Fertility and Fertiliser Research and Development

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So far, world food supply has managed to stay ahead of rising population due to increasing productivity and a modest expansion of cultivated area. However, finite resource reserves, the increasing cost of energy and the increasing environmental cost of opening new land pose new challenges. Africa is a special case where increased food production has come mainly from expansion of farmland, while low fertiliser use and extensive soil mining have retarded productivity.

Recent limited public–private initiatives show promise of reversing this low productivity. Global food security depends on a focused effort to increase production of food crops; in this effort fertiliser must play an important part. Government policy must be supportive of the provision of purchasing power support for smallholder farmers using such instruments as vouchers.

The production agronomic performance of current fertiliser products is quite inefficient and must be improved. New products using new resources must be developed. Much of the nutrient content of current fertiliser products is wasted at high cost to the environment because only 30–40% is absorbed by crops. This can be improved by better application techniques and improved products, and by improving crop attributes. There is also ample scope for increased use of nutrient-bearing waste products. Nanotechnology and biotechnology open new opportunities for collaborative research between the public and private sectors. For the world to be provided the next generation of fertilisers, the private sector must play a significant role — in partnership with public institutions.

DR AMIT H ROY, IFDC President and CEO since 1992, came to IFDC as a chemical engineer in 1978. Under his leadership, IFDC — an International Center Creating Food Security and Agricultural Sustainability — expanded its mission to address not only food security but also trade, equity and the environment. Leading IFDC from fertiliser to agribusiness and economic development, he instituted research and development of new or modified fertiliser materials and processes using indigenous sources, especially phosphate rock. Roy encouraged the development of fertiliser industries in many developing countries and provided needed technical assistance. He played a key role in organising the landmark Africa Fertilizer Summit held in Abuja, Nigeria, in June 2006.

Introduction

The world has so far managed to avoid the Malthusian catastrophe through great leaps in agricultural yields from agricultural extension (bringing new land into cultivation) and innovations in fertiliser, pesticides and crop breeding. However, whether the food supply will be able to keep pace with exponential increases in world population remains a pertinent question. According to the World Watch Institute (2009), the world population stood at 6.8 billion in early 2009 and could reach 9.4 billion by 2050. More than 95% of the population growth is occurring in Africa and Asia, which already account for three-fourths of the global population (Fig. 1).

There is certainly a finite limit to the availability of arable land. Even though there remains land that could be converted to agricultural production, particularly in Africa, the environmental cost of doing so is increasing. These costs include the ensuing release of stored carbon into the atmosphere, as well as the destruction of animal habitat and biodiversity. Over the last half-century, Africa and Asia have differed markedly from one another in their method of increasing food production. As can be seen in Figure 2, productivity (as measured by grain yield) has lagged in Africa, while in Asia and the rest of the world it has been steadily increasing. Figure 3, which compares Sub-Saharan Africa (SSA) with South Asia, shows clearly that Africa has relied primarily on the opening of new land for increased production. In Asia, the main challenge remains how to maintain steady yield growth in the face of diminishing marginal returns to agricultural inputs. In Africa, the main challenge is how to reduce the delivered cost of plant nutrients so that farm intensification becomes economically preferable to opening new land.

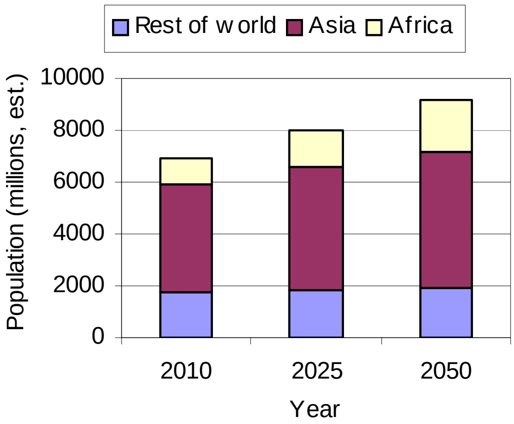

Figure 1. Population growth forecasts (Source: United Nations 2008)

