Research Findings

Potash Fertilizers in Africa: Background, Assessment and Prospects

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Introduction

The African continent will face unprecedented challenges in food production and increased pressures on its natural resources in the 21st century. Projections suggest that the African population will continue to increase well into the 21st century, from some 800 million in 2000 to 2.2 billion in 2050 and 3.6 billion by 2100 (Fig. 1). Malnutrition rates in sub-Saharan Africa (SSA) are the highest in the world, with some 30 percent of the population living in chronic hunger (FAO, 2010), a rate that has remained stubbornly high for the past two decades. Combined with a burgeoning population (both current and projected), this implies that the absolute number of undernourished people is increasing.

This paper examines some of the fundamental causes of low agricultural productivity in SSA and suggests that market-driven solutions can dramatically increase food security. The role of mineral fertilizer nutrients in achieving and sustaining increased productivity is highlighted, with particular attention to potassium (K), a macronutrient of emerging interest.

In terms of this paper, the term SSA will be used to denote sub-Saharan Africa excluding South Africa. The SSA region is characterized by low agricultural productivity (production per land unit), in contrast to South Africa and Northern African countries primarily in the Sahara (Algeria, Egypt, Libya, Morocco, Sudan, Tunisia and Western Sahara).

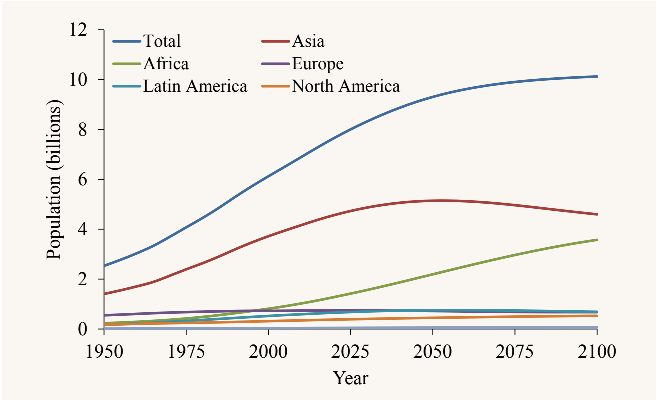

Fig. 1. Medium variant projections of population growth for various regions of the world. *Source:* Collated from UNDP, 2010.

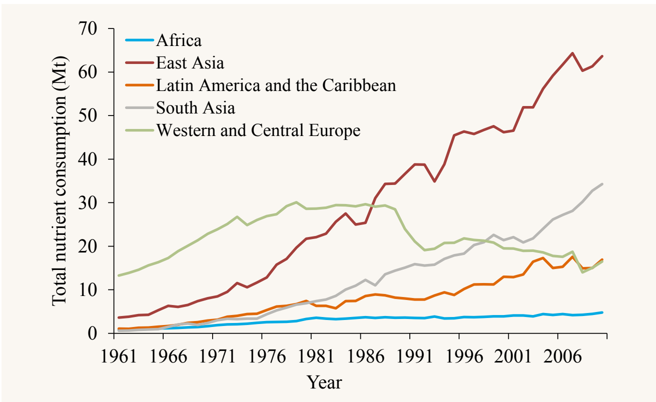

Fig. 2. Nutrient consumption (NPK) in regions, 1961-today. The term "Africa" includes North African countries, sub-Saharan Africa and South Africa. *Source:* IFA.

Agricultural development

SSA is characterized by a diversity of soil types (Map 1), agro-ecological zones (Map 2) and cropping systems, with some similarities to those of South America.

SSA largely missed the Green Revolution of the 1950s-1970s, which led to dramatic increases in productivity throughout the world due to the use of improved germplasm, mineral fertilizers, irrigation and good management practices. Mineral fertilizer use is fundamental to increasing yields and replacing nutrients removed in harvested products and loss through volatilization (i.e. nitrogen), leaching and soil erosion. The increase in N, P and K consumption in Asia and Latin America over this time was huge, while consumption in Africa stagnated (Fig. 2). Currently, some 13 percent of the world's cultivated area is in SSA, yet the region accounts for less than one percent of global fertilizer use (Fig. 3). The result is that yields in SSA have increased slowly relative to the rest of the world (Fig. 4).

