Nutrient Supply and Management

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Abstract

This paper analyzes the evolution of world fertilizer demand and supply, and it discusses the medium-term outlook. It also addresses some of the main challenges facing the fertilizer industry, such as the need to ensure food security, to reduce its footprint on the environment, to fertilize crops to improve human health, to address the specificity of Sub-Saharan Africa, and to constantly innovate.

Fertilizer demand and supply

Evolution of world fertilizer demand

World fertilizer consumption increased steadily from the beginning of the 1960s till the end of the 1980s, rising from 31.7 million metric tonnes (Mt) of nutrients ($N + P_2O_5 + K_2O$) in 1961/62 to 142.5 Mt in 1989/90. From 1989/90 to 1993/94, consumption fell to 120.3 Mt due to the collapse of fertilizer use in Central Europe and the Former Soviet Union. This fall was partly offset by increases in Asia. From 1993/94, demand firmly rebounded, to reach 168.4 Mt in 2007/08, driven by surging crop prices. In 2008/09, demand was severely hit by the global economic downturn, and dropped by 7.7% to 155.4 Mt, before starting to rebound in 2009/10, to 163.9 Mt (IFA, 2012).

Since the early 1960s, aggregate world fertilizer consumption increased more than five-fold. Nutrient-wise, N fertilizer use rose much faster than P and K fertilizer consumption. Between 1961/62 and 2009/10, N fertilizer consumption increased 8.7 times (from 11.8 to 102.7 Mt N), while P use rose 3.4 times (from 11.0 to 37.5 Mt P_2O_5), and K consumption increased 2.7 times (from 8.8 to 23.7 Mt K_2O). In 2008/09, demand for all three nutrients was affected by the economic crisis, with nitrogen (N) being less impacted (-2.5% from previous year) than phosphate (P, -12%) and potash (K, -21%) (IFA, 2012).

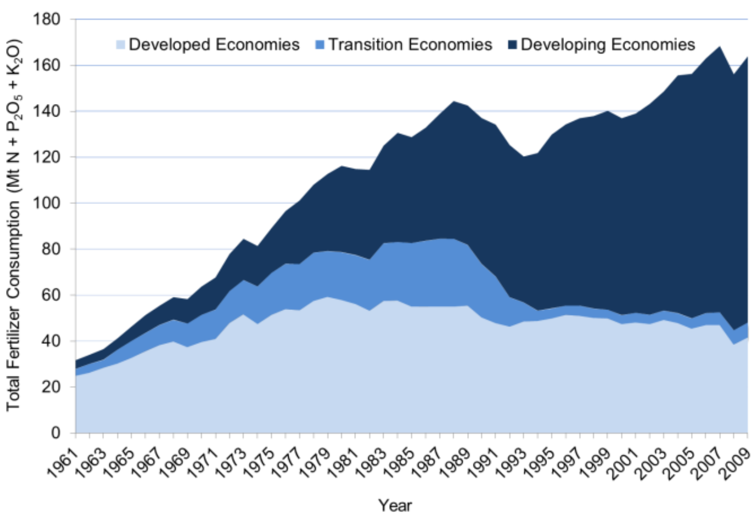

Figure 1. Evolution of total fertilizer consumption (Adapted from IFA, 2012)

At the regional level, between 1961/62 and 2009/10, moderate growth rates have been registered in industrialized countries, which already had a relatively high base for fertilizer use in the early 1960s. Fertilizer use in most industrialized countries peaked in the 1980s, and then started to decline as a result of stringent environmental regulations on the use of nutrients, coupled with increased fertilizer use efficiency arising from better nutrient management practices. Further to the collapse of the Former Soviet Union, demand in countries with economies in transition contracted five times, from 29.5 Mt in 1987 to less than 4 Mt in the mid-1990s; it is progressively recovering since 2004. In contrast, consumption grew very quickly in developing countries, particularly in Asia. China, India and Brazil multiplied their domestic consumption 47, 62 and 39 times, respectively, since the early 1960s. In Sub-Saharan Africa, fertilizer consumption grew in the 1960s and 70s, but then stagnated (Figure 1).