Rationale

This paper argues that fertiliser research and development can make a major contribution in addressing the food security challenges faced by both Asia and Africa. Public-sector fertiliser research and development, particularly in the United States during a three decade period starting in the early 1940s, was the primary contributor to the fertiliser production processes and products that are prevalent today. That era in fertiliser research and development has been a prime driver of growth in global agricultural productivity. The fertiliser technology research was supported and influenced by agronomic and economic research programs, including the programs of the international agricultural research centres and national agricultural research institutions. Today there is

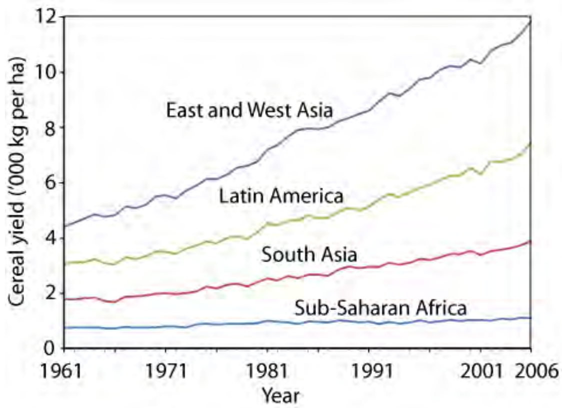

Figure 2. Cereal yields in different developing regions from 1961 to 2007 (Source: Derived from FAO data)

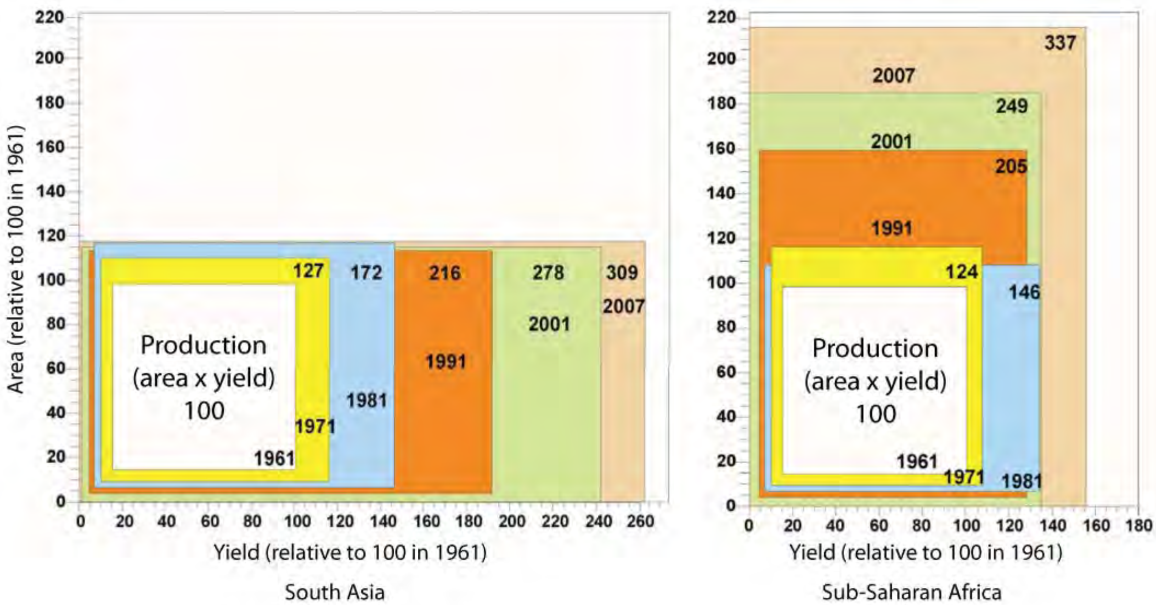

Figure 3. Relative growth of cereal yield per unit area and area in cereal production in South Asia and Sub-Saharan Africa between 1961 and 2007 (1961 = 100 for yield, area and production) (Source: IFDC)

growing emphasis on the need for the private sector to take on a more prominent role. The question is, can private-sector research and development (R&D) on soil fertility and fertiliser products reach the poor? What role can the private sector play in research to address the needs of poor farmers?

