

Profitable and Sustainable Nutrient Management Systems for East and Southern African Smallholder Farming Systems – Challenges and Opportunities

A synthesis of the Eastern and Southern Africa situation in terms of past experiences, present and future opportunities in promoting nutrients use in Africa

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Executive Summary

Sustainable agricultural intensification is still one of the major issues to meet the growing demand for food in the coming decades, and to make sub-Saharan Africa (SSA) a food-secure sub-continent. The majority of soils in SSA are unsuitable for intensified crop production without thorough recognition of their inherent soil fertility constraints. In addition, continued mining of soils during the past decades has rendered even originally fertile soils low-productive. The combined average depletion rate of N, P and K of all SSA countries is 54 kg/ha/yr. Thus, not surprisingly, nutrient limitation is the major bottleneck for increasing yields in Africa. However, nutrient depletion rates vary significantly spatially, depending on the overall crop productivity level and farmer's access to fertilizer. Site/region-specific knowledge of the soil fertility levels is thus a precondition for the establishment of profitable and sustainable nutrient management systems.

It has been argued that in the short term, chemical fertilizers are the best way to feed Africa. Clearly, this is because fertilizer consumption of SSA is stagnating at a mere 8-12 kg/ha/yr since at least last ten years. In 2010, none of the SSA countries reached the 50 kg/ha/yr target set by the Abuja Fertilizer Summit in 2006 to be reached on average for SSA in 2015. Lack of enabling policies for the private industry, poor infrastructure (access to fertilizer), and low demand by fertilizer consumers, especially in rural areas of SSA, are three major causes of low consumption. The benefit-cost ratio often is too low to encourage farmers to apply fertilizer, because of the relatively high fertilizer price at farm gate, the low market price of food crops like maize and the high year-to-year variability of the agronomic efficiency of fertilizer applied. An overestimation of the risk of failure to break even when applying fertilizer by farmers adds to the dilemma. Furthermore, fertilizer recommendations developed in the past often ignore differences between soils and are highly incompatible with smallholders' resources.

To develop and disseminate appropriate nutrient management recommendations, up-to-date and spatially explicit information about the condition and trend of soil health is necessary. Results of the CIAT-led Africa Soil Information Service (AfsIS) project showed that, clearly, N and P were not the only yield constraining factors in SSA. K-deficiency was common and multi-nutrient deficiency observed in 15 % of the sites. Mid-Infrared Spectroscopy (MIRS) in combination with multivariate statistical analysis allowed for describing soils in terms of their inherent yield potential, and as such offering the potential to bypass labour, money and time-consuming lab-based wet-chemistry analysis. MIRS, however, is still in its infancies and further research is required to consolidate this promising technology for broader scale, mainstream application.

The optimal technical approach of SSA countries to increase the use of mineral fertilizer is likely to be a function of a number of location-specific, agro-climatic, demographic and economic variables. In most SSA countries the private sector was not able to stop the decrease in total fertilizer consumption after market liberalisation and abolishment of subsidies. After the re-introduction of targeted fertiliser subsidies in the 2000s, some East and Southern African countries (Malawi, Zambia and Tanzania) have realised increased fertiliser consumption growth. Key policy measures for the establishment of well-functioning fertilizer markets are: the establishment of a consistent and predictable price (subsidized, if warranted) and trade policy, introduction of risk-sharing financial mechanisms, investment in human capital development (farmers and private sector), development and enforcement of fertilizer legislation and regulatory framework.

Farm-scale bio-economic models, like APSFARM, offer the possibility to quantify benefits from the

adoption of alternative technologies, aiming at identifying “best-fit” pathways out of poverty. Results of such modelling analysis revealed that for the poorest farmers in East and Southern Africa, investment in N-fertilizer would be difficult to finance and therefore, to increase nutrient inputs, these farmers might need to initially rely on cheaper options, such as rotation with N-fixing legumes.

