Africa Fertilizer Summit
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Background Papers


Fertilizer Use and the Environment in Africa: Friends or Foes?

IFDC

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Background Paper Prepared for the African Fertilizer Summit

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by

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Acronyms and Abbreviations

AS	Ammonium sulfate
CAN	Calcium ammonium nitrate
CMDT	Compagnie Malienne pour le Developpement des Textiles
DAP	Diammonium phosphate
DPSIR	Driving Forces-Pressures-State-Impact-Response
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
Fe	Iron
GEF	Global Environmental Facility
INM	Integrated Nutrient Management
ISRIC	International Soil Reference and Information Centre, Wageningen
MDGs	Millennium Development Goals
MEA	Millenium Ecosystem Assessment
N	Nitrogen
NEPAD	New Partnership for Africa's Development
OECD	Organization for Economic Cooperation and Development
P	Phosphorus
SSA	Sub-Saharan Africa
Zn	Zinc

Fertilizer Use and the Environment in Africa: Friends or Foes?

Summary

This background paper for the Africa Fertilizer Summit addresses the interface between fertilizer use and the environment. The context is set by confronting Millennium Development Goals (MDGs) 1 and 7, with targets of halving hunger as well as increasing environmental sustainability by 2015. Future projections by the Food and Agriculture Organization of the United Nations (FAO) and the recently completed Millenium Ecosystem Assessment (MEA) show that neither target is likely to be met in Africa. The different "ecosystem services" as depicted by MEA are useful with regard to fertilizers and the environment. "Provisioning" services are used in agriculture for private gains and are supplemented by fertilizers; "regulating" and "supporting" services are used for public, or global environmental benefits.

It is now well known that agricultural activities affect and are affected by the quality of the environment. Stigmatized because of overutilization in intensive agricultural systems elsewhere in the world, fertilizer use in Africa is extremely low, particularly south of the Sahara. The paper argues that in Africa, the non-use of fertilizer has a greater negative effect on the environment than does its use. Soils are poor due to old age, and are further stripped of vegetation and native soil fertility as area expansion rather than intensification continues to be the main mechanism to increase production in rural areas.

Non-use of fertilizers in Africa adds to different forms of land degradation (removal of natural vegetation, soil physical degradation, soil fertility depletion, wind, and water erosion), but it also negatively affects biodiversity and actual and potential carbon sequestration. Also, in old African soils, fertility is almost tantamount to its organic matter content. Hence, fertilizer use is linked to at least three focal areas of the Global Environmental Facility (GEF): climate change, biodiversity, and land degradation. As such, it may help in realizing synergies between the post-Rio conventions addressed by GEF and its focal area programs.

Avenues towards increased, environmentally benign use of fertilizers are advocated at the international level, in a series of national policy and institutional improvements, and in technological and people-centered innovations, making better use of and sharing scientific and indigenous knowledge. Particularly relevant are the raising of international awareness concerning Africa's poor soils and, therefore, the unlevel playing field when it comes to international trade and strategy building at the level of the African Union (AU) and New Partnership for Africa's Development (NEPAD) on future food needs given the impact of urbanization and ongoing area expansion for cultivation. Room for improvement lies in the understanding and valuation of trade offs between economic and ecological goals; in quantifying and realizing synergies at the country, landscape, and village scales; and in rewarding land users for maintaining non-market ecosystem services. Efficiency gains in fertilizer use, i.e., by using them on the best soils and with the best management, may render them far more profitable. Fertilizer use in Africa has to be *increased significantly,* preferably in a context of integrated nutrient management aimed at interlinkages between crops and livestock, between cash and food crops, and between landscape plots and time (residual effects of fertilizers and manure).

1. Fertilizer Use in the Context of Millennium Development Goal 1

Millennium Development Goal 1	**Eradicate extreme poverty and hunger**
	Target 2. Halve, between 1990 and 2015, the proportion of people who suffer from hunger

Millennium Development Goal (MDG) 1, Target 2, implies increased and satisfactory access to food for half of those currently undernourished. There are three ways to realize this: (i) bring the people to the food, which would imply massive migration and socio-political unrest; (ii) move the food from surplus to deficit and hunger areas, which is indeed happening, through trade and through the interventions of the World Food Programme (Figure 1)—if food imports and aid continue to add to countries' indebtedness and dependence, again this is undesirable socio-politically and economically; (iii) assist people in deficit areas to produce and generate more food and income, which seems by far the most desirable option.

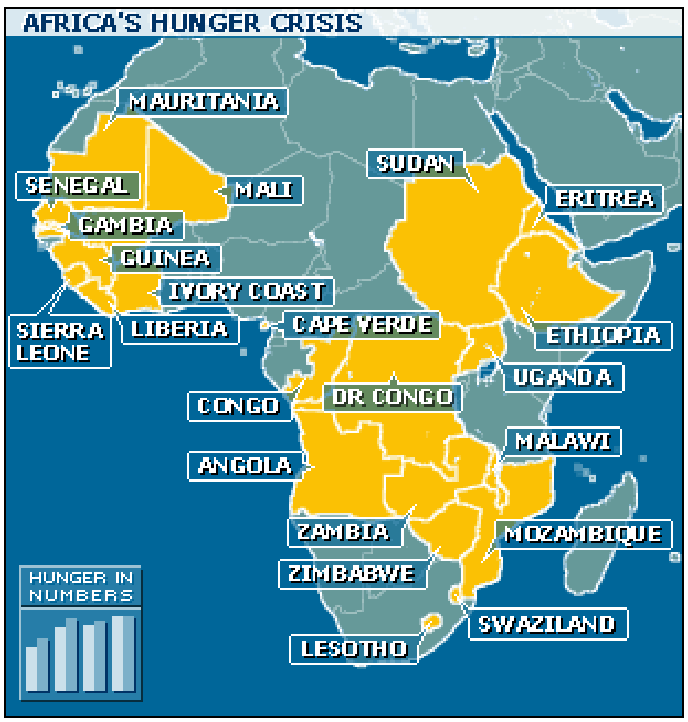

Figure 1. World Food Programme 2002 Hunger Map

The MDG-1 seems close to being met in Asia and Latin America but not in Africa, as Figure 2 shows (FAO, 2003a). There are two major reasons why sub-Saharan Africa (SSA) is lagging behind in meeting MDG-1:

- **Low and Declining Soil Fertility**—The major European agricultural soils, for example, have at least twice as much soil organic carbon as those in SSA. Also, European soils are near neutral as opposed to those in SSA, which are acid (Table 1). Africa is the world's most ancient land mass. Nutrient-impoverished granites, basement sediments, and sands cover about 90% of the African land surface. Moreover, Henao and Baanante (2006) recently confirmed earlier assessments of nutrient mining being a major problem in the African agricultural lands (e.g., Stoorvogel et al., 1993; Buresh et al., 1997; Vanlauwe et al., 2002).

- **Extremely Low Use of Mineral Fertilizers as Compared With Other Parts of the World** (Table 2)—Compared with a current world total consumption of approximately 150 million tons and an application rate of 100 kg/ha arable land, SSA is stranded at 6 kg/ha; North Africa, however, applies 75 kg/ha. Projected annual growth in SSA until 2030 is a dismal 1.9%/year. Compared with Asia, SSA has a very small area under irrigated agriculture. There is a sharp contrast between the Malian farmer harvesting 500 kg of rainfed sorghum/ha without using fertilizer and the farmer in the Indo-Gangetic plains who harvests 5,000 kg of irrigated rice/ha after double cropping and using fertilizers. Meanwhile, the sorghum crop withdraws approximately 30 kg N+P+K (nitrogen, phosphorus, potassium) from the soil, whereas the Asian system withdraws 300 kg from soil and fertilizers. In both cases, the difference is a full order of magnitude!