The matter is complex for a number of reasons. First, the private sector must have the incentive to do such research. Thus far, the incentive is lacking because poor farmers do not constitute a viable market justifying private-sector investment in R&D targeted at them. Second, the private sector must have the capacity to do such research. This capacity requires funds, staff with knowledge of the issues at hand and physical infrastructure (facilities, equipment). Currently, the private sector in developed countries is doing little or no research on soil fertility and fertiliser products that can be marketed to poor farmers. And, even if the products of private-sector research were targeted to the needs of poor farmers, there remains the challenge of the poor farmer being able to afford them at market prices. In general, private firms in the fertiliser industry focus their research programs on achieving advances that will yield the greatest economic return to the firm. Improving process technology (to achieve production, economic and performance efficiencies) and product technologies that provide the firm some comparative advantage in terms of improved product performance (in their target market or allowing for improved economic use of an asset) are two priority concerns that significantly influence private-sector research efforts. In addition, any research the private sector does is proprietary research or market research owned exclusively by the firm paying for it.

The development and adoption of fertiliser products and soil fertility management technologies for poor farmers hinges on the capacity of the actors of the so-called research triangle (the private sector, the public sector and international agricultural research centres) to productively interact. It will be increasingly important for all of these actors to collaborate to develop technologies that are adapted to the biophysical constraints and socio-economic characteristics of smallholder farmers. Two fundamental questions are relevant to the success of a research triangle to improve agricultural productivity in developing countries:

- What are the key soil fertility issues that smallholder farmers face?
- How can research on soil fertility and fertilisers address these issues?

The objective of this paper is to provide an overview of the soil fertility issues faced by poor farmers in Asia and Africa, share best practices on public–private sector collaboration for technology and market development, and put forward some answers as to how research can help mitigate some of these issues.

Soil fertility issues for poor farmers

The long-term decline in ecosystem function and land productivity, or land degradation, is gaining in severity and extent for poor farmers (Fig. 4). According to recent studies by the Food and Agriculture Organization of the United Nations (FAO), an estimated 1.5 billion people, or a quarter of the world's population, depend directly on land that is being degraded (FAO 2009). In Africa, land degradation affects an estimated 485 million people, resulting in losses of about $42 billion in income and 6 million hectares (ha) of productive land each year (Bationo *et al.* 2006).

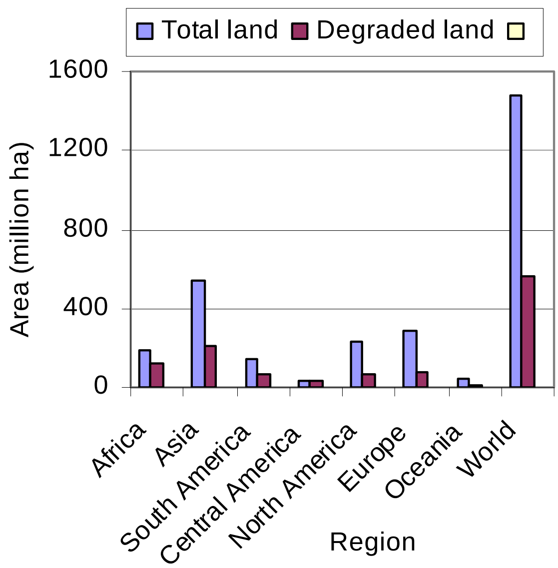

Figure 4. Global estimates of agricultural land degradation by region (Adapted from Bationo *et al.* 2006)

The soils in Sub-Saharan Africa (SSA) are naturally fragile (parent material, climate). Sixteen percent of all soils in Africa have low nutrient reserves, while in Asia the equivalent figure is only 4%. Henao and Banaante (2006) have shown that the number of African countries with average nutrient depletion rates exceeding 60 kg ha^{-1} y^{-1} increased from 12 in 1995–1997 to 19 in 2002–2004. Table 1 presents the main soil fertility constraints faced by poor farmers in Africa.