Two sustainable, intensified nutrient management concepts, that have been proven successful in farmer’s field, are Integrated Soil Fertility Management (ISFM) and Conservation Agriculture (CA). ISFM includes the combined use of mineral fertilizer and organic resources management with the aim to improve agronomic efficiency and crop yields. These components and others (e.g. improved varieties) can be adopted stepwise. CA, on the other hand, is advocated as a package that the farmer should preferably adopt as a whole. Also, CA is stricter than ISFM in regard to the must-have key components, above all minimum tillage and surface residue retention. Even though proven profitable in the long-run, the attractiveness of ISFM and CA is often impaired by smallholders’ limited resources (money, labour) as well as the delayed responsiveness in terms of improved yields. In mixed crop-livestock systems it is primarily the competition for crop residues that vitiate the farmer’s willingness to adopt. Farmers keeping livestock see little value in leaving residues on top of the soil (CA) or incorporating it into the soil (ISFM). Feeding residues to the animals is considered a much better investment. Research is needed to identify the true value of residues, so as to be able to balance the competing uses. Both, ISFM and CA, intend to move farmers out of subsistence and therefore depend on access to input (credit, fertilizer, herbicides, and modern varieties) and output markets (selling surplus production). They also are knowledge intensive as far as management of residues, fertilizer, herbicides and (zero-tillage) direct seeding of crops is concerned. We believe that the combination of ISFM and CA, which we named ISFM+ — i.e. working towards full adoption of CA but using the step-wise approach of ISFM — allows for easier, smoother and faster adoption, as farmers can implement improved management components at the pace they feel comfortable with.

Innovation Platforms offer a promising way to put farmers into the position to link with the fertilizer and agro-input sector, as well as to establish collaboration with the (micro-) finance sector, NGOs or (contract farming) companies that provide such services. Combining IPs and the stepwise adoption of ISFM+ seems to be a powerful alliance to move farmers into intensified, sustainable production.

During the last 1-7 years a new generation of entrepreneurs has appeared in the agricultural development arena, with in part sizeable financial means, a clear goal-driven agenda and an impressive short-term track record. We believe that these players in combination with the renewed strong interest of the classic major stakeholders (such as The World Bank) in agricultural development provide reason for optimism that after some decades of stagnation there is now the time to achieve notable impact in sub-Saharan Africa for intensifying farming systems in a sustainable manner. Yet, most of these new players will require, and indeed explicitly ask for, scientific backup to make sure that their chosen intensification pathways are not only profitable in the short run, but also sustainable in the long run.

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Introduction

Population growth and dietary change is projected to drive global food demand to unprecedented levels. To keep pace, food production will have to increase 70 % by 2050 (Bruinsma 2009). Even though 2001-2010 was perceived as a “decade of growth”, Africa’s agricultural sector’s growth has lagged behind national economic growth. This slow growth is an obstacle to regional poverty reduction, as agriculture underpins the livelihoods of over two-thirds of Africa’s poor (Diao *et al.* 2012). Sustainable agricultural intensification is still one of the major issues (Pretty *et al.* 2011).

Sustainable intensification of farming systems to improve livelihoods in smallholder agriculture across Eastern and Southern Africa requires increasing and stabilizing yields so that land, labor, and cash can become available for the diversification of farmers’ sources of income. Intensification requires to be achieved in a way that also builds the resource base for the long term performance.

Chemical fertilizer application in Africa has been low ever since, and especially the use of phosphate and potassium fertilizer did not increase in the last three decades (Figure 1). Consequently, it has been argued that, “...in the short term, chemical fertilizers are the best way to feed Africa. ... Impoverished African farmers cannot afford to wait for the international community to deliberate on the long-term, green methods needed for a sustainable global agricultural system. They need to deploy methods that work now – and that means that in the short term they need access to chemical fertilizers” (Nature, 2012). The challenge, however, remains in the development of pragmatic approaches and incentives that increase food production and profits now and build the base towards sustainability in the near future. The issue is how to increase nutrients use and improve the natural resource base of African smallholders, so that farmers can first reliably feed themselves, and allow people to seek out opportunities for a sustainable economic growth.