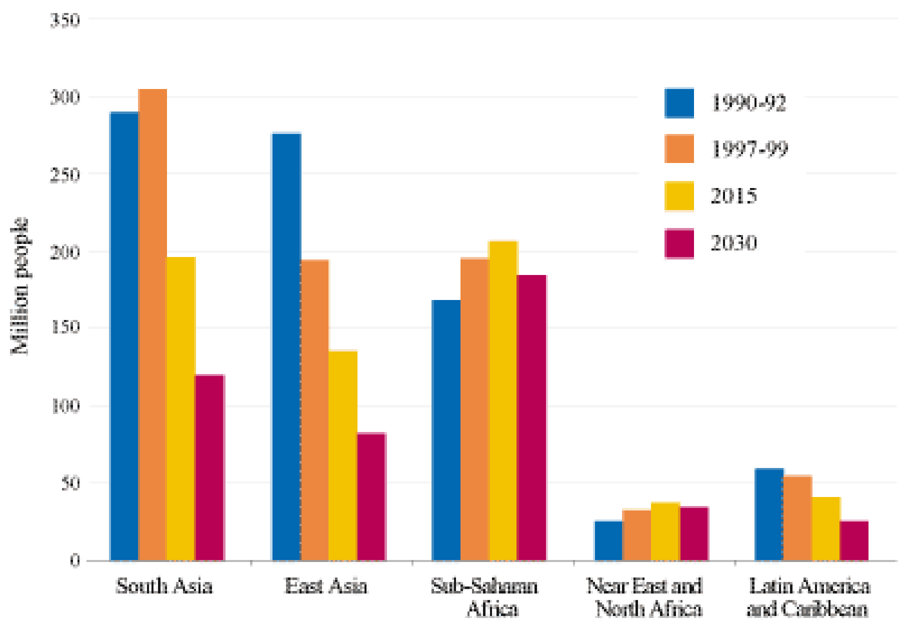

Figure 2. Past and Projected Levels of Malnourished Individuals (FAO, 2003a)

Table 1. Soil Carbon and pH in European and SSA Soils (compiled from the WISE Database of the International Soil Reference and Information Centre, Wageningen [ISRIC])

	Organic Carbon	pH
	(%)	
Europe		
Cambisols	2.6	6.3
Chernozems	2.2	7.4
Luvisols	1.8	6.2
Sub-Saharan Africa		
Ferralsols	1.3	4.9
Acrisols	1.0	5.0
Luvisols	0.6	6.1

Table 2. Global Past and Projected Fertilizer Consumption (FAO, 2003a)

	1961/63	1979/81	1997/99	2015	2030	1961-99	1989-99	1997/99 -2030
	(kg/ha arable land)					(% change per year)		
Sub-Saharan Africa	1	7	5	7	9	4.5	-2.4	1.9
Latin America + Caribbean	11	50	56	59	67	6.0	0.0	0.6
Near East/North Africa	6	38	71	84	99	5.7	3.9	1.0
South Asia	6	36	103	115	134	9.5	4.5	0.8
Excluding India	6	48	113	142	178	8.8	4.3	1.4
East Asia	10	100	194	244	266	8.3	3.6	1.0
Excluding China	12	50	96	131	92	6.1	3.3	-0.1
All above	6	49	89	102	111	7.7	3.3	0.7
Excluding China	6	35	60	68	71	6.9	3.2	0.5
Excluding China and India	7	35	49	58	58	6.0	2.6	0.5
Industrial countries	64	124	117			1.3	0.3	
Transition countries	19	101	29			0.9	-14.4	
World	25	80	92			3.3	0.1	

Annex 1 provides more details on fertilizer production, export, and consumption in Africa. Fertilizer production is a major business in Egypt (nitrogen [N]) and Morocco and Tunisia (phosphorus [P]), but in SSA there is little home production apart from South Africa. Nigeria was a producer until the mid-1990s when removal of fertilizer subsidies killed the home industry. Total fertilizer exports in Africa were approximately 3.5 million tons in 2002, exceeding total imports (approximately 2.6 million tons). However, exports are almost entirely confined to the five North-African countries. Fertilizer consumption in 2002 was 4,278,401 tons. On a total area coined "arable and permanent crops" by FAOSTAT, i.e., 221,612,000 ha, this gives an average use of 19.3 kg/ha; when leaving out giants Egypt and South Africa, fertilizer use is 2,044,498 tons on a surface area of 202,978,000 ha, giving an average fertilizer use of 10.1 kg/ha. Even this small figure has a skewed distribution, with high inputs in the pockets that have high-value crops and on farms of well-to-do farmers, and no fertilizer use whatsoever in the vast areas under rainfed subsistence agriculture, dominated by one or two staple crops. Recent model projections indicate that N fertilizer use in Africa will not surpass 5 million tons in 2050. Only under a "rehabilitation of degraded lands" scenario, may close to 10 million tons be used in 2050 (Wood et al., 2004).

Fertilizers can play a major role in the realization of MDG-1. Targeting application to soil conditions and plant needs will lead to substantial yield increases at high fertilizer use efficiency or recovery rates. Table 3 shows that maize in different areas in Kenya responded differently to application of N, P, or both. Table 4 shows how the typical ring management systems in semi-arid West Africa give different yields and yield increases upon application of fertilizers. A systematic account of fertilizer use and effects on crop yield can be found in the country booklets by FAO. Summaries of their contents are given in Annex 2.

Table 3. Maize Yields and Nutrient Uptake on Three Soils in Kenya During the Long Rainy Season of 1987 as Affected by Fertilizer Application (Smaling and Janssen, 1993)

Treatment (kg/ha)	Yield	Uptake		
		N	P	K
	(kg/ha)			
Kisii Red Soils				
N 0 – P 0	2,100	42	5	30
N 0 – P 22	4,900	79	12	58
Homa Bay Black Soils				
N 0 – P 0	4,500	63	24	95
N 50 – P 0	6,300	109	35	126
Kwale Brown Sands				
N 0 – P 0	2,600	38	7	42
N 50 – P 22	3,700	66	16	77

Table 4. N Stocks (0-15 cm), N Uptake, and Millet Yield as a Function of Distance From the Homestead in the Bankass Area, Mali, and Effect of NP Fertilizers on Millet Yield (Samaké, 2003)

Distance From Compound	Soil N Stocks	Millet N Uptake	Millet Grain Yield	
(m)	(kg/ha)			
		(N 0 P 0)	(N 0 P 0)	(N 38 P 20)
10-200	600	24	1,130	1,730
500-2,000	300	14	480	1,020

Until 1990, many African governments were heavily involved in the fertilizer sector. This meant a high level of regulation and price control. Fertilizer subsidies were widespread but placed a burden on the limited financial resources of these countries. During the 1980s the World

Bank imposed financial structural adjustment programs in most countries, but the privatization of fertilizer distribution in countries with a low level of fertilizer consumption on food crops has not proved successful. Demand is low, irregular, and dispersed; there is considerable financial and credit risk; and the product is bulky. Fertilizer prices for the African farmer are often high and food crop prices low. The quantity of grain required to purchase 1 kg of N varies from 6 to 11 kg, compared with about 2 or 3 kg in Asia. The cost is particularly high in landlocked countries.