Table 1. Soil fertility constraints in Africa (Adapted from Bationo *et al.* 2006)

Soil type	Countries	Soil fertility constraints
Ferrasols	Angola, Burundi, Cameroon, Central African Republic, DRC, Rwanda, South Sudan, Uganda and Zambia	Low retention capacity Deficiencies in Ca, Mg and K
Acrisols	Benin, Southern Cameroon, Côte d'Ivoire, Southern Ghana, Nigeria, Tanzania and Togo	Low mineral reserves Deficiencies in boron and Mg Leaching
Nitrosols	Eastern DRC, Ethiopia, Kenya and Tanzania	Mg toxicity
Lixisols	Parts of West and Southeast Africa, Madagascar	Low capacity to store nutrients Deplete quickly under farming
Arenosols	Angola, Botswana, Chad, Southwest DRC, Central Mali, Mauritania, Southern Niger, Senegal and Sudan	Low water-holding capacity Low nutrient retention capacity Deficiencies in Zn, Mg, Fe, Cu, S, K
Vertisols	Parts of Ethiopia, Sudan and Tanzania	Flooding and erosion
Gleysols and Fluvisols	Equatorial Africa	Acidity

Land degradation has been attributed to many factors. Population pressure has been a main driver of land clearing for cultivation and consequently deforestation. Shifting cultivation without fallows or proper soil management and cultivating marginal lands causes nutrient mining. Overgrazing of livestock and the ensuing reduction in land cover leaves the soil vulnerable to wind and water erosion. Climate change, particularly through rising sea levels and seawater inundation, has lead to increased salinity in soils.

To mitigate the impact of land degradation on soil nutrients, farmers apply fertilisers. As seen in Figure 5, Asia has the highest rate of fertiliser use, whereas SSA has the lowest. This suggests significantly different implications for the two regions. In Asia, the urgent need for increased crop productivity cannot be met by simply applying more fertiliser. Rather, the production functions of major crops must be shifted by technological advancement. In Africa, where fertiliser application is so low, the case could be made that no new technology is needed until the genetic potential of existing crops is being more nearly realised through the increased and judicial use of fertiliser and other inputs.

The problem, however, is that fertiliser is relatively more expensive in Africa and often inaccessible to the millions of small farmers. The average retail price of urea fertilisers in coastal African countries is 50% higher than in an Asian country. In Thailand the average retail price of urea fertilisers is $282/metric tonne compared with $453/mt in coastal African countries (Ghana, Mozambique and Tanzania) and $515 in land-locked African countries (Malawi, Mali and Uganda) (Chemonics and IFDC 2007) (Fig. 6). Furthermore, the inefficient use of fertiliser products by poor farmers also constitutes a serious problem. For instance, smallholders' current practices of hand-broadcasting urea in rice fields leads to less than 30% of the applied N being used by the plant.

Best practice in public–private sector collaboration for fertiliser technology and market development

One 'pocket of success' in public–private-sector partnerships that target fertiliser technology and soil fertility management for smallholder farmers is the case of urea supergranule (USG) technology and fertiliser deep placement (FDP) in Bangladesh. Like most smallholder farmers in Asia and Africa, Bangladesh farmers are resource-poor and risk-adverse. Technology introduction in such an environment often has a slow return to invested capital, a deterrent to major private-sector investment.