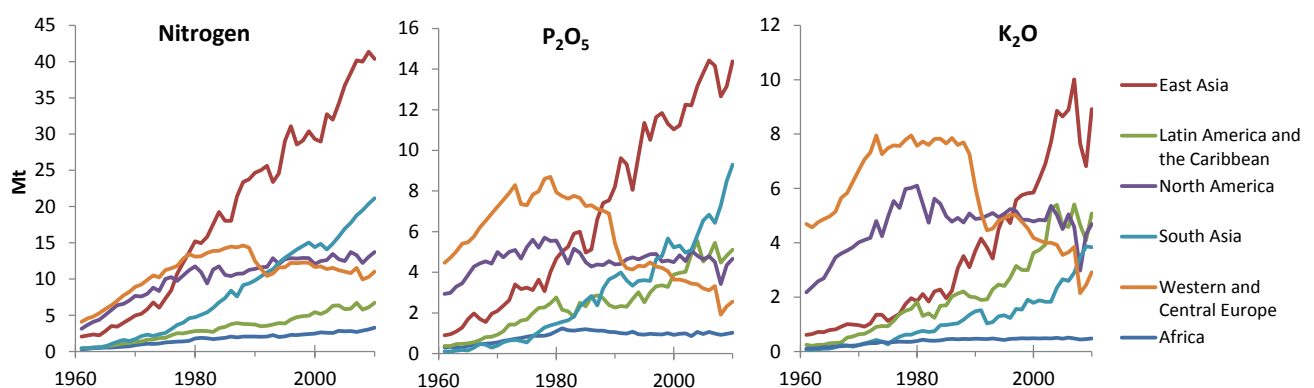


Figure 1: Total annual nitrogen, phosphate (P₂O₅ equivalent) and potassium (K₂O equivalent) fertilizer consumption (million tons) from 1961 to 2010 for various regions of the world (IFA, 2013)

Agronomists and agro-economists tend to agree that fertilizers alone and other single component technologies (e.g. improved seed) will not solve the farmers' problems in the medium to long-term. First of all, in the longer term, rising energy prices could raise the cost of fertilizers affecting profitability in smallholder farming systems. Secondly and more important, sound management of soil health integrates the physical and biological fertility of the soil, which can only be achieved if soil organic matter levels can be maintained or increased. Under most farmer circumstances across

eastern and southern Africa, this can only be realized in a stepping stone approach that reduces nutrient constraints, increases biomass production and organic matter levels in the soils (Wall 2007, Thierfelder and Wall 2012).

Improving soil fertility and crop management, and providing risk neutral incentives for farmers to invest in their farming systems are cornerstones for the sustainable economic growth in smallholder agriculture across eastern and southern Africa countries, and our best chance to significantly reduce food insecurities among some of the most vulnerable people in the world.

Actions are needed

- i. to address the current and near term needs for food security and income, and
- ii. to identify sustainable, resilient and profitable nutrient management systems that are better capable of responding to future challenges i.e. biotic and abiotic stresses, and markets.

This report contains an overview of the current understanding of nutrient management systems in eastern and southern Africa, the missing pieces and opportunities for investing in soil fertility and crop management, and providing low risk incentives for farmers. It follows a synthesis from an industry-policy-science workshop on *Market-Smart Interventions to Facilitate the Availability, Access and Use of Nutrients by Smallholders in Eastern and Southern Africa*, held in Harare, Zimbabwe, 16–17 April 2013. The third component outlines a framework for multi-disciplinary research aiming to create incentives for farmers and agro-business entrepreneurs as well as for the development of private agricultural inputs and products markets.

I. Revision of existing information and data sets, and analysis of gaps, priorities and opportunities

1. Fertility status of soils in Eastern and Southern Africa

1.1. Summary

The majority of soils in sub-Saharan Africa are unsuitable for intensified crop production without thorough recognition of their inherent soil fertility constraints. In addition, continued mining of soils during the past decades has rendered even originally fertile soils low-productive. The combined average depletion rate of N, P and K of all sub-Saharan African countries is 54 kg/ha/yr. Thus, not surprisingly, nutrient limitation is the major bottleneck for increasing yields in Africa. However, nutrient depletion rates vary significantly spatially, depending on the overall crop productivity level and farmer's access to fertilizer. Site/region-specific knowledge of the soil fertility levels is thus a precondition for the establishment of profitable and sustainable nutrient management systems.

1.2. Agro-ecosystems, soil types and soil fertility constraints

The African countries south of the Saharan spread over four Agro-Ecological Zones (AEZs), namely (1.) the warm arid and semi-arid tropics, (2.) warm sub-humid tropics, (3.) warm humid tropics, and (4.) cool (highland) tropics. The east and southern African countries Djibouti, Somalia, Sudan and parts of Ethiopia, Kenya, Tanzania and Uganda, as well as Botswana, Namibia, Swaziland, and parts of Angola, Madagascar, Malawi, Mozambique, Zambia and Zimbabwe belong to AEZ 1. Parts of Ethiopia, Tanzania, Uganda, Angola, Madagascar, Malawi, Mozambique, Zambia and Zimbabwe are in AEZ 2. Madagascar has also a small share of its country in AEZ 3, and Burundi, Lesotho, Rwanda, and parts of Angola, Ethiopia, Kenya, Madagascar and Tanzania are in AEZ 4 (CGIAR Technical Advisory Committee 1994).