2. Fertilizer Use in the Context of Millennium Development Goal 7

Millennium Development Goal 7	**Ensure environmental sustainability**
	Target 9. Integrate the principles of sustainable development into country policies and programs and reverse the loss of environmental resources

Millennium Development Goal 7, Target 9, addresses environmental sustainability. When looking at the recently completed Millennium Ecosystem Assessment (MEA), four groups of ecosystem services are recognized (Table 5). Agriculture clearly makes use of those that are provisioning, and fertilizers "help" the provisioning ecosystem services in obtaining higher agricultural output. Those that are regulating and supporting are "non-market" ecosystem services, providing global environmental benefits rather than private benefits. This is the domain of the GEF, which, among others, funds development activities geared at the realization of the post-Rio conventions on biodiversity, climate change, and desertification.

Table 5. Ecosystem Services (Millennium Ecosystem Assessment, 2005)

Provisioning	Water supply
	Food, fodder
	Raw materials (wood, fiber, etc.)
	Genetic resources (medicines, scientific and technological resources)
Cultural	Recreation opportunities (nature-based tourism)
	Aesthetic, cultural, and spiritual (existing values)
Regulating	Gas regulation (atmospheric composition)
	Climate regulation (temperature, rainfall)
	Disturbance regulation
	Water regulation (hydrological cycle)
	Erosion control and soil/sediment retention
	Biological control (populations, pest/disease control)
	Refuges (habitats for resident and transient populations)
Supporting	Nutrient cycling and storage (including carbon sequestration)
	Assimilation of waste and attenuation, detoxification
	Purification (clean water, air)
	Pollination (movement of floral gametes)
	Biodiversity
	Soil formation

Human actions at all scales required to feed the current world population have increased the "leakiness" of ecosystems with respect to nutrients. This leakiness can be better understood by using a nutrient balance approach. The nutrient flows depicted in Figure 3 show three types of flows: those that enter (inputs); those that leave the farm (outputs); and those that move inside the farm, such as farmyard manure applied to a particular plot (internal flows). The inputs IN 1 and IN 2 (mineral and organic fertilizers) and the outputs OUT 1 and OUT 2 (harvested products and residues) generally have money values and are part of private costs and benefits, which are in the realm of land users' decision-making. Outputs OUT 3-6, however, can constitute a burden to the environment, and often constitute costs to society as a whole. On a global scale, for example, only half of all anthropogenic N inputs on croplands is taken up by harvested crops and their residues. Losses to the atmosphere (OUT 4) are estimated at 26 to 60 millions tons, whereas ground and surface water bodies receive between 32 and 45 million tons from leaching (OUT 3) and erosion (OUT 5). Cultivation, irrigated rice production, and livestock production release between 106 million and 201 million tons of carbon per year in methane. About 70% of anthropogenic nitrous oxide gas emissions is attributable to agriculture, mostly from land conversion and N fertilizer use (MEA, 2005).

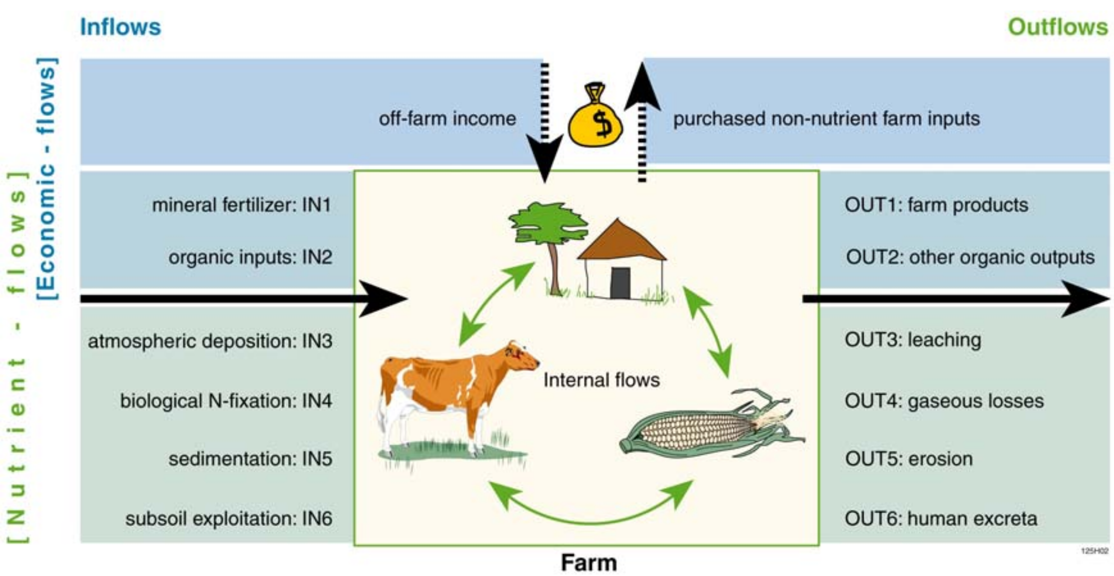

Figure 3. Nutrient Inputs, Outputs, and Internal Flows in a Farm System

A key threat to the environment and to non-market ecosystem services in particular is the continued slashing and burning of natural vegetation to meet growing needs for crop and animal production. Under most MEA scenarios, 10%-20% of grassland and forestland is projected to be converted between 2000 and 2050 (primarily to agriculture). The projected land conversion is concentrated in low-income countries and dry land regions. Henao and Baanante (2006) indicate that some 50,000 ha of forest and 60,000 ha of grasslands in Africa are lost to agriculture annually, and approximately 70% of deforestation in Africa is a result of clearing land for cultivation. Table 6 provides data taken from Dixon et al. (2001) showing the contributions from area expansion and yield increases to agricultural production in SSA. In the past 30 years, for example, maize area expanded by 1.5%/year while yield increased by only 1.2%/year.

Table 6. Trends in Crop Area, Yield, and Output in SSA, 1970-2000 (Dixon et al., 2001)

Crop	Harvested Area 2000	Production 2000	Yield 2000	Average Annual Change 1970-2000		
				Area	Production	Yield
	(m ha)	(m tons)	(t/ha)	(%)		
Rice	7	11	1.6	2.4	2.9	0.6
Maize	26	38	1.5	1.5	2.7	1.2
Millet	20	14	0.7	1.4	1.8	0.4
Sorghum	21	18	0.8	1.2	1.6	0.5
Oil crops	24	6	0.3	0.9	1.6	0.7
Roots and tubers	18	154	8.4	1.7	2.8	1.0
Pulses	16	7	0.4	1.6	1.9	0.2
Vegetables	3	22	6.6	1.9	2.6	0.8
Fruits	8	47	6.2	1.6	1.6	0.0

Source: FAOSTAT (2002).

In 2000, SSA had 219 million head of cattle, 19 million goats, and 189 million sheep (Dixon et al., 2001). Increasing numbers of cattle are raised in areas that were originally tsetse infested in the moist sub-humid and dry sub-humid zones. This trend is likely to continue. Nevertheless, cattle numbers per household tend to be higher in the dry farming systems than in the moist systems. From 1970 to the present, regional cattle, goat, and sheep numbers have growth moderately, but poultry and pig populations have grown faster at around 3%/year. Between 2000 and 2030, livestock and poultry numbers are projected to grow at a moderate rate, due to expansion of urban consumer demand for meat, milk, and eggs. This growth is due partly to “free range” livestock raised in savanna areas, and partly to more intensive crop production systems in higher, more disease-free environments. In the latter case, the animals do not use much land themselves, but the fodder crops and residues do.

