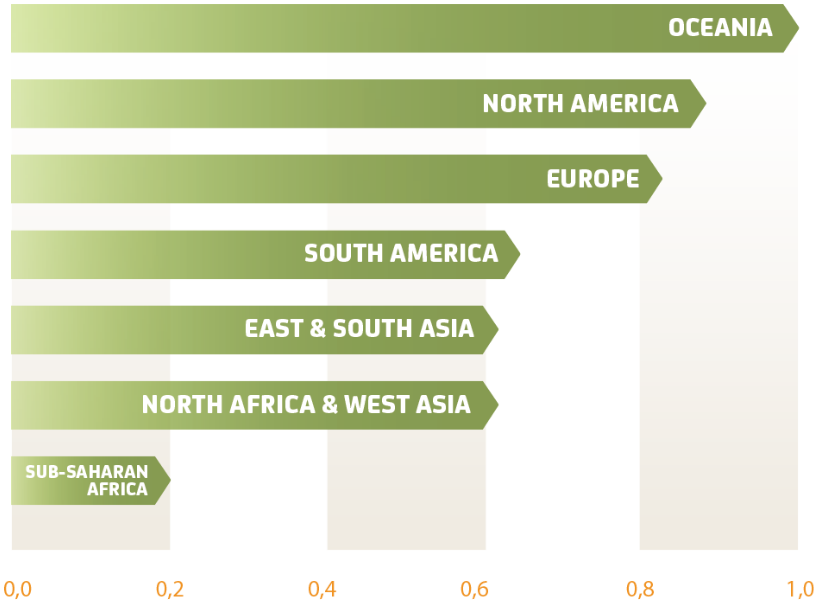
Figure 1



Source: How a century of ammonia synthesis changed the world. J.W. Erisman et al. In Nature Geoscience, Vol. 1 October 2008.

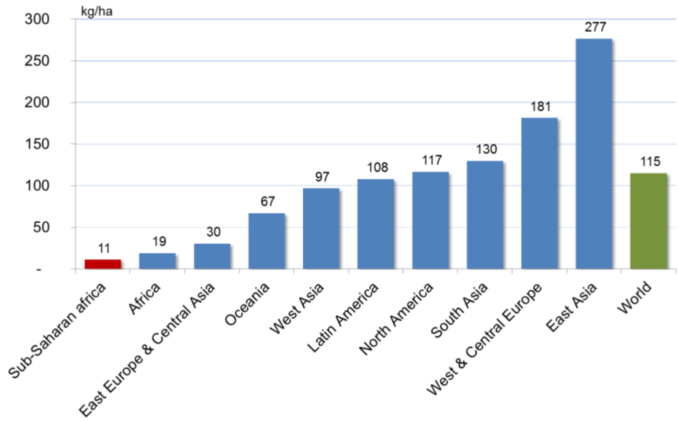
Despite these tremendous advances, however, there are still regions with unacceptably high yield gaps, and unsurprisingly, these are often correlated with insufficient fertilizer use to bridge the yield gap (fertilizer gap) and high prevalence of hunger. For instance, in Sub-Saharan Africa the average maize yield is only one fifth of the attainable yield (Figure 2), fertilizer use is only one tenth of the global average (Figure 3), and prevalence of hunger is the highest in the world (Figure 4).

Figure 2
Yield gap for maize (ratio between actual and attainable yields)



Source: IFA Fertilizer Facts, 2015[8]