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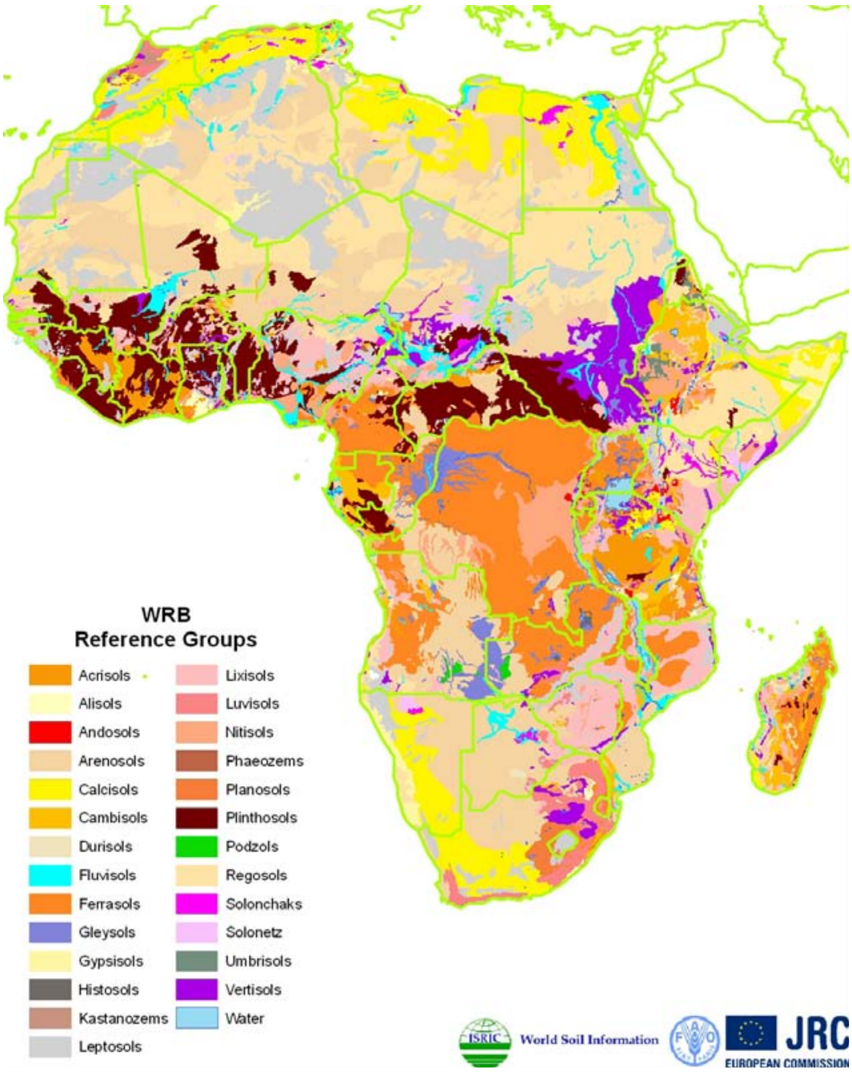
In spite of this stagnation in SSA yields, overall food production has just managed to outpace the dramatic population increases. Population in SSA increased by 370 percent from 1961 to 2010, and food energy value produced increased by 122 percent (from 1,955 to 2,380 kcal per person per day; FAOSTAT). However, this did not translate into a reduction in the percentage affected by malnutrition, as increasing urban populations consumed most of the calorie increase. The number of malnourished in SSA increased about three-fold – from 88 million in 1970 to 239 million in 2010.