3. The Fertilizer-Environment Interface

It is now a well-known fact that agricultural activities affect and are affected by the quality of the environment. A major, paradoxical, challenge is the challenge of “preserving access to the environment and its resources AND improving the standard of living.” Here, public interest also meets private gain. A clean environment is appreciated, but we do not want to pay very much to achieve it (FAO, 2003b). The fertilizer-environment interface can roughly be characterized by two types of pressures—one where overuse of fertilizers causes other ecosystem services to be jeopardized (“too much”) and one where under use of fertilizers contributes to depletion of soil carbon and soil fertility and to high rates of area expansion for crop and animal production (“too little”).

3.1 Too Much—Nutrient Loading

High Fertilizer Rates, Low Fertilizer Use Efficiency—At best, 50% of N, 10%-20% of P, and 50% of K applied in mineral fertilizer is taken up by the aboveground plant parts. In spite of major achievements in plant breeding, higher uptake rates have so far hardly been realized (e.g., Mosier et al., 2004). The fertilizer nutrients not taken up stay in the soil or are lost to the environment (OUT 3-5 in Figure 3). In some parts of the world, these losses are high. Table 7 shows that, for example, in The Netherlands more than 500,000 tons of N is not utilized by crops and grasses and adds to loading of the soil and the atmosphere. The "too much" problem is amplified here as a result of the high inputs of organic manure (IN 2), due to imports of feedstuffs from Asia and the Americas. This type of pollution does not occur in Africa on a large scale. Of the 15 Farming Systems depicted by Dixon et al. (2001), only irrigated agriculture and peri-urban agriculture occasionally receive very high levels of mineral fertilizers. Gaseous emissions in Africa through synthetic fertilizers are expected to be quite low, even in the decades to come (Bouwman, 1997).

Table 7. Nitrogen Budgets of the Agricultural Land in the Netherlands[a] in 1986, 1990, and 1996 (thousands of tons per year)

Description of Items	1986	1990	1996
Inputs			
Fertilizers (net)	492	403	392
Animal manures (net)	496	479	519
Atmospheric deposition	84	82	60
Planting materials	15	18	19
Other inputs	20	20	18
Total net input	1107	1,002	1,008
Output			
Harvested crops and herbage	489	497	473
Inputs–Output			
Net loading of the soil and the atmosphere	618	505	535

a. Inputs via animal manure and fertilizers are corrected for losses via ammonia volatilization and represent net inputs (Oenema et al., 1998).

Nutrient Loading in River Systems—Most MEA scenarios project that the global flux of N to coastal ecosystems will increase by a further 10%–20% by 2030. River N will not change in most industrial countries, while a 20%–30% increase is projected for developing countries. This is a consequence of increasing N inputs to surface water associated with urbanization, sanitation, development of sewerage systems, and lagging wastewater treatment, as well as increasing food production and associated inputs of N fertilizer, animal manure, atmospheric N deposition, and biological N fixation in agricultural systems. Growing river N loads will lead to increased incidence of problems associated with eutrophication in coastal seas. Since 1960 flows of reactive (biologically available) N in terrestrial ecosystems have doubled, and flows of P have tripled. This may become an issue in Africa as urbanization progresses, but is not immediately related to current fertilizer use.

Greenhouse Gases—Natural processes in wetland ecosystems account for about 25%–30% of current methane emissions, and about 30% of emissions are due to agriculture (ruminant animals and rice paddies). Ecosystem sources account for about 90% of current N_2O emissions, with 35% of emissions from agricultural systems, primarily driven by fertilizer use. Africa, however, does not contribute significantly to these emissions.

Acidification—Many African soils are acidic because of old age, and acidification is stimulated when land is stripped of its natural vegetation and cultivated. Mineral fertilizers may aggravate the process, particularly when they are ammonium-based (ammonium sulfate [AS], calcium ammonium nitrate [CAN], urea, and diammonium phosphate [DAP]). The collation of long-term data collected by Smaling and Braun (1996) for a series of trial sites across rainfed Kenya, Bado et al. (1997) for western Burkina Faso, and Vanlauwe and Giller (2006) for the West African moist savanna zone showed that pH declines under no inputs and under acidifying fertilizers can reach up to one full unit in 5-10 years. Application of lime or dolomite can prevent and rectify this situation, but manure also helps.

3.2 Too Little—Nutrient Mining

Nutrient Depletion—In sub-Saharan Africa, nutrient outputs tend to be greater than nutrient inputs. A continental study pointed in that direction (Stoorvogel et al., 1993), and similar conclusions were reached in a recent study by IFDC (Henao and Baanante, 2006). Figure 4 provides the summary outcome for N for the continental study. An average of 22-26 kg N is lost per hectare per year, mainly due to removal of harvested product (OUT 1) and erosion (OUT 5). Hence, nutrient depletion is a reality *at the macro-level* of sub-Saharan Africa. Although bright spots do exist, the above findings were to a large extent confirmed by case studies at lower spatial scales.

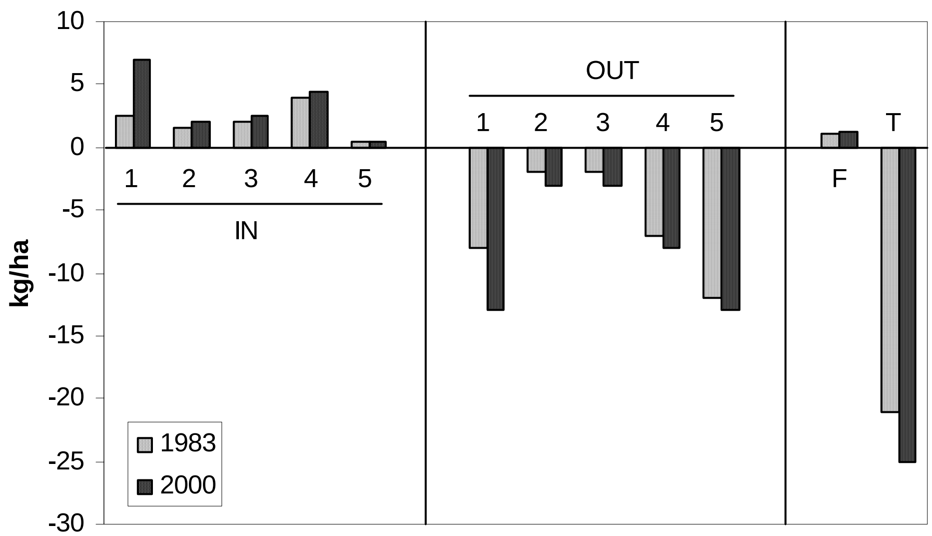

Figure 4. Nitrogen Balance in Sub-Saharan Africa (Stoorvogel et al., 1993), Estimates for 1982-1984, Projections for 2000) (INs and OUTs are Given in Figure 3, F = Fallow, T = Total)

An FAO study shows that at a lower district level, cash crops and tree crops tend to have "better" nutrient balances than do annual food and fodder crops (Table 8; FAO, 2004). Either they receive more fertilizer and manure (coffee, cotton) or they are soil protecting and deep rooting (cocoa, oil palm). In farming systems where cash crops and food and fodder crops are rotated or grown side-by-side, the "more depleting" and "less depleting" components are often interlinked by scavenging on residual fertilizers, preferential manuring of certain plots and crops, or moving crop residues from one plot to the next. Napier grass in Kenya's highlands, after having been fed to stalled livestock, often ends up as manure on neighboring plots with cash crops. Subsistence farmers, relying on just one or two staple crops without external inputs are those most in need of fertilizers as they have few options to improve their management systems in the ways described above.