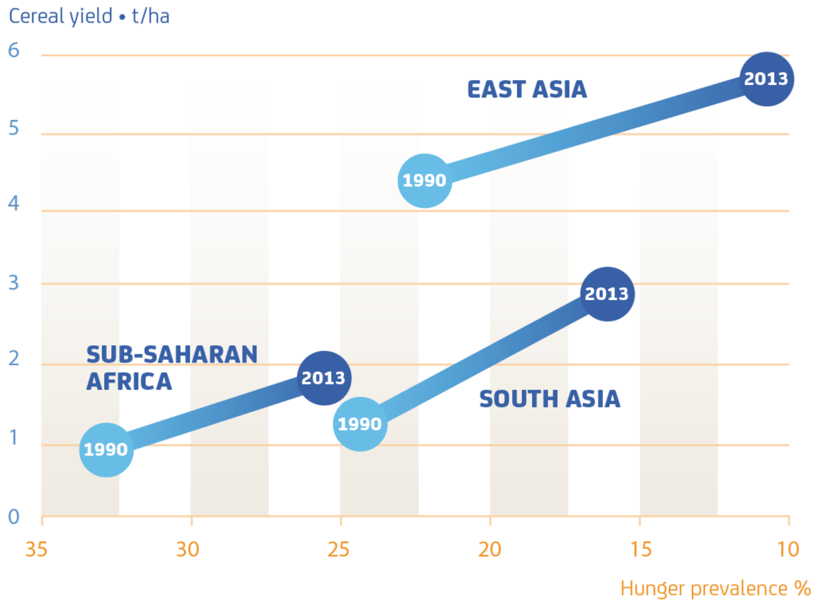
Figure 3
Average fertilizer application rate in 2013
(kg of nutrients/ha of arable + permanent land)



Calculated using FAOSTAT for the land area and IFADATA for fertilizer consumption.

[8] www.fertilizer.org//en/Knowledge_Resources/Library/Selection_Fertilizer_Facts.aspx

Figure 4
Relation between prevalence of hunger and cereal yield
(from 1990-92 to 2011-13)



Source: IFA Fertilizer Facts, 2015

Nutrient Losses to the Environment

While humanity cannot do without fertilizers, incorrect fertilizer use can have negative impacts on water, air, soils and climate, as nitrogen and phosphate that is not taken up by the plants can be lost to the environment. Since agricultural systems, and related nitrogen and phosphorus cycles are complex and leaky, zero nutrient loss is not an achievable goal, but nutrient use efficiency[9] can be significantly increased by more precise fertilization.

As an example, we know that in well managed research plots, some 40-65% of the N fertilizer applied is utilized in the year of application (since some of the remaining N stays in the soil and is available to crops during the next planting season, not all of it is lost to the environment), whereas in improperly managed farm plots, up to 70-80% of the applied N can be lost in rain fed conditions, and some 60-70% in irrigated fields.

As far as P use efficiency is concerned, losses to the environment occur mostly through soil and particulate matter erosion. Therefore, the main problem is limited to areas with sloping land, and with excess concentrated livestock farming, which result in high P application rates through animal manure. The efficiency of fertilizer P use in the year of application is low but, when evaluated over an adequate time scale (at least a decade) using the balance method, it is often high, up to 90% (Syers *et al., 2008*[10]).N and P losses can run off into rivers and watersheds or leach into groundwater, triggering eutrophication, thus negatively impacting water quality and biodiversity of aquatic systems. Gaseous N losses can produce (i) nitrous oxide (N_2O), a compound with a strong greenhouse gas potential and that participates in stratospheric ozone depletion when converted to nitric oxide (NO) and (ii) ammonia (NH_3) that can contribute to particulate matter formation. Use of acidifying fertilizer products and anthropogenic emissions of sulphur dioxide (SO_2), nitrogen oxides (NO_x) and ammonia may also result in acidification of agricultural soils and natural ecosystems.

It is important to point out that mineral fertilizers are not the sole contributor of nutrient losses to the environment, with manure, wastewater and energy combustion also responsible for significant losses, but the fertilizer industry acknowledges and is actively working to promote enhanced nutrient use efficiency.

Furthermore, while it may seem counterintuitive, it bears emphasis that higher nutrient use efficiency across the board is not always a laudable goal. Sub-Saharan Africa serves as a good example in this regard. Minimal or altogether lacking access to fertilizers has led to severe nutrient mining and subsequent nutrient depletion, which in turn can speed up soil degradation and desertification, in unacceptably large parts of the Continent.