Overall production increases are due largely to expansion of agricultural lands. Table 1 shows that while food commodity yields increased modestly from 1961 to 2010, total land area devoted to production of food commodities increased by 227 percent (a process known as extensification). Production increases (the product of yield and land area increases) ranged from 235 percent to 758 percent across commodity groups. Moreover, even the increase in productivity from 1961 to 2010 leaves yields per hectare well below 2010 world averages, with most commodity yields varying from one third to half of the global average (Table 1). In sum, while the rest of the world was achieving increased food security from higher crop yields generated by the use of



Map 1. Major soil types of Africa.
Source: http://eusoils.jrc.ec.europa.eu/library/maps/africa_atlas/images/COVER.pdf

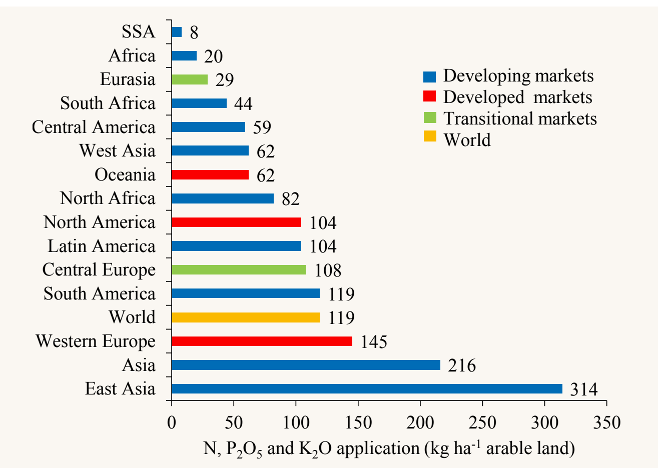


Fig. 3. Fertilizer use (kg ha^{-1}) for various regions and markets, 2010. *Source:* IFDC, derived from FAOSTAT.

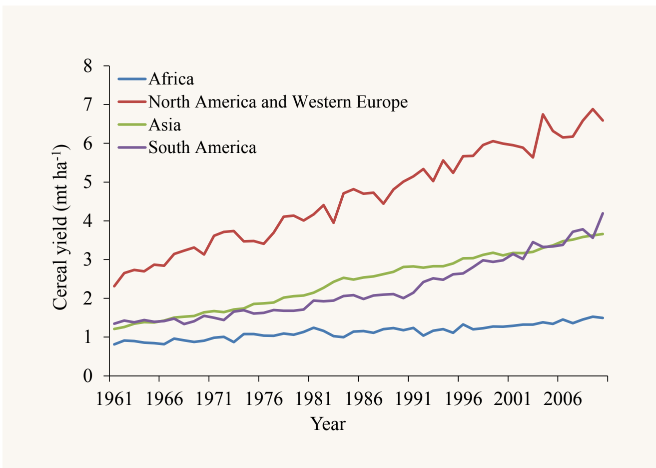
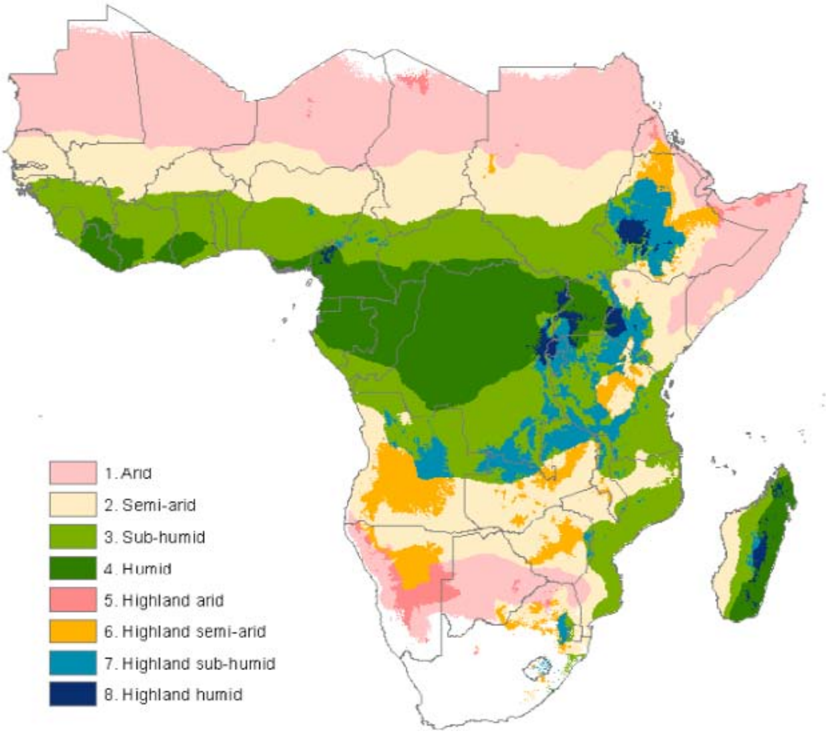