Table 8. District-Level Nutrient Balances (kg/ha per year), Singling Out Cash Crops (FAO, 2004)

Study Area and Crop	N	P	K
Ghana, Nkawie District	-18	-2	-20
Cocoa	-3	0	-9
Ghana, Wassa Amenfi District	-4	-1	-11
Cocoa	-2	0	-9
Kenya, Embu District	-96	-15	-33
Coffee	-39	-8	-7
Tea	-16	-1	-2
Mali, Koutiala Region	-12	1	-7
Cotton	-14	12	17

Unchecked nutrient depletion eventually leads to a situation as shown in Figure 5. Two hypothetical soils with N stocks of 4,500 and 1,500 kg/ha are subjected to continuous cultivation without mineral and organic fertilizers. In Phase I, nutrient mining takes place but yields are still constant. Assuming that no factors other than N are limiting crop production, yields remain constant as long as the amount of mineralized soil N exceeds crop requirements. This phase takes a longer period of time in richer soils. Phase II starts when soil supply and crop uptake match. From that moment, yields go down, alongside N stocks. Phase III is reached when yields are stabilizing at very low levels. Here, N uptake roughly equals small inputs by atmospheric deposition and biological fixation.

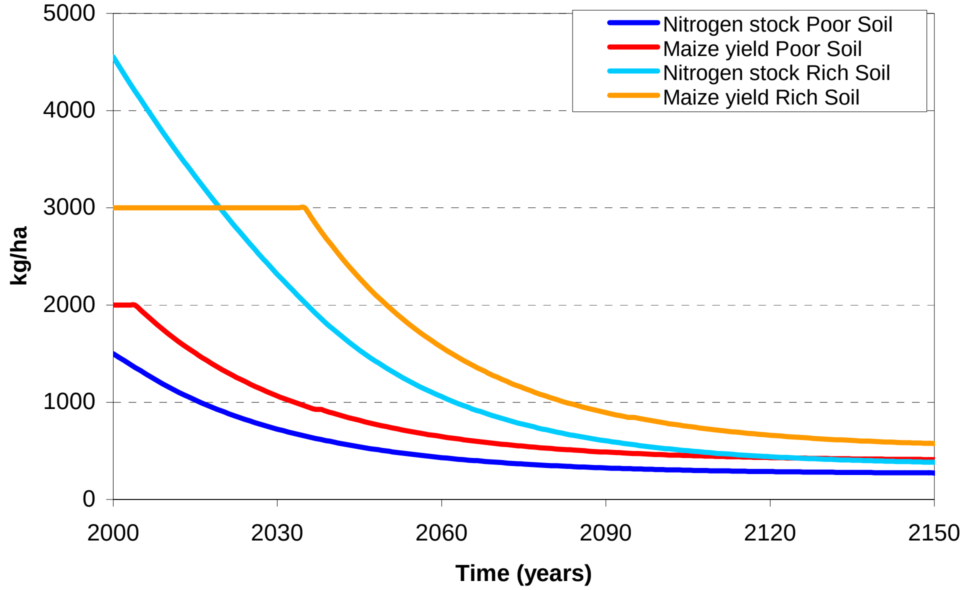

Figure 5. Model of Soil N and Crop Yield Dynamics in No-Input System (FAO, 2004)

Organic Matter Decline—Organic matter levels of agricultural land are below those of virgin land, as the rapidly decomposable part of the organic matter disappears quickly upon the removal of vegetation (see also De Ridder et al., 2004). Breman et al. (2004) provide an interesting data set on total organic matter in West Africa (Table 9). Soil organic matter levels in “cropland and overexploited rangeland” are just over one-third of those under “well-protected natural vegetation”. In contrast, “intensive and sustainable agriculture” manages to maintain levels that are relatively close to the organic matter contents in “well-protected natural vegetation” in the drier agro-ecological zones but not in the Guinea Savannah Zone.

Table 9. Variability of Aboveground and Topsoil Organic Matter (ton per hectare dry matter) Under Different Conditions in Sahelian Countries (Breman et al., 2004)

	Sahel	Sudan Savannah	Guinea Savannah
Soil organic matter			
Well-protected natural vegetation	27	54	106
Exploited present vegetations	18	36	71
Cropland and over-exploited rangeland	10	19	38
Intensive and sustainable agriculture	12–25	25–50	25–50
Roots			
Well-protected natural vegetation	2	8	22
Exploited present vegetations	1.5	7	19
Cropland and over-exploited rangeland	1	4	9
Intensive and sustainable agriculture	2–3	6–10	7–17
Aboveground phytomass			
Well-protected natural vegetation	2	11	41
Exploited present vegetations	1.5	8	36
Cropland and over-exploited rangeland	1	5	16
Intensive and sustainable agriculture	2–3	6–11	7–25

3.3 Further Considerations

MEA (2005) addresses the issue that one ecosystem service often causes the degradation of other services. For example, because actions to increase food production typically involve increased use of water and fertilizers or expansion of the area of cultivated land, these same actions reduce the availability of water for other uses, degrade water quality, reduce biodiversity, and decrease forest cover, which in turn may lead to the loss of forest products and the release of greenhouse gasses. Hence, it seems that land uses are incompatible, i.e., a plot is either under agriculture, rangeland, or forest or woodland. On a larger scale, however, this “zero-sum” situation is no longer valid. Combinations or mosaics of land uses are possible that together provide more ecosystem services than the sum of the parts (Swift et al., 2004). “Landscape” level approaches may therefore have added value compared with plot and farm level approaches in addressing ecosystem services. A rather unexpected synergy is shown in Figure 6. Wildlife habitats and wildlife numbers per country in Africa turned out to be positively correlated with the intensity of fertilizer use (Breman, 2002). Hence, nature protection has a chance to be effective where agricultural intensification allows farmers to make a living from their land without consuming the entire area.

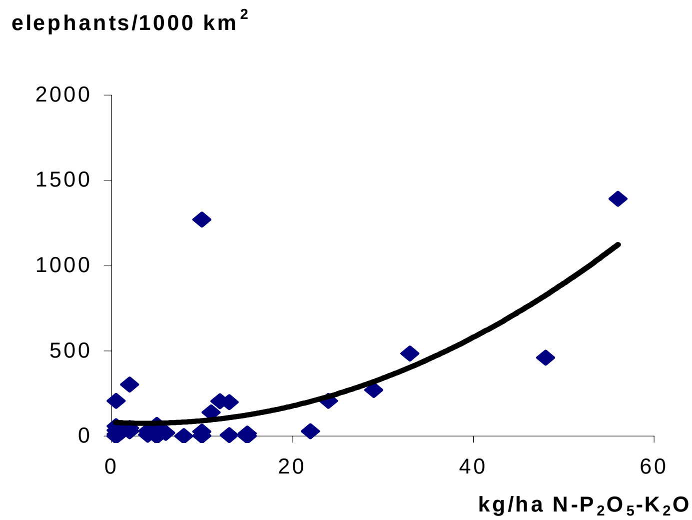

Figure 6. The Elephant Density on Elephant Range in Relation to the Use of N, P, and K Fertilizer on Cropland Per Country in sub-Saharan Africa (Breman, 2002).