In terms of products, urea, ammonium phosphates and potassium chloride have strongly increased their share of the world market over the past five decades. In 2009/10, urea and ammonium phosphates are estimated to account for 56% of the world N and P fertilizer markets, respectively, and potassium chloride represents 63% of the K fertilizer market (IFA, 2012).

According to the latest data available on fertilizer use by crop, cereals received half of world fertilizer applications in 2007/08, with maize and wheat accounting for 15% each of world uses, rice for 14%, and the other cereals for 5%. Fruits and vegetables is the second largest crop category, contributing to 17% of world fertilizer demand, followed by oil crops, representing 10%. The other crops, including sugar crops, fiber crops, roots and tubers, pastures, etc. receive the balance, i.e. approximately 23% of world fertilizer applications (Heffer, 2009).

In 2010/11, aggregate world consumption is estimated to have fully recovered, to 172.2 Mt, with contrasting situations between nutrients and between regions (Heffer and Prud'homme, 2012). Between 2007/08 and 2010/11, world N and P fertilizer consumption increased by 3.6 and 2.1 Mt, respectively, while world K consumption remained 1.3 Mt below its 2007/08 record. At the regional level, South Asia, driven by very strong demand growth in India, accounted for all the net increase in world consumption during that three-year period. Demand in Eastern Europe and Central Asia resisted the downturn, supported by favourable agricultural policy reforms in Russia. In contrast, demand remained deeply depressed in Western and Central Europe, and it did not fully recover in East Asia and in Latin America.

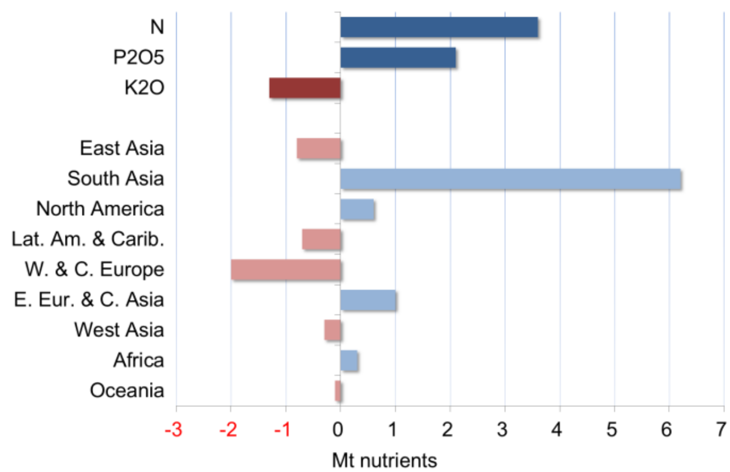

Figure 2. Evolution of fertilizer consumption between 2007/08 and 2010/11 (Adapted from Heffer and Prud'homme, 2012)

Evolution of world fertilizer supply

Over the past five decades, two major events have greatly impacted fertilizer production and trade trends. In the late 1980s and early 1990s, the collapse of the Former Soviet Union led to an 80% drop in regional demand, but also resulted in an important shift in availability of new supply into the international market. In the N sector, Russia and Ukraine became major exporters of ammonia, urea and ammonium nitrate; In the P sector, Russia and Kazakhstan expanded their respective exports of phosphate rock and processed phosphates; In the K sector, Belarus and Russia are nowadays ranked amongst the world's top four exporting countries. The second most significant event has been the emergence of China as the world's largest producer and consumer of urea and processed phosphates. Up to the early 2000s, China was heavily reliant on imports to fulfill its growing annual requirements of N and P fertilizers. Since 2000, the Chinese industry has expanded its capacity in the N, P and K sectors. In 2006, China became self-sufficient in urea and di-ammonium phosphate and emerged as an important exporter because a structural capacity surplus developed in the late 2000s. The shift of China from an importing country to a major exporter has impacted trade flows.