Fig. 4. Cereal yields in various parts of the world, 1961-2010. *Source:* Compiled from FAOSTAT.

improved seeds and nutrients delivered by mineral fertilizers, SSA was increasing production primarily through expansion of agricultural lands with minimal mineral nutrient inputs.

The practice of increasing overall productivity primarily through land expansion has several undesirable consequences. At farm level, low yields translate to high production costs per harvested unit. As a result of its low competitiveness, Africa's share of global agricultural trade declined from eight percent in 1965 to a paltry three percent by 2000. Low productivity also threatens other eco-systems: Henao and Baanante (2006) estimated that some 50,000 ha of forest and 60,000 ha of grassland are lost annually in Africa due to agricultural land expansion. Moreover, increasingly shorter fallow periods are inadequate for soil fertility regeneration. Poor productivity also decreases soil vegetative cover and



Map 2. Agro-ecological zones for sub-Saharan Africa based on FAO/IIASA methodology.
Source: HarvestChoice/IFPRI, 2009.

Table 1. Changes in yield, land area and production for various commodity groups in SSA from 1961-2010, and world average yields for commodity groups, 2010.

Commodity group	Year	Yield	Area	Production	Change 2010 relative to 1961			As proportion of food crop area
					Yield	Land area	Production	
		mt ha^{-1}	ha	mt	---------------%		---------------	
Cereals	SSA 1961	0.73	39,400,000	28,740,000				54
	SSA 2010	1.22	81,070,000	98,520,000	167	206	343	49
	World 2010	*3.23*						
Oil crops	SSA 1961	0.25	13,640,000	3,370,000				19
	SSA 2010	0.33	24,190,000	7,900,000	132	177	235	15
	World 2010	*0.63*						
Roots and tubers	SSA 1961	5.7	8,070,000	46,340,000				11
	SSA 2010	9.0	22,810,000	206,190,000	157	283	445	14
	World 2010	*13.9*						
Pulses	SSA 1961	0.48	6,090,000	2,940,000				8
	SSA 2010	0.61	20,370,000	12,470,000	127	334	425	12
	World 2010	*0.88*						
Fruits	SSA 1961	5.05	3,420,000	17,270,000				5
	SSA 2010	6.30	8,640,000	54,420,000	125	253	315	5
	World 2010	*10.92*						
Vegetables	SSA 1961	4.68	1,470,000	6,890,000				2
	SSA 2010	5.90	4,960,000	29,240,000	126	337	426	3
	World 2010	*18.98*						
Tree nuts	SSA 1961	0.61	330,000	200,000				0.5
	SSA 2010	0.72	2,130,000	1,540,000	117	645	758	1.3
	World 2010	*1.33*						
Total			72,420,000					
			164,170,000			227		

Source: Compiled from FAOSTAT.

water transpiration, which in turn results in increased erosion and nutrient leaching through the soil – thus perpetuating a downward spiral of soil fertility. Henao and Baanante (2006) warned that some 95 million ha of agricultural lands (40 percent of total African farmland) were reaching such a state of degradation that the large investments required to return them to productivity would not be economically justifiable.