Climatic conditions, along with parental material, age and physiography determine the soil pattern in east and southern Africa (Table 1; Figure 2). Therefore, there is a strong correlation between nutrient depletion, the AEZ and the dominant soils.

Table 1: Dominant soils in the four agro-ecological zones of sub-Saharan Africa (adapted from Deckers 1993)

AEZs of tropical Africa	Dominant soils	Less dominant soils
(1.) Warm arid and semi-arid	Lixisols, Arenosols, Vertisols	Regosols, Podzols
(2.) Warm sub-humid	Ferralsols, Lixisols	Acrisols, Arenosols, Nitosols
(3.) Warm humid	Ferralsols, Acrisols	Arenosols, Nitosols, Lixisols
(4.) Cool (highland)	Cambisols, Vertisols, Nitosols	Ferralsols, Luvisols

Ferralsols are the most inherently nutrient depleted soils in sub-Saharan Africa. They cover extensive areas on generally well drained, flat land, are associated with old geomorphic surfaces and are thus strongly weathered.

Similarly, or only little less nutrient depleted are **Acrisols**. They are distinguished from Ferralsols by the accumulation of low activity clays in an argic (= Lat. for clay) subsurface horizon, and thus drainage may be hampered. Both soils may often have low cation exchange capacities (i.e. the capacity to adsorb and retain macro nutrients like potassium, calcium and magnesium), a low soil pH accompanied with toxic amounts of aluminium, and deficient levels of micronutrients (boron, manganese, molybdenum).

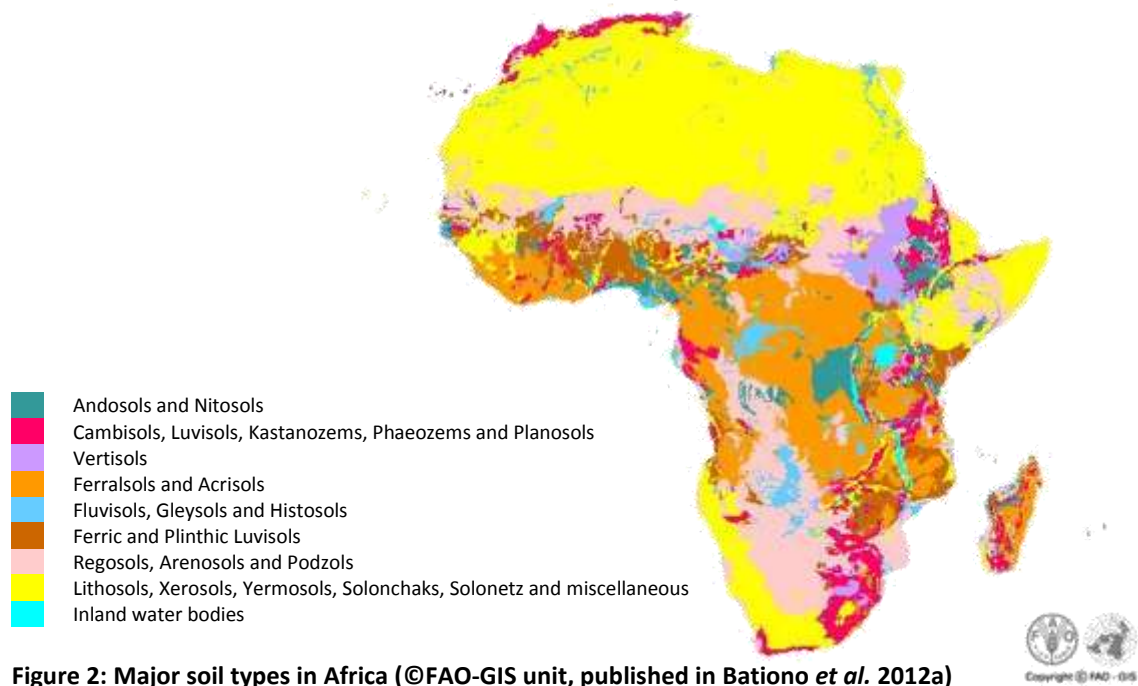


Figure 2: Major soil types in Africa (©FAO-GIS unit, published in Bationo *et al.* 2012a)

Lixisols also are characterized by a clay accumulation horizon, as well as a low capacity to store plant nutrients, this, however, well saturated with cations. Lixisols are thus not as infertile as Ferralsols and Acrisols, but will become quickly depleted under agricultural use, if organic or inorganic fertilizer is not applied.