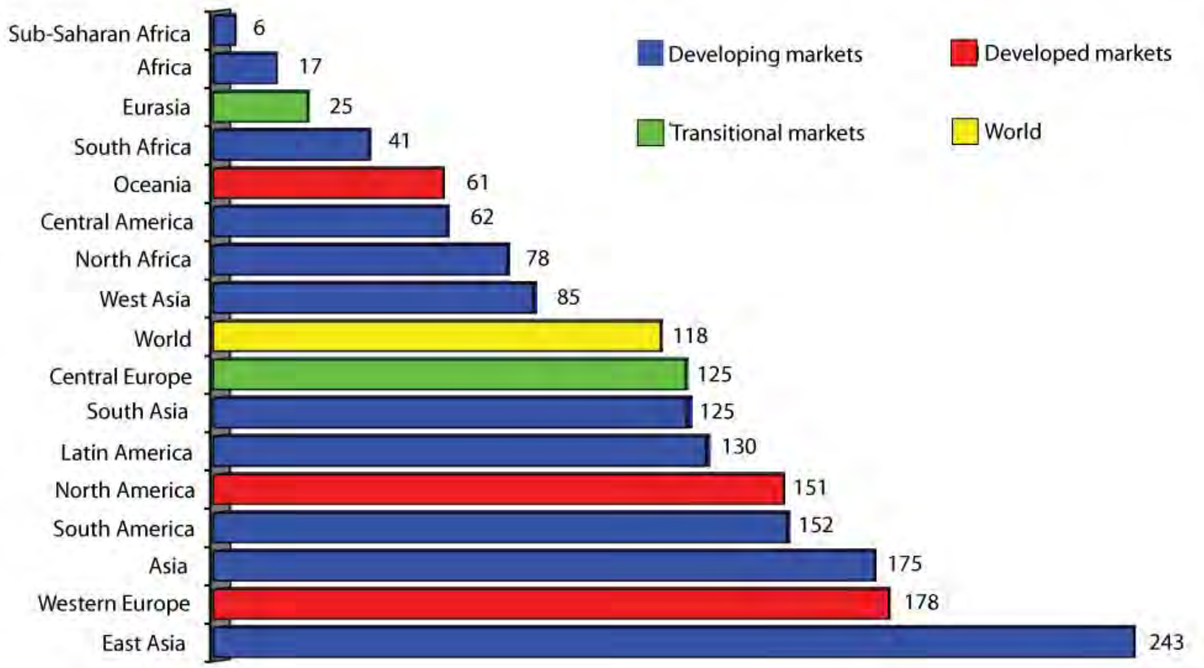

Figure 5. Average rates of NPK use in various markets (kilograms per hectare), 2007–2008 (Source: FAO data)

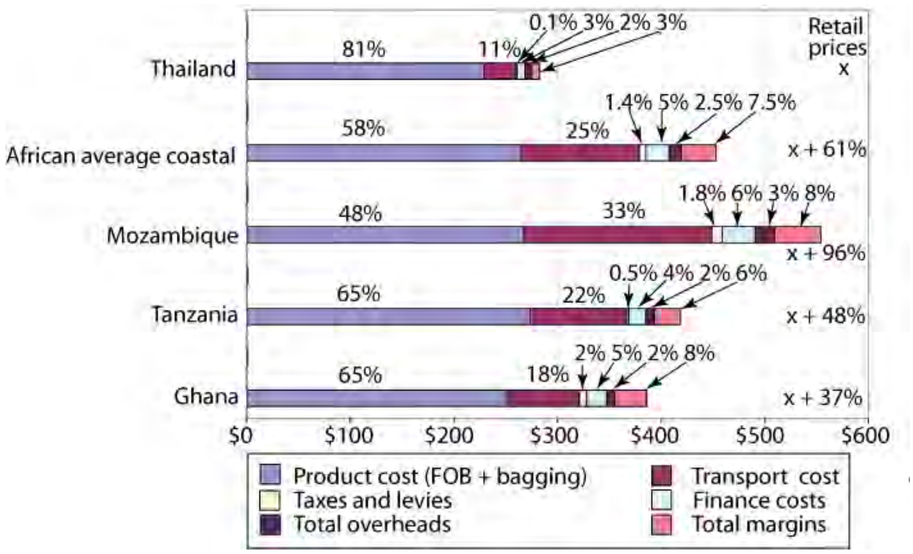

Figure 6. Fertiliser cost chain comparison of African coastal countries with Thailand (Source: Chemonics and IFDC 2007)