Nutrient losses in Africa

Monitoring annual nutrient losses on a scale as large as Africa is a complex task that must take into account soil type (Map 1), agro-ecological zone (Map 2), topography and land use. Building on the nutrient depletion work by Stoorvogel and Smaling (1990, 1993, 1998), Henao and Baanante (2006) estimated soil nutrient balances for Africa. Inputs include fertilizers, organic residues and manures, nitrogen fixation and sedimentation, while outflows include losses from soil erosion, leaching, volatilization and crop removal.

Table 2 (derived from Henao and Baanante, 2006) shows current major sources of nutrient losses and inflows in various agro-ecological zones of Africa. Under the low yield scenario prevalent throughout most of Africa, crop removal (harvest plus crop residues) accounts for some 43 percent of N, 87 percent of P and 73 percent of K losses. (This calculation excludes the Mediterranean and arid North Africa, which are not part of SSA and receive high fertilizer inputs.) Erosion accounts for an additional 43 percent of N loss. As yields increase due to appropriate fertilization, one would expect reductions in the proportion of nutrients lost by means other than crop and residue removal.

Increased fertilizer use increases crop production (grain and biomass), thereby providing additional benefits beyond the yield increases. Because biomass in SSA is primarily used for livestock fodder or for cooking fuel, additional production increases the possibilities for a larger portion remaining on or being returned to the field. Crop residues left on the field are important in preventing the loss of topsoil, maintaining soil organic matter and recycling crop nutrients, particularly K.

Potassium availability in African soils

Given the diversity of environments in Africa, one cannot refer to K in African soils in general, but must highlight the diversity of K availability in African soils. No simple soil test exists to evaluate K availability for all soils, but ammonium acetate-exchangeable K (which correlates closely with other methods such as the

Table 2. Estimated nutrient losses and gains in various agro-ecological zones of Africa.

Region/nutrient	Annual nutrient losses (2002-2004 average)					Annual nutrient gains and inflows (2002-2004 average)						Total
	Harvest	Residues	Leaching	Gaseous	Erosion	Manure	Deposition	Fixation	Sediments	Fallow	Fertilizer	
	kg ha^{-1} yr^{-1}											
Humid Central												
N	-11.3	-3.4	-4.7	-9.3	-18.8	0.2	2.8	4.2	0.1	1.9	1.1	-37.2
P_2O_5	-4.2	-2.9			-1.4	0.1	0.9		0.1	1.9	0.8	-4.7
K_2O	-10.1	-3.7	-4.4		-2.9	0.3	2.4		0.1	1.9	1.1	-15.3
Humid and Sub-Humid West												
N	-16.3	-6.1	-3.2	-4.6	-18.8	1.4	3.6	4.7	0.8	0.7	2.9	-34.9
P_2O_5	-6	-2.7			-1.4	0.7	1.3		0.3	0.7	1.5	-5.6
K_2O	-12.6	-6.2	-3.3		-2.9	2.8	2.8		0.8	0.4	1.1	-17.1
Mediterranean and Arid North												
N	-31.5	-7.6	-2.7	-4.3	-17.3	0.9	1.7	3	0.7	1.3	41	-14.8
P_2O_5	-9.1	-3.1			-1.3	0.5	0.6		0.3	1.3	10.2	-0.6
K_2O	-13.3	-3.3	-3		-2.1	0.8	1.3		0.4	0.7	5	-13.5
Sub-Humid and Mountain East												
N	-17.4	-6.5	-3.6	-5.2	-13.5	1.2	2.7	3.6	0.6	0.6	7.3	-30.2
P_2O_5	-6.9	-3.2			-1	0.6	1		0.3	0.6	3.1	-5.5
K_2O	-13.5	-6.2	-2.7		-2.1	1.4	2.2		0.5	0.3	0.9	-19.2
Sudano-Sahelian												
N	-13.5	-3.7	-4.2	-7.3	-18.4	1.7	2.4	4.2	0.7	1.4	3	-33.7
P_2O_5	-5.3	-2.1			-1.4	0.8	0.8		0.2	1.4	0.7	-4.9
K_2O	-10	-3.8	-4.8		-2.5	3.1	1.8		0.4	0.7	0.5	-14.6
Sub-Humid and Semi-Arid Southern												
N	-24.4	-6.6	-5.3	-7.6	-19	1.6	3.1	4.9	0.7	1.7	23.8	-27.1
P_2O_5	-10.5	-4.4			-1.5	0.6	0.1		0.1	1.7	8.8	-5.1
K_2O	-17.5	-6.6	-3.8		-3	3	2.5		0.6	0.8	7.2	-16.8