Fertilizer supply was severely hit by the economic downturn in the second half of 2008 and in 2009. Production decreased mostly for P and K fertilizers due to large carry-over stocks in the worldwide distribution pipeline. World nutrient production in 2009 dropped by 8%, to 194 Mt of nutrients, the lowest level since 2003. In the N sector, world ammonia production remained relatively stable, and the urea output expanded moderately due to its expanding share of the global N market. In 2009, production of phosphate rock decreased by 7% and that of potash by 40% (Heffer and Prud'homme, 2010). In 2010, P and K production picked-up; on average, the N and P fertilizer industry operated at close to 95% of effective capacity. A strong rebound was also observed in the K fertilizer sector, with an average operating rate jumping to some 85%, compared to a very low 55% the year before (Heffer and Prud'homme, 2012).

The strength in the growth of fertilizer demand in early 2008, combined with very high operating rates in the fertilizer sector and the prospect of a potential shortage of supply, prompted high interest in future capacity developments from the investment community and exploration companies and led to massive investments for the construction of new capacity. Close to US$40 billion was invested in new capacity between 2008 and 2010 (Heffer and Prud'homme, 2010).

Medium-term outlook for world fertilizer demand and supply

According to the medium-term projections by the Organisation for Economic Co-operation and Development and the Food and Agriculture Organization of the United Nations (OECD/FAO, 2011), agricultural markets are seen to remain relatively tight in the next ten years. Agricultural commodity prices are projected to slightly decline in real terms but they would remain attractive, well above levels observed prior to the 2007/08 food price crisis. Because stocks held by the major exporters are seen to be rebuilding at a low pace, prices are anticipated to stay very volatile over the outlook. This supportive context is expected to stimulate fertilizer demand, but with possible significant year-on-year variations. World demand is projected to reach 192.8 Mt by 2016/17, corresponding to a compound annual growth rate of 2.1% over the base year (average of the three-year period 2009/10-2011/12). Average annual growth is seen stronger for K (3.7%) than for P (2.3%) and N (1.5%) (Table 1).

Table 1: Medium-term forecasts for world fertilizer demand (Mt nutrients) (Heffer and Prud'homme, 2012)

	N	P_2O_5	K_2O	Total
Average 2009/10 to 2011/12	104.7	39.7	26.3	170.7
2016/17	114.7	45.4	32.7	192.8
Average annual growth rate	*+1.5%*	*+2.3%*	*+3.7%*	*+2.1%*

The highest growth rates are projected in regions with recovering agriculture such as Eastern Europe and Central Asia (+3.8% per annum) and Oceania (+3.1% p.a.) and in regions with a large potential to increase agricultural production such as Latin America (+4.1% p.a.) and Africa (+3.5% p.a.). Compared to historical trends, demand growth is seen to be decelerating significantly in Asia because some of the largest consuming countries are approaching maturity: +2.5% p.a. for South Asia, +1.9% p.a. for West Asia, and +1.7% p.a. for East Asia. Demand in North America and in Western and Central Europe would expand modestly, by 0.9 and 0.8% p.a., respectively. In volume terms, three regions would account for the bulk of the increase in the next five years: East Asia (30% of the total), South Asia (24%) and Latin America (21%) (Figure 3). The three regions together would account for 68, 77 and 82% of the projected increase in world N, P and K fertilizer demand, respectively.

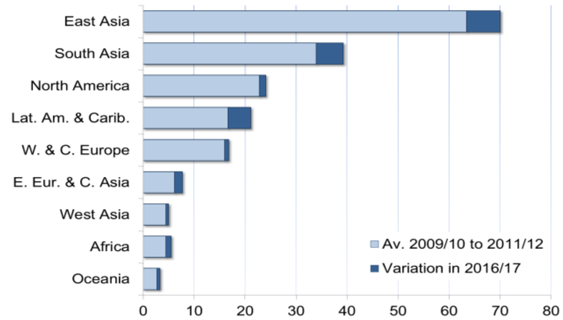

Figure 3: Medium-term outlook for total regional fertilizer demand (Mt nutrients) (Heffer and Prud'homme, 2012)

In response to tight market conditions and prospects for rising demand, close to 250 new fertilizer units are projected to come on stream between 2011 and 2016, in addition to 30-35 projects related to phosphate rock mining. These developments would equate to a total investment of US$90 billion (Heffer and Prud'homme, 2012).