Banding

Banding a fertiliser close to the seed row (Fig. 7) has been shown to improve the uptake of nutrients contained in that fertiliser (Ohio State University 2009). This technique stimulates early growth of seedlings, increases the availability of phosphates to crops grown in acidic soils where fixation of phosphates is a problem and promotes early root development. Under rainfed conditions, where extensive and deeper root development conditions prevail, banding will enable plants to draw moisture from lower depths of soil and better withstand drought.

Fertigation

Fertigation (Fig. 8) saves money by combining the tasks of applying water and fertiliser and allows growers to fertilise crops throughout the growing season rather than stop when the plants become too unwieldy to allow mechanised applications with conventional machinery. Many crops can thrive with less fertiliser when it is applied through fertigation (United States Department of Agriculture 2004).

Figure 7. Ron Smith banding using NPK Granules in IFDC's greenhouse

Integrated soil fertility management

This involves the integrated use of inorganic fertilisers and soil amendments, such as organic matter, lime and phosphate rock. Such soil amendments interact with mineral fertilisers to improve the soil quality, including organic matter status, tilth, water-retention capacity, pH and available P. ISFM does not completely rely on organic manure and amendments to provide all plant nutrient needs as is the case with organic farming. The ISFM approach improves the release and availability of nutrients from organic sources by modifying the C:N:P ratio and increasing the efficiency of applied mineral fertilisers. This is done through increased nutrient and water retention, increased microbial activity and increased root development. Soil compaction and poor root development are among the major causes for poor nutrient- and water-use efficiency. ISFM thus makes the soil hospitable for better crop growth.

Figure 8. Fertigation — IFDC/Agrium field trials in Ghana

During the past two decades, IFDC scientists have worked with the public sector (e.g., Bangladesh Ministry of Agriculture and the Bangladesh Rice Research Institute) and the private sector (e.g., small private entrepreneurs) to develop FDP technology based upon USG. The technology, initially targeting rice farmers, involved:

- applied research to modify conventional urea fertiliser so that it was readily adapted to point placement by hand in flooded rice
- agronomic research to determine the agronomic efficiency of the USG and FDP
- economic research to assess the economic performance of the FDP technology and USG.

The benefits of the technology are significant: improved yields of up to 30% while using 30–35% less urea than conventional urea broadcast methods. In addition, the environmental consequences of the technology are positive, with less urea applied and lower losses to the atmosphere and ground water.

The public–private sector partnership that contributed to FDP and USG development and introduction is based on supply by small microenterprises. IFDC designed a small-scale briquetter to compact conventional urea fertiliser particles into briquettes of up to 2.7 g by weight. And private, locally owned metal fabrication shops improved upon the design and started to fabricate and market the machines to local entrepreneurs at prices equivalent to only $1500 per machine. In the past three months, at least one major urea factory in Bangladesh has started to assess the feasibility of a factory modification to mass produce the supergranules. The Bangladesh government has fully embraced the technology as a centerpiece in its agriculture strategy.

Another best practice in public–private partnerships that fostered fertiliser market development was achieved through the application of the Competitive Agricultural Systems and Enterprises (CASE) approach in West Africa. CASE is a market-driven approach that strengthens the innovative capacities of and coordination between the private sector (importers and dealers), research and extension services, lending institutions and market information systems. The approach stresses farmer participation in technology development, integrated soil fertility management (ISFM) and the development and strengthening of commodity chains. Strengthening the linkages among farmers and commodity and fertiliser traders is a critical component of the CASE approach. IFDC and partners have used this approach for the last five years to promote fertiliser market development and improve agricultural productivity in seven West African countries: Benin, Burkina Faso, Ghana, Mali, Niger, Nigeria and Togo. Presently, more than 100 000 farmers have adopted ISFM technologies. On average, agricultural productivity has more than doubled and farm-level incomes have increased by 20–50%. The value : cost ratios of adopted ISFM options are well above 2.