Source: Summarized from Henao and Baanante, 2006.

Mehlich-3 or dilute acid solutions) is a commonly used method. The Booker Tropical Soils Manual (1984) highlights the various interpretations of the exchangeable K value. Deficiency limits of <0.20 meq 100 g^{-1} is the norm for Malawi, <0.25 meq 100 g^{-1} for the USA, <0.50 meq 100 g^{-1} for New Zealand and <0.15 meq 100 g^{-1} for the UK. For sandy, sandy loam and red-brown clays in Zimbabwe the critical K values are 0.05, 0.10 and 0.15 meq 100 g^{-1}, respectively. Maria and Yost (2006) report critical K norms of 0.1, 0.2, and 0.4 meq 100 g^{-1} for respective sandy, intermediate and clay soils in Mozambique.

However, potassium availability is not solely a function of exchangeable K. An exchangeable K value of 0.2 meq 100 g^{-1} represents some 78 parts per million (ppm) exchangeable K, which would equate to 203 kg of K in the upper 20 cm of a soil with a bulk density of 1.3 g cm^{-3}. This is a relatively small K quantity that would be completely depleted after two to three 5 mt ha^{-1} maize harvests with residue removal. Soils have non-exchangeable and labile (gradually available) K reserves, held primarily in 2:1 clay minerals such as smectites and illites, which are gradually released and as such buffer K supply. These minerals are generally associated with less weathered soils. Because of this buffering capacity, some soils can be cropped for many decades without depleting K reserves, particularly if plant residues, which contain substantial quantities of K, are recycled. In contrast, N and P reserves are generally depleted more rapidly, particularly with cereal crops, and crop response to N and P can often be observed without K application, whereas the reverse is less commonly true. Under conditions of low fertilizer use that prevail throughout SSA, low yields limit K removal, though notable exceptions exist, and are discussed below.

Exchangeable K levels vary widely in Africa. Kanyanjua *et al.* (2006) found exchangeable K levels in Kenya ranging from 0.2 to 1.8 meq 100 g^{-1}, and found that maize in low K soils began to show K response only after continuous cropping with N and P fertilizers. In an extensive sampling of soil types in Mozambique, Geurtz and Van den Berg (1998) found exchangeable K values in Acrisols, Arenosols, Ferralsols, Lixisols and Luvisols to average 0.98, 0.26, 0.36, 0.53 and 0.83 meq 100 g^{-1} respectively. Similar results were found by Maria and Yost (2006) in a sampling of four of Mozambique's 10 agro-ecological zones, where K levels were found to range from 0.20 to 1.7 meq 100 g^{-1}. In Nigeria, Ataga (1973) found very low K levels in sandy acid soils under palm oil production (0.03-0.11 meq 100 g^{-1}), but higher contents under soils formed from basement complex rocks (0.10-0.32 meq 100 g^{-1}). Acquaye (1973) found exchangeable K levels in Ghanaian soils ranged from 0.12 meq 100 g^{-1} on sandstones to 0.32 meq 100 g^{-1} on basic rocks (average values), and also found that plant K uptake related best to exchangeable K compared to several K indices used to measure K supply. In Tanzania, Hartemink *et al.* (1996) found K levels to be commonly below 0.10 meq 100 g^{-1} in Ferralsols and somewhat higher levels in Acrisols, where K levels averaged 0.5 meq 100 g^{-1} under secondary forest, but declined under bush fallow and continuous sisal cropping.