[9] In this paper, by “nutrient use efficiency”, we mean the ratio between the total nutrient output (in the harvested product) and the total nutrient input (from fertilizers + livestock manure + biological nitrogen fixation, etc.)

[10] J.K. Syers, A.E. Johnston and D. Curtin. Efficiency of Soil and Fertilizer Phosphorus Use. Reconciling Changing Concepts of Soil Phosphorus Behaviour with Agronomic Information. FAO Fertilizer and Plant Nutrition Bulletin 18, January 2008

Box 1 : Fertilizer Use in sub-Saharan Africa

Fertilizer use is extremely low in much of the sub-Saharan Africa (SSA) region, covering more than 40 countries south of the Sahara, except South Africa.

Low fertilizer use is one of the main factors explaining lagging agricultural productivity growth in SSA.

Over the past 5 decades, cereal crop yields have been stagnant at less than 1 t/ha, despite an increase in food demand by 3 to 3.5% per year due to a rapidly growing population.

Currently, chronic food insecurity affects 28% of the 700 million people who live in SSA.

At the present trends of population growth, cereal crop productivity must grow by 4% annually or more than double by 2020 to make SSA self-sufficient in cereal production.

Most of the soils in Africa are inherently infertile, and poor agricultural management practices during the past decades have led to a severe decline in their productive capacity.

Nutrient balances for SSA show large negative values, and losses of nutrients are estimated at more than 50 kg/ha annually.

Source: Africa Program of the International Plant Nutrition Institute (IPNI)

The little amount of fertilizers applied in SSA (Box 1) actually results in a high nutrient use efficiency (often well above 100%), but in these cases, that is not a sustainable situation because it reflects higher nutrient removal than additions from fertilizers and other sources. Thus, *increasing* nutrient use efficiency in areas of no or very low fertilizer use would actually lock in low yields and soil health deterioration. The term “improved” nutrient use efficiency is therefore more appropriate in these cases than “increased” nutrient use efficiency as it takes into account the need to replenish soil nutrient pools and to enhance crop productivity.

Elements of “Responsible” Plant Nutrition

Solutions to advance agricultural productivity and environmental sustainability can often be found *both* by returning to knowledge and practices that have perhaps been neglected over time, as well as by embracing innovative products and practices.

The importance of balanced plant nutrition, the application of all needed plant nutrients in their correct dosage, was already acknowledged in the early 1840s, when the German soil scientist Justus von Liebig set forth the Law of the Minimum, which stipulated that crop yields are proportional to the amount of the most limiting nutrient (Figure 5). Von Liebig demonstrated that if just one required nutrient was not sufficiently available to a plant, then the uptake of all other nutrients by the plant was jeopardized and thus became an early advocate of balanced plant nutrition.

Figure 5

Liebig's Law of the Minimum (ca 1840).

The recognition that soils as well as plants have quite specific nutrient needs, is not new, but arguably has been neglected. Soil scientists have argued for many decades that it is imperative to undertake soil testing to ascertain the level of nutrients in the soil, so that these can be supplemented with the correct type of fertilizers to meet the nutrient needs of a specific crop. Likewise, experts have long promoted the benefits of integrated nutrient management, which specifies that nutrients available in organic sources should be supplemented, when necessary by mineral fertilizers to achieve the farmer's yield goal. Not only do organic fertilizers provide some nutrients; adding manure to soils and leaving crop residues in fields also helps build up soil organic matter, which is crucial for soil health and improving some properties such as water retention capacity.