Addressing soil fertility issues through research

To address the soil fertility issues faced by poor farmers in Africa, it is important that public–private partnerships focus on research to improve the efficiency of fertiliser use, reduce the farm-gate price of fertiliser for smallholder farmers and develop new products that yield economic and agronomic benefits incremental to the current range of products.

Improving fertiliser-use efficiency

Reducing nutrient losses is a critical step towards improving soil fertility and agricultural productivity for poor farmers. It makes sense from every perspective — agronomic, economic and environmental. A critical question, however, is whether the private sector is interested in conducting research to improve fertiliser-use efficiency. The private sector may not have the incentive to improve nutrient-use efficiency because of the potential negative impact on their market shares or sales. However, declines in fertiliser sales may be only a short-term impact of improved nutrient-use efficiency. In the long term, farmers will see and reap the benefits of fertiliser use, leading to scaling-up and adoption of fertiliser technologies in rural areas. In addition, improving fertiliser-use efficiency is not just the issue of less fertiliser use (lower product sales by companies) but their role in protecting the environment. Hence, fertiliser companies can use the environmental agenda to their benefit in terms of marketing their products. A new generation of farmers is very keenly aware of their role in protecting the environment.

The key to improving fertiliser-use efficiency is research oriented towards developing site-specific nutrient management packages. Five methods of fertiliser application are currently known that can improve fertiliser-use efficiency for poor farmers:

Controlled-release nitrogen fertilisers (CRF)

These are fertiliser compounds that release either by design or naturally their nitrogen content over an extended period of time. CRFs can and do prevent losses of N fertiliser by matching, to the extent possible, N supply with crop demand. They can be effective tools to chemically or physically influence the movement and transformation of N in order to reduce losses. The major constraint associated with widespread use of CRFs on food crops is the cost of the commercial products. Unless the costs of production can be reduced significantly or the potential benefits found to be greater than expected, CRFs may not be a practical solution. Therefore, medium-term research is needed to develop more cost-effective technology for controlled- or slow-release fertilisers.

Figure 9. IFDC's FDP field trials on rice in Rwanda

Fertiliser deep placement technology (Fig. 9)

As described above, FDP is a simple yet innovative technology that provides a unique opportunity for sustainable agricultural development in many rice-producing countries. FDP involves the placement of 1–3 g USG or briquettes at a soil depth of 7–10 cm shortly after transplanting rice. The FDP technology addresses the challenge of low productivity in rice ecologies by increasing nitrogen-use efficiency. Deep placement of urea eliminates nitrogen losses due to volatilisation, leaching and floodwater runoff, allowing farmers to realise a 30% increase in yields over the same nitrogen when conventionally applied. FDP also ensures N availability beyond the flowering stage due to higher amounts of available N, encourages algal biological nitrogen fixation because of low floodwater N concentration and reduces weed competition. Research is needed in this area to acquire a basic understanding of the nutrient quality of the soil prior to fertilisation.

Reducing the farm-gate price of fertilisers for smallholders in Africa

Finding ways to reduce the delivered cost of crop nutrients should constitute a high priority for research in Africa. Improving value-chain efficiencies can contribute to lower transaction costs and, when combined with market efficiencies, contribute to lower margins and lower farm-gate prices. That may not be sufficient, however, to enable smallholder farmers to buy the soil nutrient management materials needed. Input-voucher programs are a pro-poor farmer, market-friendly means of providing either direct 'market-smart' subsidies or crop production credit to resource-poor farmers (Fig. 10). These programs have been implemented by IFDC in Afghanistan, Malawi and Nigeria. Integral characteristics of voucher programs are the provision of technical assistance and training to both the recipient farmers and private-sector agro-dealers and the targeting of voucher recipients. Voucher programs are generally backed by a declining smart subsidy designed to overcome the risk aversion associated with new technology adoption, to offset the rising cost of fertiliser and to build a commercial support system for a sustainable business model.