Decline in soil fertility indices is commonly observed under continuous cropping with no or limited inputs. In most cases, declines in soil organic matter, soil pH and exchangeable bases (Ca, Mg, K) occur together. Some examples of decline include the Tanga Region of Tanzania (Hartemink, 1997), where Ferralsols' and Acrisols' organic matter, pH and exchangeable bases declined significantly from the 1950s and 1960s to the 1980s and 1990s. Hartemink found that, in general, fertility decline in Cambisols and Luvisols was substantially less, though K decline was still considerable in these soils. Mouttapa (1973) noted that the most severe K deficiencies in Africa are in the savanna belt on sandy soils of the humid inter-tropical zone, and stated further that K deficiencies generally occur in the humid forest zone only after many years of continuous cropping, and are seldom found on Cambisols or Luvisols in semi-humid regions. Mukashema (2007) found that soil fertility indices in the Gishwati watershed in the Rwandan highlands declined over a period of 25 years under various land uses, with agricultural land degrading more rapidly than forests or pastures, and sandy acid soils deteriorating more rapidly than soils of volcanic origin. Haefele *et al.* (2004) studying soil fertility changes in Senegal for irrigated rice over 16 seasons (two seasons per year) on Gleysol and Vertisol, found that soil P dropped precipitously when only N was applied, but the exchangeable K decline was much slower. They concluded that the K buffering capacity in these soils was such that yields could be sustained for decades without K addition.

Market-driven strategies for accelerating fertilizer adoption

A seemingly obvious but often neglected fact is that farmers will adopt fertilizers only when fertilizer use is profitable. Most farmers in SSA have limited means, and are more inclined to invest in opportunities that balance the twin objectives of return and risk.

Those promoting nutrient inputs often have a tendency to direct their use to the most broadly cultivated crops – commonly cereal crops such as sorghum or maize. But these crops do not always represent the best return on fertilizer investment. In years of good production, large-scale fertilizer use can result in supply gluts at harvest, particularly in countries with low capacity to store harvest, depressing prices. If farmers are not linked to a specific market opportunity (such as a milling operation or a processor) or do not have access to warehouses to store produce until prices improve, low or even negative returns can result.

In many cases it is the less cultivated crops that can provide the best returns on fertilizer investment. As an example, leguminous crops such as groundnuts and soybeans require a relatively low fertilizer investment (often only P and K) as they fix their own nitrogen, but can result in strong returns as their value is high.

Farmers throughout Africa invest in NPK blends for vegetables, which in general offer good returns on fertilizer investments.

An additional key to accelerating fertilizer consumption is having targeted fertilizer blends. The most available fertilizers in Africa are urea, di-ammonium phosphate and NPK blends, commonly 15:15:15 or 17:17:17. Formulae best suited to specific crops are commonly not available. However, African-based fertilizer blenders are increasingly creating blends for specific vegetables, legumes, cereals and root crops. Some blends now contain secondary and micronutrients to overcome deficiencies that are limiting response to N, P and K in many environments. Until recently, secondary and micronutrients have not been available to many African smallholders. Sulfur is a commonly deficient nutrient, as are the micronutrients zinc and boron. One response to this is providing fertilizers targeted to particular crops in packages as small as 1 kg. Small quantity packages allow farmers to evaluate fertilizer response to different formulae at a small financial risk.

Combining fertilizer nutrients with other agro-inputs also generates profitable synergies. Improved seed is a key input for yield maximization. Minor investments in pesticides can often double legume yields. Herbicides, combined with minimum tillage, can drastically reduce tillage costs and weed pressure, a major cause of yield reduction, particularly in extensive farming systems where farm labor is a constraint. Addressing pests and weeds reduces farmer risk and increases the likelihood that investments in fertilizers will result in greater yields and profits.