Yet, this longstanding scientific understanding of concepts such as the need for balanced nutrition, of crop- and site-specific fertilization, and the importance of building up soil organic matter was arguably not always sufficiently heeded, perhaps because of the tremendous conveniences provided by mineral and nutrient rich fertilizers. Calls for more balanced nutrition, including greater attention to micronutrients, and for integrated nutrient management (use of organic and mineral fertilizers) are essentially an acknowledgement of longstanding, but perhaps temporarily forgotten, knowledge. Cognizant of this, the fertilizer industry has been devoting ever greater attention to placing nutrients on the market that are more specifically tailored to individual crops and soils, to incorporating a wider array of required nutrients, and to facilitating soil testing and outreach to farmers. Using the shorthand of "4Rs," the fertilizer industry is encouraging farmers around the world to closely consider the soil and crop specific nutrient needs and to apply not only the "right source" of fertilizers, at the "right rate," but also at the "right time" and in the "right place" (Box 2).

Box 2 : 4Rs at a Glance

No single R is more important than the others and all have to be taken in consideration

Right source principles:

Plants need 16 macro and micronutrients to grow well. It is important to match specific nutrient needs of crops and soils with the right nutrient type for balanced crop nutrition and to avoid nutrient deficiencies. Nutrients applied should be plant-available, or is in a form that converts in a timely fashion into a plant-available form in the soil. The nutrient applied suits the physical and chemical properties of the soil. And, compatibility is taken into account when blending different sources of nutrients.

Right rate principles:

It is important to apply the right rate of nutrients to meet a plant's nutrient needs. When determining the right nutrient rate, it is important to set an attainable yield target to estimate crop nutrient requirements. It is also necessary to assess the nutrients already available in the soil, as well as alternative nutrient sources - such as biological nitrogen fixation, manure, composts, biosolids, crop residues, atmospheric deposition and irrigation water - to ensure the adequate amount of additional nutrients are added.

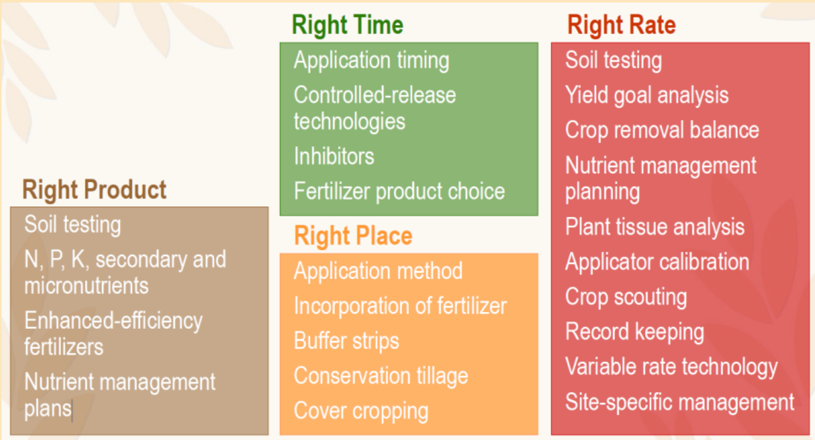
Right time principles:

To maximize nutrient uptake by plants, nutrients should be applied at the right time, when the plant can best access and use the nutrients. Nutrients should be applied to best match the seasonal crop nutrient demand. It is useful to assess the dynamics of soil nutrient supply and of soil nutrient loss. Climate patterns and rainfall should also receive consideration when making timing decisions.

Right place principles:

Nutrients placement can address both spatial variations across a field and nutrient dynamics in the soil. Specifically, plant uptake of less mobile nutrients like phosphorus and potassium is enhanced when these nutrients are placed closer to the plants root zone. Nutrient placement can also be targeted using variable rate application across a field when high yielding and low yielding zones are identified. Additionally, nutrient placement must work in conjunction with tillage systems; some of which conserve crop residue cover on the soil, to conserve nutrients and water.

Examples of Best Practices in the 4 Management Areas



Source: 4R Nutrient Stewardship - A Policy Toolkit. IFA, March, 2015[11]

Nutrient use efficiency can also be fostered through the use of new technologies and techniques. A whole slew of so-called "specialty fertilizers" are also available to farmers. These include innovations such as coatings on granular fertilizers to allow a controlled release of nutrients in the root zone; using slow-release fertilizer compounds to produce a gradual release of nutrients to match plant nutrient demand; adding nitrification inhibitors to nitrogen fertilizers to reduce potential nitrate losses and urease inhibitors to slow the conversion of urea in order to minimize ammonia losses to the air.