Many tradeoffs associated with ecosystem services are expressed in areas remote from the site of degradation. For example, conversion of forests to agriculture can affect water quality and flood frequency downstream of where the ecosystem change occurred. Increased application of N fertilizers to croplands can have negative impacts on coastal water quality. These tradeoffs are rarely taken fully into account in decision-making, partly due to the sectoral nature of planning and partly because some of the effects are also displaced in time (such as long-term climate impacts).

Another mechanism of importance is that land use change brings about positive and negative feedbacks that cause changes to proceed non-linearly. Overgrazing, for example, causes loss of vegetation and land cover, which triggers soil physical deterioration that again leads to enhanced wind and water erosion. Similarly, taking out too much bushmeat from land under natural vegetation causes a decline in animal population and biodiversity as well as a decline in protein intake and health of the population. This increases the need to clear more vegetation for agriculture now that the bushmeat is no longer amply available. Loss of vegetation also decreases water cycling and rainfall, leading to loss of production and living space.

In addressing the fertilizer-environment interface, tailoring fertilizer use to soil conditions, crop needs, and desired production levels represents the optimal situation, where both yields and nutrient use efficiency are high, and where marginal areas can be left under natural vegetation or mosaic landscapes can be developed. This quest for synergies and some degree of optimization of land use and cover is key to the GEF in its efforts to address Land Degradation, Biodiversity Management, Carbon Sequestration and International Water Management in an integrated way. The programming document for GEF Phase IV (2006-2010) singles out a number of strategic objectives that link the different agendas for its focal areas. “Mainstreaming biodiversity within productive landscapes and adaptation to climate” is the most relevant.

4. Realities Concerning the Fertilizer Environment Interface in Africa

- *The myth that fertilizers are always bad for the environment* is hard to eradicate in some circles. Fertilizers have been, still are, and will be indispensable in future to feed the world population. The Nobel Prizes for Haber and Bosch, who developed the procedure to combine nitrogen and hydrogen into a fertilizing agent, were well-deserved. Where fertilizer is often seen as the culprit, it is the policies and the management surrounding its use which are causing environmental strain.

- *Fertilizers are relatively expensive in a risk-averse environment,* triggering nutrient mining and the need to clear more land currently under natural vegetation. Spot checks reported by Sanchez (2002) indicated that a metric ton of urea at that time cost about US $90 in Europe; $120 delivered in the ports of Mombasa, Kenya or Beira, Mozambique; but $400 in Western Kenya, $500 across the border in Eastern Uganda, and not less than $770 in Malawi.

- *Liberalization* of the fertilizer market may have been a relief to government budgets, but the supply response in Africa by the private sector is mostly weak and unreliable (including tampering with fertilizer content and quality). In addition, the forced abolishment of formerly well-functioning vertical supply chains has undermined shareholder trust and credibility of parastatals; the Compagnie Malienne pour le Developpement des Textiles (CMDT) in Mali is a case in point (Kangasniemi, 2002).

- *Fertilizers improve the low native soil fertility.* To realize higher levels of self-sufficiency in the future, fertilizer use in Africa must increase a lot faster than the <2%/year currently projected (Table 2).

- *Fertilizers help in reducing nutrient mining.* Fertilizer use efficiency generally ranging between 10% and 50% implies that nutrient inputs through fertilizer (IN 1) are always higher than the extra nutrient outputs through increased production (OUT 1) and residues (OUT 2).

- *Fertilizer use can reduce the need to clear natural vegetation for cultivation*, and targeted production can be realized from smaller tracts of land. As such, it saves forest, savanna, wildlife, rangeland, and biodiversity from degrading and declining. These are positive externalities of fertilizer use that receive little attention.

- *Fertilizers help in sequestering carbon* through increased root mass and crop residue production, but only under systems of reduced tillage so as to dampen decomposition rates.

- *Next to "too much" and "too little"* use, *unbalanced fertilizer use* is detrimental, as often seen in irrigated rice systems in Asia. Cheap urea is applied at very high rates as compared with the application of other nutrients, leading to very low N recovery in rice, and increased mining of the nutrients that were not applied in the fertilizer. Table 3 gives an example of higher K uptake by maize in fields that received N or P than in the fields that received no fertilizer at all. Some bio-availability problems of micronutrients (iron [Fe], zinc [Zn]) may occur under high P applications (Buerkert et al., 1998; Slingerland et al., 2006) and deserve attention. Also, combinations of mineral and organic fertilizers address agricultural production AND the maintenance of non-market ecosystem services better than mineral fertilizers alone. *Acidification* is also reduced by a combination of mineral and organic fertilizers, but lime and dolomite can more effectively and instantly cause pH and yield increases.

5. Avenues to Environmentally Benign, Increased Use of Fertilizers in Africa

International Policy Issues

- *Build Advocacy and International Clout*—At the level of the African Union (AU) and the New Partnership for African Development (NEPAD), it should be realized that Africa is poorly endowed in terms of soil fertility. The low use of fertilizers aggravates this problem and will lead to further area expansion, nutrient mining, and low yields. Africa has a right to be compensated, because international policies do not take this unlevel playing field into account. Also, in a period where food aid tends to become mainstreamed, and receiving governments are even pressured to accept, against their will, genetically modified food aid from surplus countries, the aim should be that the World Food Programme only serves emergency situations with surpluses obtained from the region itself. *Inaction implies further increases in food imports for Africa*. Henao and Baanante (2006) mention that in 2003, Africa imported about 43 million tons of cereals at a cost of $7.5 billion, and is projected to import about 60 million tons by the year 2020 at a cost of $14 billion. Is that a desirable situation, particularly if not matched by export earnings of the same magnitude?

- *Call for a Revision of Fertilizer Subsidy Systems at International Level*—Government subsidies paid to the agricultural sectors of the Organization for Economic Cooperation and Development (OECD) countries between 2001 and 2003 averaged over $324 billion annually or one-third the global value of agricultural products in 2000. A significant proportion of this total involved production subsidies that led to greater food production in industrial countries than the global market conditions warranted, promoted overuse of fertilizers and pesticides in those countries, and reduced the profitability of agriculture in developing countries. Many countries outside the OECD also have inappropriate input and production subsidies, and inappropriate subsidies are common in other sectors such as water, fisheries, and forestry. Compensatory mechanisms are needed for poor people who are adversely affected by the removal of subsidies, and removal of agricultural subsidies within the OECD would need to be accompanied by actions designed to minimize adverse impacts on ecosystem services in developing countries (MEA, 2005).

- *Build Strategies on Key Issues for Africa: Urbanization, "Empty" Land, and Fragile Frontier Zones.* A strategy is needed at the level of AU and NEPAD, and at regional levels on the continent, to focus on a future with growing cities and changing dietary preferences (Figure 7). To what extent should the continent provide all the food and feed needs by itself? What will be the fertilizer needs and how will further environmental degradation be halted? How should the currently "empty" Miombo woodlands and Guinea Savanna zones be used or protected? Should Africa consider approaches followed in the South American cerrados and llanos, which are agro-ecologically not too different, and where good pasture management was able to keep soil fertility levels close to and even above original savanna levels (Lilienfein et al., 2003)? What fertilizer and environmental protection policies are needed for the fragile frontier zones, both in dry lands and at the forest margins?