Global ammonia capacity is projected to increase by 17% between 2011 and 2016, to 230 Mt NH_3. The global supply and demand balance shows tight market conditions in 2012, moving into growing surpluses between 2013 and 2016. Regarding urea, 60 new production units are planned to come on stream between 2011 and 2016, of which 18 would be located in China. Massive capacity additions are also planned in India in 2015/16. World urea capacity would increase by 24%, to 226 Mt. The world urea market would move from relatively tight to balanced conditions in 2012, to growing potential surpluses by 2016 (Heffer and Prud'homme, 2012).

Global P rock supply is forecast at 256 Mt in 2016, up 20% compared to 2011. The largest increases would be in Africa and in East Asia. World phosphoric acid capacity is forecast to grow by 4% per annum compared with 2011, to 61.3 Mt P_2O_5 in 2016. The global phosphoric acid supply/demand balance shows a moderate surplus in 2012 and 2013, growing gradually by 2016. If a few projects were to be delayed, market conditions would remain tight until 2016. Global capacity of the main processed P fertilizers would reach 47.6 Mt P_2O_5 in 2016, with large capacity increases in China, Morocco and Brazil (Heffer and Prud'homme, 2012).

Between 2012 and 2016, 40 capacity expansion projects are expected to come on stream in the K sector. However, most of the announced projects have experienced slippages of 6 to 18 months. Global capacity in 2016 is forecast at 61.4 Mt K_2O. The largest increases would occur in North America and in Eastern Europe. The global K supply/demand balance shows a reduced potential surplus in 2011, growing moderately in 2012 and 2013. A potential imbalance may emerge by 2016, assuming that all planned projects are completed on schedule (Heffer and Prud'homme, 2012).

It its Current World Fertilizer Trends and Outlook to 2015, FAO (2011) projects similar trends for world fertilizer demand, supply and supply/demand balances.

Fertilizer demand and supply in Oceania

Regional fertilizer consumption increased from 1.0 to 3.5 Mt nutrients between 1961 and 2004. N demand accounted for the bulk of the increase since P and K consumption were already high in the 1960s. The succession of severe droughts, unfavourable terms of trade, and of the world economic downturn led to a continuous decline of regional consumption between 2004 and 2009. In 2009, consumption dropped to a low 2.4 Mt, with P and K demand being most affected (IFA, 2012). With a return to more favourable weather and economic conditions, regional demand is projected to rebound and reach 3.3 Mt by 2016 (Heffer and Prud'homme, 2012).

Regional N fertilizer production covers approximately 40% of regional demand. New N fertilizer units are anticipated to become operational in Australia in the next five years. The region would continue to be deficit in N but the deficit would progressively diminish. Regional P fertilizer production has been progressively declining over the past ten years, and it meets approximately 70% of regional demand. K fertilizer consumption is entirely met by imports. Regional supply/demand balances for P and K will continue to remain negative in the next five years (FAO, 2011). With deficits for all three nutrients, Oceania will remain dependent on the evolution of the world market.

Challenges to the fertilizer industry in relation to fertilizer use

Food security and meeting demand

The world's population increased from 3.1 billion in 1961 to 7 billion in 2011 as a result, among others, of impressive progress achieved by the agricultural sector in general, and the fertilizer industry in particular. For instance, Erisman *et al.* (2008) estimate that without N fertilizer inputs derived from the Haber-Bosch process, the biosphere would produce 48% less food. There are however still about one billion leaving hungry, especially in Sub-Saharan Africa and in South Asia. With world population anticipated to reach 9.1 billion by 2050, FAO projects that feeding that many people would require raising overall food production by some 70% between 2005/07 and 2050 (FAO, 2009) unless dramatic changes in agricultural consumption patterns occur. FAO anticipates that 90% of the growth in crop production globally would come from higher yields and greater cropping intensity, with the remainder coming from land expansion. Feeding an additional two billion people by 2050, improving the calorie intake of the one billion hungry, meeting the increasing demand for livestock products, and supplying raw materials to the fast-developing bioenergy industry will require greater (and more efficient) use of manufactured fertilizers and other nutrient sources. Through heavy investments in additional production capacity, the fertilizer industry contributes to the fight against hunger.