A market-driven approach to increased productivity requires functional value chains, which is the objective of the Competitive Agricultural Systems and Enterprises (CASE) approach (Mattman *et al.*, 2011). An important element of CASE is vibrant agribusiness clusters. A cluster is comprised of all the actors required to build a profitable value chain, working together to develop a business opportunity around a specific commodity. Cluster collaborators commonly include farmers and their organizations, input suppliers, finance providers, those adding post-harvest value (processors, warehousing, packagers), marketing parties (traders, transporters and buyers) and business development services, who build capacity through technical advice. The CASE approach was successfully applied in IFDC's "Thousands to Millions" project in West Africa (2006-2010). The project succeeded in increasing fertilizer consumption by almost 100 kg ha^{-1} for some 700,000 farmers, resulting in increased production of 500,000 mt of cereal equivalents and average increases in farmer incomes of 50 percent.

Estimates of future fertilizer requirements, and conclusions

Henao and Baanante (2006) estimated that some 6.7 million tons of N, P and K ($N+P_2O_5+K_2O$) fertilizers would be required annually in SSA to reverse nutrient mining and contribute substantially to yield increases, which represents approximately 4.8 times the 2004 NPK consumption. Delegates to the African Fertilizer Summit (held in 2006 in Abuja, Nigeria) recognized that increased fertilizer use is essential to increasing yields and reversing soil fertility decline in the face of rising population. The *Abuja Declaration on Fertilizer for an African Green Revolution* (NEPAD, 2006) set a fertilizer use goal of 50 kg ha^{-1} by 2015. This amounts to more than a five-fold increase in current fertilizer use for SSA.

The African Union agreed with the tenets of the *Abuja Declaration*, and NEPAD monitors continental progress on a country-by-country basis. Market-driven initiatives show that the 50 kg ha^{-1} usage level is achievable on a broad scale, though not likely by 2015. One question that arises is how much yield SSA would realize if this goal were achieved.

For SSA to move into a more food-secure situation as envisaged by the *Abuja Declaration*, the region would need to produce yields similar to other regions, such as Central America, Western Asia, Northern Africa, Central Asia and South Africa. These regions consume an average of 53 kg ha^{-1} of N, P and K. Collectively, their yields of cereals, pulses, oil crops and roots and tubers are approximately twice that of SSA. Thus, one might roughly expect yields to double if the goals set in the *Abuja Declaration* are achieved. Doubling of yields would lessen the incentive for land expansion, dramatically increase food security and reduce production costs, increasing the competitiveness of SSA on world markets. However, it should be noted that the population of Africa is projected to triple by 2050. Fertilizer use may have to be in the order of 100 kg ha^{-1} of N, P and K by then if demand is to be met by local production. Land expansion may also play a role, but even if new lands are opened, fertilizer use on those lands will have to increase over current average use.

In conclusion, SSA must rapidly accelerate its fertilizer use to reverse environmental degradation and feed its growing population. SSA can draw upon the success of some Latin American and Asian nations which have achieved increasing yields over the past four decades with similar soils, agro-ecologies and cropping systems. Land expansion – extensification – is not a viable alternative to increasing yields through agricultural intensification, as it results in unsustainable production, low productivity and high production costs that render SSA uncompetitive on world markets.

Encouraging fertilizer use requires market-driven approaches. Agribusiness clusters have proven successful in developing profitable value chains and encouraging millions of smallholder farmers to increase productivity, with fertilizers playing a major role in yield increases. Fertilizer blenders across Africa are increasingly important in these clusters, producing blends targeted to specific crops and soil conditions to maximize returns from fertilizers. Other inputs, such as improved seeds and crop protection products, are also important in increasing productivity, are complementary to fertilizers and render fertilizer application more profitable and less risky.

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