Arenosols (arena = Lat. for sand) are sandy-textured soils with low water holding capacity, low nutrient content and low cation exchange capacity and often deficient in micro-nutrients. They cover vast amounts of the Saharan countries, but are also found in Botswana, Angola and the Democratic Republic of the Congo.

Cambisols are comparably young, fertile soils with beginning soil formation. Soil horizons are only weakly established. Cambisols are developed in medium and fine-textured materials and are found, among others, in the highlands of Kenya, Ethiopia and Tanzania. However, hilly relief and stoniness limit their development.

Vertisols are soils with a high content montmorillonite clay minerals that expand when wet and shrink when dry. Such, alternate shrinking and swelling causes self-mulching, but poses a challenge to plant root growth of perennials. Water infiltration is low when the soils are wet, and erosion is thus a problem. Fertility is moderate, and Vertisols are very productive if well managed, but present constraints to low-input agriculture, as temporal changes in physical attributes of these soils require accurate timing of agricultural practices for efficient use.

Further details on the major soils of Africa can be found in Bationo *et al.* (2012a).

In summary, the majority of soils in sub-Saharan Africa are constrained in terms of chemical or physical soil characteristics (or both), and are unsuitable for intensified crop production without thorough recognition of their inherent soil fertility constraints. It is thus not surprising that Folie *et al.* (2011) identified nutrient as well as the combination of water and nutrient limitations as the major bottleneck for increasing maize yields in Africa by 50 % (Figure 3). Water limitations were only identified for southern Zimbabwe and some regions of South Africa.

In addition to inherent soil fertility constraints, continued mining of soils during the past decades has rendered even originally fertile soils low-productive (Thierfelder *et al.* 2013a). Limited application of mineral fertilizer (see subsequent chapters) in combination with extraction of nutrients in the form of crop yields and crop residues, soil erosion, and insufficient recycling of nutrients (such as compost or manure) is the norm rather than the exception in many east and southern African countries, and sub-Saharan Africa as a whole.

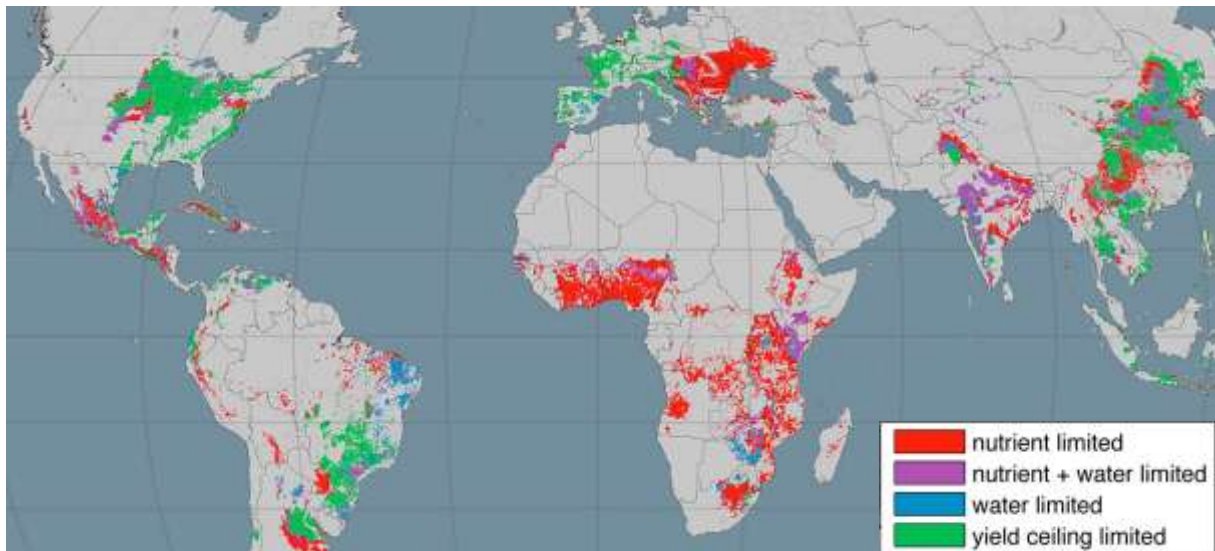


Figure 3: Factors that most limit the increase of maize production (50 % yield increase above baseline) in Africa in comparison with America, Europe, South Asia, East Asia and Southeast Asia (Folie *et al.* 2011)