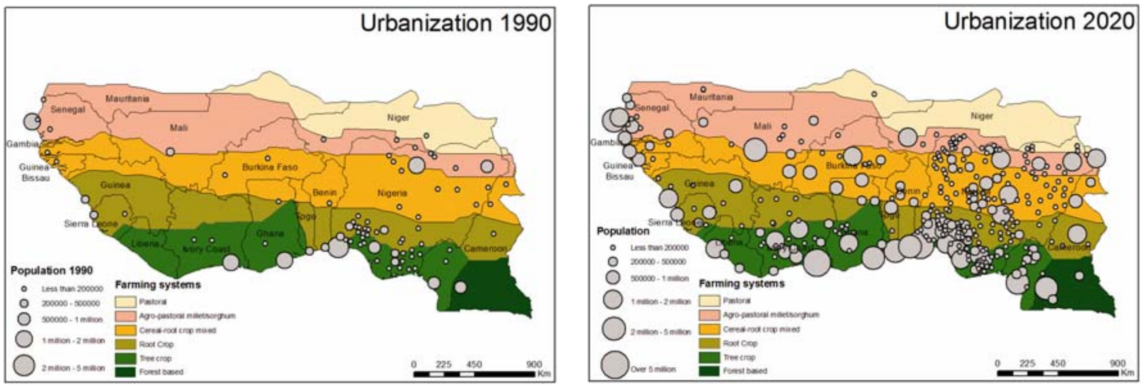

Figure 7. Urbanization in West Africa in 1990 and Projections for 2020 (based on Cour and Snrech, 1998)

- *Operationalize Benefits From Synergies Between GEF Focal Areas*—The premise is that more, more efficient, and more spatially explicit use of fertilizers (and manure and other amendments) can reduce the conversion rate from forest and woodland to agriculture, saving biodiversity, adding to carbon sequestration in two ways (directly and off-site), and limiting the risk of pollution of major water courses, rivers, and wetlands. These are also tradeoffs between private and global benefits, and are at the heart of GEF and the conventions to which it is attached. Soil fertility and organic matter restoration should partly be regarded as a social cost with global environmental benefits (see also Izac, 1997), and these costs could be borne by funding mechanisms running parallel to current Kyoto-driven carbon funds. *After all, carbon sequestration in African soils is almost tantamount to soil fertility conservation.*

National Policy and Institutional Issues

- *Improve the Legal Framework Against Pollution, Soil Degradation, and Land Use and Cover Change (Alongside Continental Initiatives Such as Terrafrica)*—Since 1991, the European Union (EU) has had a Nitrates Directive, concerning the protection of waters against pollution caused by nitrates from agricultural sources. This directive recognizes that while the use of N-containing fertilizers and manure is necessary for EU agriculture, any overuse of fertilizers and manure constitutes an environmental risk. The objectives of the directive are to ensure that the nitrate concentration in freshwater and groundwater supplies does not exceed the limit of 50 mg NO_3-/L, as imposed by the EU Drinking Water Directive, and to control the incidence of eutrophication. The measures also include a maximum limit for the addition of livestock manure equivalent to 170 kg N/ha. Africa may need a similar common legal framework that allows monitoring of pressures, the status and impacts of fertilizer (non-)use, agricultural production and yields, and environmental sustainability.

- *Develop Knowledge Management, and Monitoring and Evaluation Instruments*—Current knowledge regarding fertilizers and the environment is poorly reflected in legal frameworks and in extension messages. Also, there is a general absence of monitoring and evaluation mechanisms, environmental reporting systems, and strategies that link resource quality and dynamics to future targets in agriculture, livestock development, and forestry. The Driving Forces-Pressures-State-Impact-Response (DPSIR) framework, used by the European Environmental Agency and by GEF (Gisladottir and Stocking, 2005), is a convenient representation of the linkages between the driving forces and the pressures exerted on the land by human activities, the change in quality (state, impact) of the resource, and the response to these changes as society attempts to release the pressure or to rehabilitate land that has been degraded. The interchanges among these form a continuous feedback mechanism that can be monitored and used for assessment of land quality and degradation. Finally, market surveys and information systems are also poorly developed, hindering fertilizer use development. Information assembled by FAO on a country-by-country basis could also be put to more effective use. Some examples are given in Annex 2.

- *Develop Reward Systems for Protecting Non-Market Ecosystem Services*—The population should be rewarded for safeguarding non-market ecosystem services at the district and catchment level. At this level, land use mosaics (agriculture, livestock, forest and woodland, wetlands, built-up areas, infrastructure) can be developed that have multiple (private and global) benefits and high total system productivity.

- *Support Pluralism in Approaches*—Documented successes on packaging of small amounts of fertilizer, often in combination with cereal and legume seed (micro-dosing), deserve attention as a scaling-up mechanism, with a focus on the steep parts of the production curve, which are within reach of poorer farmers. The larger scale Millennium Village approach, however, should be followed closely as well. As long as we do not know what works best in the long run, a pluralistic approach is the best value for money. Proper monitoring and evaluation will then lead to conclusions on best policies and best technologies for different agro-ecozones.

Technical Issues

- *Correct Acidity and Currently Low P Levels and Avoid P Depletion When Still Possible* by large-scale subsidized application of rock or higher-solubility phosphates and lime or dolomites. This approach will remove at least one major constraint to production and ecosystem viability, and make following investments more profitable. Unutilized P largely stays in the soil and has positive residual effects for many years. Attention should be given to reduced bio-availability of micronutrients (Fe, Zn) on high P applications (Buerkert et al., 1998; Slingerland et al., 2006). Here, two birds may be killed by one stone, realizing higher yields and better-value diets. Breman et al. (2003) showed that investments in soils are less than one-tenth of investments in small-scale irrigation, while the cost:benefit ratios are more favorable. In spite of this, in 2003, FAO and World Bank had US $800 million in the pipeline for irrigation projects against US $1 million for soil improvement projects.

- *Promote Integrated Nutrient Management (INM) and Make Use of Agronomic and Spatial Efficiency Gains*—INM can be regarded as the judicious and integrated manipulation of the terms in the nutrient balance (Figure 3). Fertilizers play a role, but so do manure, crop-livestock interaction, N-fixing species, rotations, erosion control, agroforestry, and conservation tillage. The successful introduction of maize/soybean and millet/cowpea systems in West Africa has generated multiple private and global environmental benefits (Sanginga et al., 2003). INM is a "basket of options" rather than a single solution. Farmers' exchange of "best practices" from this basket of options may help to optimize the fertilizer-environment interface. There is a lot of information that can help to better target fertilizer use in an efficient, environmentally benign, and profitable way. Large strides are possible towards more efficient fertilizer application, i.e., based on the “ideal” N-P-K ratio in plants and not on soil tests alone. The pH and secondary and micronutrients levels need to be checked from time to time for corrective measures. Fertilizer response programs in Kenya, for example, clearly show where N or P fertilizer is the proper answer, and where a combination of both is needed (Table 3). Similarly, in many West-African villages with their typical ring-based agricultural architecture, fertilizers applied in the home fields address conditions that are markedly different from those in bushfields (Table 4). A sound strategy could be to gradually expand the home fields, releasing the pressure on bushfields and maintaining mosaic landscapes.