Moreover, smallholder farmers' access to fertiliser markets can also be improved through wider dissemination of market information and greater transparency. Research is needed in this area to determine communication channels that are adequate for rural areas and the most cost-effective ways for farmers to access market information. IFDC is currently developing the AfricaFertilizer.org web site, an on-line platform that will serve as a global internet forum on fertilisers for Africa (Annequin 2009) (Fig. 11). The site will provide timely information on many aspects of fertiliser products, including production, trade, prices, actors and fertiliser news.

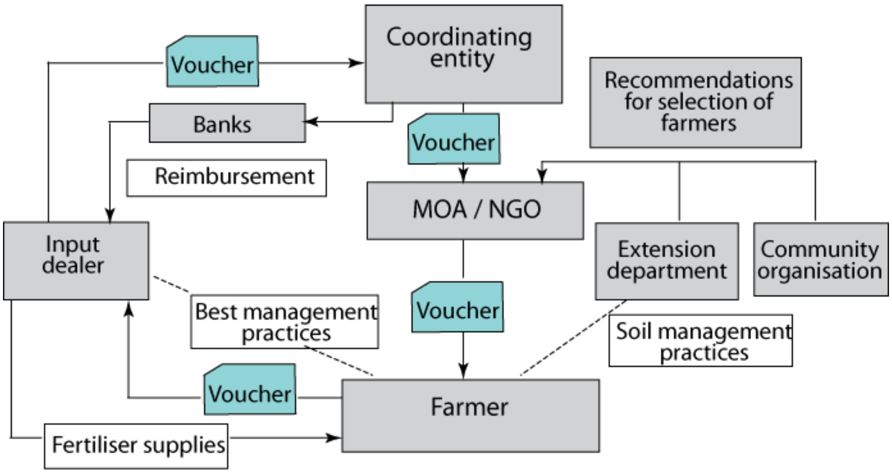

Figure 10. Schematic diagram of the targeted voucher system

Figure 11. Current mock 'AfricaFertilizer.org Website' – www.shoalsweb.com/IFDC/Africa_Fertilizer/index.html

Developing the next generation of fertiliser products

Given the dramatic food and fertiliser crisis events of the past few years and the growing awareness that the key non-renewable raw materials needed for fertiliser manufacture are being depleted, the time has come for a bold and new research initiative to create the next generation of fertilisers. The need for new and innovative research is a global issue; it requires a global solution. However, the key constraints to a typical 'start-up' fertiliser research and development initiative are limited time and financial resources. Assembling a multidisciplinary staff of scientists and engineers, along with construction of laboratories and pilot plants, is a daunting task that would be both costly and time-consuming.

To address the above constraint, IFDC will provide leadership and serve as the hub for a 'Virtual Center of Excellence for Fertilizer Research and Development' (VRC). The centre will bring together the best scientific, business and governmental minds to focus on creating a research system that challenges the current state of knowledge and considers new and non-traditional paradigms. The model for pursuing this new generation of research focuses on:

- modifying and improving existing fertiliser products and technologies
- developing and incorporating new fundamental concepts and methods to generate viable fertiliser products and technologies
- developing and institutionalising a global approach to create, monitor and sustain a universal research agenda.

Conclusions

Meeting the food security needs of low-income households will require close collaboration between the private sector and public institutions. Together, they will need to undertake research and development targeted at reducing the farm-gate price of fertilisers, improving fertiliser efficiency and developing the next generation of fertiliser products. Under the umbrella of the VRC, scientists from the public and private sector have the potential to develop technologies to create new fertiliser products from a variety of natural and man-made resources around the world. Research areas range from developing a high-quality granular fertiliser product from various nutrient-rich by-products, producing fertilisers using waste streams from coal-combustion power plants, finding more efficient and effective technologies that are less fossil-fuel dependent and developing genetic modification technologies of farm crops that will increase plant uptake from soil and the new generation of fertiliser products.

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