Foliar application of fertilizers provides another way to more closely target plant nutrition, and adding liquid or water-soluble fertilizers to irrigation water - so-called "fertigation" – allows a more timely and precise delivery of nutrients and water. While many of these specialty fertilizers allow for great gains in nutrient use efficiency, and their usage is growing at a fast rate, they nonetheless remain a niche market, and are mainly applied to high value-added crops where the higher costs of such fertilizers can be more easily recouped.

The rise of precision agriculture has also facilitated a improved recovery of nutrients by plants. High-tech equipment such as remote sensing and applicators capable of applying varying combinations of required nutrients at variable rates all within the same field, have allowed for great strides in more precise and balanced plant nutrition. Less sophisticated options such as the leaf color chart developed by the International Rice Research Institute (IRRI) facilitate implementation of site-specific nutrient management by smallholders.

So-called "biostimulants" – products that enhance crop metabolism and resilience, are also experiencing rapid market growth.

While in this paper, the emphasis is on fertilizer application, fertilizer producers are also carefully monitoring and steadily improving their energy use efficiency and related

[11] http://www.fertilizer.org/NutrientStewardship

greenhouse gas emissions in order to also reduce the impact of their industrial processes on the environment. Every three years, ammonia producers around the world are invited to participate in IFA's performance benchmarking surveys. Its 2015 edition shows continuous improvement in performance. Comparing a representative sample that participated in the 2010-11 and 2013-14 surveys shows a solid 2% improvement in performance with respect to energy consumption and greenhouse gas emissions. Adoption of best available technologies will help keep this momentum, within the limits of thermodynamic boundaries.

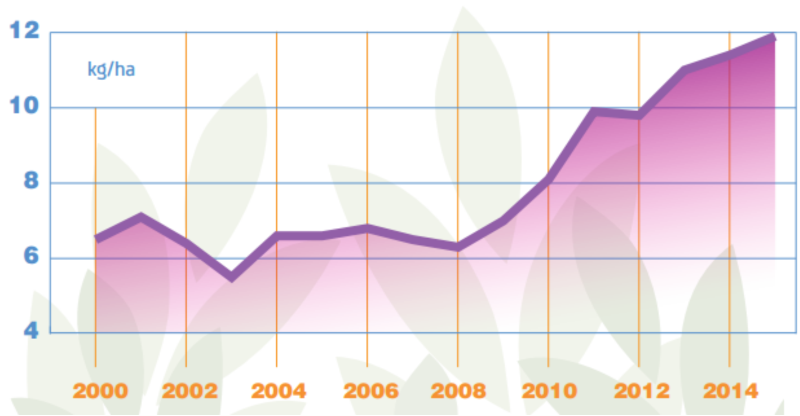
Challenges and Opportunities

There are tremendous opportunities in the realm of specialty fertilizers, as well as other technologies and products that enhance nutrient use efficiency.

Another potentially very promising area lies in plant genetics: research is underway to engineer enhanced nitrogen uptake capacity into crop varieties, which, if successful and economically-competitive, might provide a further boost to nutrient use efficiency.

Improved outreach and greater knowledge transfer to farmers is also required. Great advances in nutrient use efficiency have been made in many countries, in particular those where farmers have access to appropriate fertilizers and best management practices through government and private crop advisory services. Increasing sustainable fertilizer use in Sub-Saharan Africa is another key challenge and opportunity for our industry. The average fertilizer application rate in SSA (without South Africa) has been increasing rapidly in recent years, from 6-7 kg/ha in 2008 to 11 kg/ha in 2014, and it is expected to reach 12 kg/ha in 2015. While the trend is positive, there is clearly still a long way to go to reach the 50 kg/ha target set in the Abuja Declaration (Figure 6).