Reducing our footprint on the environment

Preventing land use changes

The world arable land and permanent crop area was estimated at 1,533 million hectares (Mha) in 2009 (FAO, 2012). Despite the anticipated increase in yield and cropping intensity, the world arable land area is projected to expand by some 70 Mha by 2050, with an expansion of about 120 Mha in developing countries partly offset by a decline of some 50 Mha in developed countries (FAO, 2009). Land use changes have strong negative impacts on the environment especially through the release of huge amounts of carbon dioxide to the atmosphere, and through the induced loss of biological diversity. Increasing agricultural productivity offers opportunities to prevent land use changes.

Burney *et al.* (2010) assess that, in order to achieve the same crop output in 2005 with 1961 yields, 1,514 Mha more land area would have had to be converted to cropping, i.e. a doubling of the current area. Analysis of the evolution of greenhouse gas emissions from agriculture during the same period confirms the positive role of enhanced agricultural productivity in reducing total greenhouse gas emissions. Increased emissions from rising fertilizer production and use were largely offset by lower emissions associated with the conversion of forests, savannahs, wetlands and other natural habitats to cropland. Burney *et al.* (2010) estimate that the net effect of higher yields avoided emissions of up to 590 gigatonnes (Gt) CO_2-equivalent between 1961 and 2005.

When total greenhouse gas emissions related to crop production are considered, the overall carbon footprint per tonne of agricultural produce is lowest when N fertilizer application rates are close to the economic optimum. To achieve the same yield, agronomic production intensities below the economic optimum require more land and thereby increase total greenhouse gas emissions. In highly "extensive" systems, where nutrient application rates are low, cropland expansion results in surging greenhouse gas emissions per unit of crop output (Figure 4).

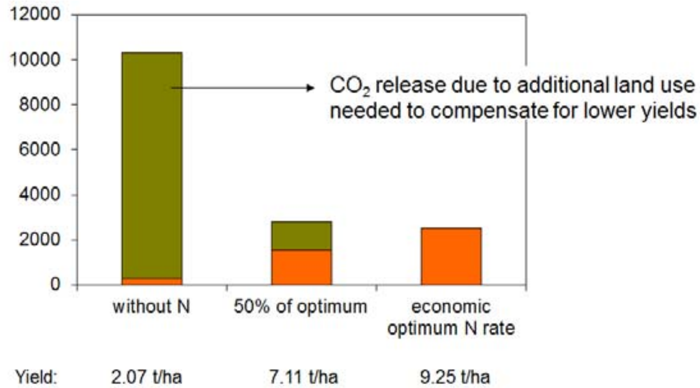

Figure 4: Greenhouse gas emissions (kg CO_2-eq) for producing 9.25 tonnes of winter wheat in the United Kingdom under three different N fertilization regimes (Adapted from Brentrup and Pallière, 2008) Based on the Broadbalk experiment at Rothamsted (average 1996-2000)

Improving nutrient use efficiency

Optimizing nutrient use efficiency is an imperative from agronomic, economic and environmental perspectives. From an environmental point of view, it is particularly relevant for N and P sources, both organic and inorganic, because N and P losses can have detrimental impacts on water and air quality and on biodiversity.

Cassman *et al.* (2002) and Balasubramanian *et al.* (2004) estimated that, under farm conditions, 20 to 50% of the N applied in fertilizer was recovered in the crop during the year of application in the major cereal cropping systems. By contrast, in small well-managed research trials, recovery efficiency levels of 60 to 80% are common (Balasubramanian *et al.*, 2004). This difference between farm measurements and research plots indicates that there is a good opportunity for increasing on-farm N use efficiency by improving farm management. Significant improvements in on-farm N use efficiency are observed in most developed countries. For instance, since the 1980s, maize grain yields in the United States have been increasing steadily, whereas fertilizer N use per unit area has remained almost stable (Snyder, 2009). Similar gains in N use efficiency have been recorded for cereals and oilseeds in France, where grain production increased by 20-30% between 1990 and 2009, while fertilizer N use declined by 10-20% over the same period (UNIFA, 2009a). In contrast, N use efficiency in cereal systems is still declining (or plateauing in the best case scenario) in most developing countries, but the trend could change soon in some of them, especially in China.