- *Stimulate Development of Tools for Environmental Economics and for Calculating Trade-Offs Between Economic and Ecological Goals*—A hypothetical, simplified example strongly related to this paper is—double yields on the 50% best soils and leave the other 50% to recuperate, sequester carbon, develop biodiversity, and perform non-market ecosystem services. Then make an analysis including private as well as global environmental costs and benefits. Doubling yields is technically possible but has a price, because more fertilizer has to be produced, transported, and sold and it takes extra labor and skills to get the fertilizer into the crop in the right amounts and under the right management system. Surpluses will have to be distributed to the areas that are taken out of production. This again has a cost, and farmers in marginal areas have to be given different options to make a living. At the same time, 50% of formerly agricultural land is allowed to remain idle and contribute to global environmental benefits. These landscapes may be turned into “protected areas” and have to be guarded, alongside the co-management systems that prevail around many African game parks. This is a difficult ledger to balance but certainly a challenge to be tested at some smaller scale. Less drastic is to do something similar, but at landscape level (mosaic) or at village level (intensify inner rings). One thing is clear—we tend to live in an economic world, where some ecological issues have to be solved. It is time to look upon things the other way around as well and to strike a balance somewhere.

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Annex 1. Fertilizer Production, Consumption, and Export Volumes (FAOSTAT, 2002)

Fertilizer Production in Africa (2002, tons)

Country	N	P
Algeria	78,700	8,000
Egypt	1,548,409	186,977
Libyan Arab Jamahiriya	389,600	0
Mauritius	15,300	0
Morocco	349,500	1,220,000
Senegal	33,900	28,800
South Africa	298,400	280,000
Tunisia	282,050	972,450
Zimbabwe	61,100	38,250

Fertilizer Export Volumes in Africa (2002, tons)

Country	N	P
Algeria	77,500	2,000
Egypt	505,468	44,798
Libyan Arab Jamahiriya	314,600	0
Mauritius	15,300	0
Morocco	281,482	1,039,976
Senegal	33,900	28,800
South Africa	298,400	280,000
Tunisia	219,909	913,697
Zimbabwe	61,000	38,250

Annex 1 (continued)

Fertilizer Consumption in Africa (2002, tons)
Countries With Total Consumption Below 500 tons (Cape Verde, Comoros, Rep. Congo, Gabon, Namibia, Seychelles, Sierra Leone) are Omitted

Country	N	P	K
Algeria	48,000	28,000	22,000
Benin	25,541	12,300	10,000
Botswana	4,100	300	200
Burkina Faso	926	463	282
Burundi	852	711	976
Cameroon	13,149	8,638	13,112
Central African Republic	200	200	200
Chad	11,000	2,000	4,500
Congo, Dem Republic of	3,785	4,599	2,129
Côte d'Ivoire	53,000	30,000	26,000
Egypt	1,068,923	142,179	57,701
Eritrea	2,625	1,051	
Ethiopia	77,373	72,659	
Gambia	600	100	100
Ghana	14,170	8,590	8,270
Guinea	1,000	1,400	800
Guinea-Bissau	1,000	700	700
Kenya	56,961	82,548	3,249
Lesotho	4,900	3,400	3,000
Libyan Arab Jamahiriya	17,700	39,200	5,000
Madagascar	2,182	3,975	2,968
Malawi	130,253	28,979	33,776
Mali	14,000	14,000	14,000
Mauritania	2,900		
Mauritius	6,900	8,000	10,100
Morocco	249,000	100,000	50,000
Mozambique	16,000	2,000	6,900
Niger	3,360	970	640
Nigeria	94,400	41,400	30,400
Rwanda	5,164	5,087	5,048
Réunion	2,300	1,500	1,200
Senegal	21,382	6,000	6,109
Somalia	500		
South Africa	570,800	231,200	163,100
Sudan	54,596	11,100	3,800
Swaziland	2,000	2,500	2,500
Tanzania, United Rep of	6,206	442	500
Togo	7,172	4,927	4,956
Tunisia	56,000	41,000	5,000
Uganda	4,330	2,698	2,278
Zambia	33,296	15,523	16,349
Zimbabwe	60,000	30,000	20,000
Total	**2,749,366**	**990,865**	**538,170**

Annex 2. "Fertilizer Use by Crop" Documents by FAO (www.fao.org/ag/agl)

Fertilizer use by crop in Egypt

Agricultural land accounts for only 3.5% of the land area of Egypt. Two-thirds of the agricultural land is alluvial soil, fertilized for thousands of years by the Nile floods, and one-third is land recovered since the 1950s. Rainfall is minimal and almost all the agricultural land is irrigated. Soil salinity and water logging are important problems in the reclaimed areas. Sprinkler irrigation and drip irrigation are common on the recovered area and fertigation is used on 13% of the land. There are up to three harvests per year, the overall cropping intensity being 180%. Crop yields and rates of fertilizer use are relatively high. In order to provide for a large and increasing population, while economizing scarce resources and minimizing adverse environmental impacts, the efficiency of use of both fertilizers and water needs to be improved. Continuing efforts must be made to communicate information on the best practices to a generally receptive farmer audience. Farmers' Field Schools make an important contribution to the transfer of information.

Fertilizer use by crop in Ghana

Ghana has extensive areas of land suitable for agriculture but the soils are productive only with proper management. Traditional, soil exhausting, cultivation practices are still used extensively. The average rate of fertilizer application on most crops is low and the removal and loss of plant nutrients substantially exceed their replacement. After a period of rapid increase in the 1970s, the consumption of fertilizers started to decline in the early 1980s and only recently recovered its former level. Most crops respond economically to fertilizers and organic manure. Inadequate credit facilities, unsatisfactory produce marketing arrangements and the relatively small area receiving irrigation, despite the underutilization of several large irrigation projects, are among the identified constraints to increased fertilizer use.

Fertilizer use by crop in South Africa

Only 14% of the total land area of South Africa receives sufficient rainfall for arable crop production and periodic droughts affect the rainfed arable areas. The irrigated area accounts for less than 10% of the total arable area but provides a substantial proportion of the value of the country's total agricultural output. Governmental support and regulation of the agricultural and fertilizer sectors have been greatly reduced, resulting in the closure of some fertilizer plants and in marginal cereal areas being taken out of cultivation. Forty percent of the South African population lives in poverty, mostly in rural areas. An increase in the purchasing power of this sector of the population would stimulate the demand for food and indirectly for fertilizers. A proper use of fertilizers would help to improve the productivity and income of smallholders.

Fertilizer use by crop in Zimbabwe

Zimbabwe's economy is heavily reliant on its agriculture sector. Until 2000 there were two dominant subsectors—a large-scale commercial subsector with a relatively small number of large farms located mostly on the better land; and a large number of small farms in the smallholder subsector. Most of the fertilizer use was in the large-scale subsector, with only one-fifth of smallholders using fertilizers. In 2000, the State initiated an agrarian reform policy and took over most of the large-scale farming area for redistribution. Fertilizer consumption has since fallen sharply. There is concern about degradation of the often fragile soils. Fertilizer production has fallen as a consequence of both reduced demand and financial difficulties encountered by manufacturers.

Fertilizer use by crop in the Sudan

The Sudan has almost 17 million ha of cultivated land, and the potentially cultivable area is much larger. It is the largest area of cultivable land in the Arab world. The agricultural and livestock sectors make an important contribution to the national economy. The climate is hot and rainfall uncertain but the Blue and White Nile Rivers have enabled the development of large irrigation schemes. However, the rainfed sector, which provides a livelihood for the majority of the population, has been neglected. The productivity of the irrigation schemes has declined in recent years. Food production has increased because of expansion in the cropped area, while yields have tended to fall. Outside the irrigation schemes, farmers use little fertilizer. Even in the scheme areas, fertilizers are underused. Overall, fertilizer use is at a very low level.