Figure 6: Estimated average fertilizer application rate in SSA (without South Africa)



Source: IFA Fertilizer Facts, 2015

However, reaching out to millions of farmers, in particular, smallholder farmers, remains a tremendous challenge. Infrastructural and logistical constraints, as well as difficulties accessing inputs or markets still keep fertilizers out of reach of many farmers. Moreover, government extension services were dismantled in many developing countries during the structural adjustment of their economies in the 1990's, so in too many regions and countries, there is little to no dissemination of fertilizer best management practices. There are many laudable outreach efforts by some government entities, non governmental and international organizations as well as industry – often working in partnerships and often making good and innovative use of information technology, but much more effort is required for truly scaling such outreach to farmers.

Improved outreach to farmers thus represents a challenge but also a great opportunity. While farmers certainly want to be good environmental stewards of their land, they also want to make a living. Best management practices to minimize nutrient losses to the environment must therefore go hand in hand with efforts to increase agricultural productivity, to increase the likelihood of their uptake by farmers. More precise and balanced plant nutrition results in enhanced nutrient uptake generally translates into greater agricultural productivity and increased income for farmers, while minimizing nutrient losses to the environment, and should therefore appeal to farmers. Where this may not be the case, it may make sense to put into place a scheme to incentivize best management practices. The province of Alberta, Canada, for example, has established an innovative Nitrous Oxide Emissions Reduction Program, "NERP," which allows farmers to earn offsets from foregone nitrous oxide emissions, which can be sold to other players in a carbon offset market.[12]

Whereas government subsidies have certainly enabled access to fertilizers by farmers, they can also have a detrimental environmental impact. One striking example of this is India, where urea (nitrogen fertilizer) is subsidized at much higher rates than phosphate and potash, leading to an over-application of urea vs. the other essential plant nutrients. Whereas an optimal national N-P-K ratio for India should be in the range of 4:2:1, in 2013/14, this ratio had deteriorated to 8.2:3.2:1.[13] As this is an average ratio for India as a whole, some Indian states have even much further deteriorated nutrient ratios, with alarming consequences for soil health, and increasingly also for productivity. With subsidized fertilizers estimated to account for slightly more than 50% of global fertilizer uses, it behooves governments to consider how such schemes can most effectively encourage balanced and efficient plant nutrition.

With global fertilizer demand expected to reach 200 million metric tonnes of nutrients by 2020, concerns about a slowing rate of agricultural productivity growth and an increasing awareness of the need to increase the efficiency of natural resources as well as agricultural inputs, and to reduce the environmental impacts of agriculture, efforts to promote responsible fertilization must remain at the forefront of all players in the fertilizer value chain as well as governments and other stakeholders.

[12] http://www1.agric.gov.ab.ca/Department/deptdocs.nsf/all/cl14145

[13] Data from Indian Ministry of Chemicals and Fertilizers

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To feed a growing, urbanized world population, with changing diets, we have to produce more while reducing the pressure of agriculture on the environment. The practices of fertilization therefore must evolve. In this "Point of view", Charlotte Hebebrand develops the concept of “responsible fertilization”. It requires to increase the use of fertilizers in areas where it is very low, in order to increase productivity and farmers' income, and to improve the efficiency of fertilization through better management of soil and crops, combining organic sources and mineral fertilizers. A more accurate and balanced plant nutrition is essential for a productive and sustainable agriculture.

Charlotte Hebebrand is Director General of the International Fertilizer Industry Association (IFA) since January 2013. Prior to joining IFA, she served as Chief Executive of the Washington DC based International Food & Agricultural Trade Policy Council (IPC) from February 2006 until July 2012. In that capacity, she led the efforts of IPC members - a diverse mix of distinguished international agricultural trade experts from around the world - to promote a more open, equitable and sustainable global food system. She has also worked with the European Commission, serving as Special Advisor on international development, trade, agriculture and food safety issues in its Washington delegation, and with the Brookings Institution's Foreign Policy Division.

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