As far as P use efficiency is concerned, losses to the environment occur mostly through soil and particulate matter erosion. The problem is mostly limited to areas with slopping land, and with concentrated livestock farming. The efficiency of fertilizer P use in the year of application is low; however, 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).

Recycling nutrients

In many countries, there is an increasing trend to recycle organic nutrient sources (livestock manure, crop residues, sewage sludge, etc.). For instance, in France, over the past 20 years, the contribution of animal excreta to soil P applications has remained fairly stable, around 0.7 Mt P_2O_5/year, while P inputs from manufactured fertilizers more than halved, from 1.5 to 0.6 Mt P_2O_5. In 1988/89, P from manufactured fertilizers accounted for two-thirds of total P applications to agricultural soils in France. This share declined to 45% in 2007/08 (UNIFA, 2009b). A similar trend is observed in several Western European countries, as well as for K nutrient sources. The percentage of manure recycled in the rest of the world, especially in developing countries, remains relatively low due to competing uses (e.g. source of energy, construction material) and lack of incentives.

In the long term, nutrient flows associated with manure recycling are seen to be rising significantly as a result of surging livestock production and a progressive increase in percentage manure recycled. In the longer term, organic nutrient sources may not only be applied directly to agricultural land; they may also be used as raw material by the fertilizer industry, provided there are economic incentives for doing so.

Fertilizing crops to improve human health

Traditionally, fertilizers have been used to increase crop yield. Their management has been progressively improved to optimize their economic return, while minimizing the negative impacts on the environment. More recently, there is increasing attention to another dimension: managing fertilizers in such a way that they also contribute to healthy and productive lives for all. It does not require only enough calories, but also sufficient intake of all essential nutrients. There are a number of success stories, such as the use of zinc fertilization in Central Anatolia in Turkey, and the supplementation of fertilizers with selenium in Finland. These initiatives have offered effective solutions to major human health problems. They should be implemented in a larger number of countries where similar deficiencies in soils, crops and humans are widespread. Fertilization practices can also impact the composition of food products. Enhancing the concentration in health-beneficial compounds could be considered as a fertilization objective as well. For instance, K fertilization can enhance tomato's lycopene concentration and the isoflavone content of soybean seed. The International Plant Nutrition Institute (IPNI) and the International Fertilizer Industry Association (IFA) have led an extensive scientific review of fertilizer management practices that can improve human health (IPNI/IFA, 2012).

Sub-Saharan Africa

Sub-Saharan Africa (without the Republic of South Africa) is the region of the world with the lowest fertilizer application rates. African farmers apply on average less than 10 kg of nutrients per hectare (ha) to their soils, most of it going to cash crops and very little to staple food crops. Fertilizer applications are largely offset by the quantity of nutrients that are removed from the soil annually with the harvested product, leading to massive soil nutrient mining. Henao and Baanante (2006) estimate that more than 40% of Africa's 220 Mha of farmland are losing at least 30 kg of nutrients per ha yearly, and that soil nutrients mining in Africa is worth US$ 4 billion annually. Feeding the fast-rising African population without massive food imports and without triggering desertification cannot be achieved without replenishing African soils' nutrient pools. In this connection, on the occasion of the 2006 Africa Fertilizer Summit, African leaders adopted the Abuja Declaration on Fertilizer for an African Green Revolution, which calls for increasing fertilizer use in Sub-Saharan Africa from an average of 8 kg/ha to 50 kg/ha by 2015. Fertilizer demand growth in Africa is gaining momentum (Heffer and Prud'homme, 2012) but the target of 50 kg/ha is unlikely to be met by 2015. The magnitude of the challenge requires the involvement of all stakeholders. The fertilizer industry works with multiple partners to identify and implement innovative approaches to improve nutrient supply and use in the region.

Innovation

<u>*Special products*</u>

Nutrient use efficiency can be improved either through better management of existing nutrient sources, or through development of new fertilizer products. The fertilizer industry invests in research and development of products with enhanced properties, such as slow- and controlled-release of fertilizers (e.g. coated with polymers), fertilizers stabilized with urease or nitrification inhibitors, micronutrients in forms that remain plant-available (e.g. chelated nutrients), and fertilizer products adapted to application techniques such as fertigation or foliar fertilization. These products are mostly used in the fruit, vegetable, ornamental and turf sectors as their utilization in mainstream agriculture is constrained by economic considerations. However, 'special products' should slowly increase their market share as new products with a lower price differential are developed. In 2010, in the objective of creating the next generation of fertilizers and production technologies, IFDC launched a global research initiative called 'Virtual Fertilizer Research Center (VFRC)'.

<u>*Best management practices*</u>

In order to improve nutrient use efficiency, the fertilizer industry is developing fertilizer best management practices (FBMPs) in partnership with research and development organizations. In addition to enhancing nutrient use efficiency, FBMPS are expected to increase productivity and profitability and protect the environment, thus meeting the economic, social and environmental goals of sustainable development. In order to facilitate development of site- and crop-specific FBMPs based on sound science, IFA and its members agreed on a "global framework". Under the framework, FBMPs can be summarized as the application of the right nutrient source/product at the right rate, right time and right place (4R Nutrient Stewardship), using common scientific principles (Bruulsema *et al.*, 2009; IFA, 2009). Locally-adapted FBMPs are anticipated to make it possible to partly fill the gap between current relatively low N use efficiency observed in farmers' fields and the results achieved in well-managed research plots. On-farm N use efficiency and effectiveness can be improved through better management of N sources, rates, timing and placement. A goal of improving N use efficiency by 25% from current levels is considered achievable in the United States and may be within reach of many developing countries (Snyder, 2009).

Knowledge transfer

Because about two-thirds of world fertilizer consumption takes place in developing countries and because proper fertilizer management is knowledge-intensive, transferring knowledge about FBMPs to hundreds of millions of small-scale developing-country farmers is urgent. Without substantial resource investments in last-mile delivery, efforts engaged in developing FBMPs are unlikely to dramatically influence fertilizer management practices in developing countries. The challenge is huge and requires multi-stakeholder partnerships. An international workshop on effective last-mile delivery, organized by IFA in 2010, highlighted the main challenges and opportunities in that domain (IFA, 2010). Solutions include, among others, (i) better trained 'crop advisors' and agri-input dealers, possibly through certification programs, (ii) development of common knowledge platforms to ensure that farmers receive consistent messages, and (iii) use of mobile phone technology so that farmers can receive customized, real-time, crop- and site-specific recommendations.

Conclusion

Meeting the food, feed, fiber and fuel requirements of a fast-rising and wealthier world population without depleting soil nutrient reserves will require greater use of fertilizers. In the meantime, in order to mitigate the impact on the environment, fertilizers will have to be used more efficiently, and greater recycling of organic nutrient sources will be needed. Challenges are multiple. In regions with a history of soil nutrient mining, it is urgent to improve access to fertilizer and profitability of fertilizer use. In contrast, in regions where fertilizer applications are far from optimal, it is crucial to develop site- and crop-specific FBMPs, and to transfer relative knowledge to the farmers. The fertilizer industry has a key role to play in this respect, and IFA can serve as a platform for coordinating industry's efforts. However, meaningful impacts cannot be achieved without partnerships involving multiple stakeholders sharing common goals.

References

Balasubramanian VT, Alves M, Aulakh M, Bekunda Z, Cai L, Drinkwater D, Mugendi C, van Kessel C and Oenema O (2004). Crop, environmental, and management factors affecting nitrogen use efficiency. *In*: A.R. Mosier, J.K. Syers and J. Freney (Eds.), Agriculture and the Nitrogen Cycle, SCOPE 65, pp. 19-33. Island Press, Washington, DC, USA.

Brentrup F and C Pallière (2008). GHG Emissions and Energy Efficiency in European Nitrogen Fertiliser Production and Use. Proceedings 639, International Fertiliser Society, York, UK.

Bruulsema T, Lemunyon J and Herz B (2009). Know your fertilizer rights. Crops and Soils 42(2):13-18.

Burney JA, Davis SJ and Lobell DB (2010). Greenhouse gas mitigation by agricultural intensification. Proceedings of the National Academies of Science 107(26):12052-12057.

Cassman KG, Dobermann A and Waters DT (2002). Agroecosystems, nitrogen use efficiency, and nitrogen management. Ambio 31(2), 132-140.

Erisman JW,. Sutton MA, Galloway J, Klimont Z and Winiwarter W (2008). How a century of ammonia synthesis changed the world. Nature Geoscience, Vol 1, October 2008, pp. 636-639.

FAO (2009). How to Feed the World in 2050. Food and Agriculture Organization of the United Nations, Rome, Italy.

FAO (2011). Current World Fertilizer Trends and Outlook to 2015. Food and Agriculture Organization of the United Nations (FAO), Rome, Italy.

FAO (2012). FAOSTAT (http://faostat.fao.org). Last visited on 27 July 2012.

Heffer P (2009). Assessment of Fertilizer Use by Crop at the Global Level, 2006/07-2007/08. International Fertilizer Industry Association (IFA), Paris, France.

Heffer P and Prud’homme M (2010). Fertilizer Outlook 2010–2014. International Fertilizer Industry Association (IFA), Paris, France.

Heffer P and Prud’homme M (2012). Fertilizer Outlook 2012–2016. International Fertilizer Industry Association (IFA), Paris, France.

Henao J. and Baanante C (2006). Agricultural Production and Soil Nutrient Mining in Africa: Implications for Resource Conservation and Policy Development. IFDC, Muscle Shoals, Alabama, USA.

IFA (2009). The Global “4R” Nutrient Stewardship Framework: Developing Fertilizer Best Management Practices for Delivering Economic, Social and Environmental benefits. International Fertilizer Industry Association, Paris, France.

IFA (2010). Proceedings of the IFA International Workshop on Effective Last-Mile Delivery, 10-12 February 2010, New Delhi, India. International Fertilizer Industry Association (IFA), Paris, France.

IFA (2012). IFADATA (www.fertilizer.org/ifa/ifadata/search). Last visited on 26 July 2012.

IPNI/IFA (2012). Fertilizing Crops to Improve Human Health: a Scientific Review. T.W. Bruulsema, P. Heffer, R.M. Welch, I. Cakmak and K. Moran (Eds). International Plant Nutrition Institute (IPNI), Norcross, USA and International Fertilizer Industry Associaition (IFA), Paris, France.

OECD/FAO (2011). OECD-FAO Agricultural Outlook 2011-2020. Organisation for Economic Co-operation and Development (OECD), Paris, France and Food and Agriculture Organization of the United Nations (FAO), Rome, Italy.

Snyder CS (2009). Nutrient Use Efficiency: Global Challenges, Trends, and the Future. In: J. Espinosa and F. García (Eds), Proceedings of the Symposium “Nutrient Use Efficiency” presented by IPNI at the XVIII Latin American Congress of Soil Science, 16-20 November 2009, San José, Costa Rica. International Plant Nutrition Institute (IPNI), Norcross, Georgia, USA.

Syers JK, Johnston AE and Curtin D (2008). Efficiency of Soil and Fertilizer Phosphorus: Reconciling Changing Concepts of Soil Phosphorus Behaviour with Agronomic Information (FAO Fertilizer and Plant Nutrition Bulletin 18). Food and Agriculture Organization of the United Nations (FAO), Rome, Italy.

UNIFA (2009a). Rapport d’activité 2008-2009. Union des Industries de la Fertilisation (UNIFA), Paris, France. [in French]

UNIFA (2009b). Evolution de la fertilisation en France et bilans régionaux depuis vingt ans. Union des Industries de la Fertilisation (UNIFA), Paris, France. [in French]