Henao and Baanante (2006) estimated per hectare nitrogen (N), phosphate (P) and potassium (K) nutrient balances for the whole of Africa for 2002-2004. The combined average annual depletion rate of all sub-Saharan African countries was 54 kg NPK/ha, ranging from 23 kg/ha/yr in South Africa to as much as 88 kg/ha/yr for Somalia (Figure 4). The total amount of NPK extracted accordingly was as high as 10.2 Mt/yr. Given the stagnating fertilizer consumption figures (see Introduction), there is little room for assuming that nutrient mining has substantially decreased in the subsequent, more recent years.

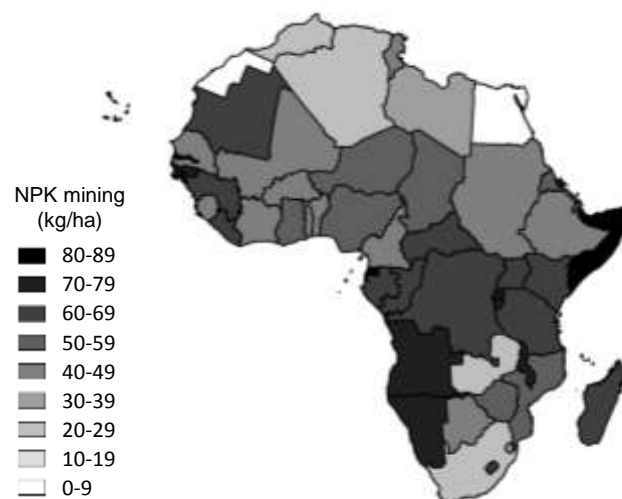


Figure 4: Country-level nutrient mining estimates (kg NPK/ha/yr) for Africa during 2002-2004 (based on data from Henao and Baanante 2006; phosphate in P_2O_5 equivalents and potassium in K_2O equivalents)

There is little information available on nutrient mining patterns at sub-country scale. However, it has to be assumed that the nutrient extraction rates vary significantly spatially, depending very much on the overall crop productivity level and farmer's access to fertilizer (replenishment of nutrients). Knowledge of the soil fertility levels at regional or farm-scale level is thus an important precondition for the establishment of profitable and sustainable nutrient management systems.

2. Quantitative analysis of major soil health constraints

2.1. Summary

To develop and disseminate appropriate nutrient management recommendations, up-to-date and spatially explicit information about the condition and trend of soil health is necessary. In the CIAT-led Africa Soil Information Service (AfSIS) project a hierarchical, spatially stratified, random sampling framework was designed to assess soil/land health at regional scale. The soil sampling was accompanied by fertilizer (omission) response trials for assessing crop response to mineral and organic fertilizer, as well as an assessment of soil fertility by mid-infrared spectroscopy (MIRS). The results showed that, clearly, N and P were not the only yield constraining factors. K-deficiency was common and multi-nutrient deficiency observed in 15 % of the sites. MIRS in combination with multivariate statistical analysis allowed for describing soils in terms of their inherent yield potential, and as such offering the potential to bypass labour, money and time-consuming lab-based wet-chemistry analysis. MIRS, however, is still in its infancies and further research is required to consolidate this promising technology for broader scale, mainstream application.

2.2. Introduction

Agriculture is the main source of livelihood and income for two-thirds of Africa's population (IFDC, 2006). However, limitations in organic matter and other key nutrients such as nitrogen and phosphorus hugely constrain agricultural productivity. Intensive cultivation without soil replenishment is the major driver of soil fertility degradation. Population pressure and climate change exacerbate the condition of soils in the region. The depleted soil has caused average yields of grain crops to stagnate at around 1 ton per hectare since the 1960s while fertilizer use across Africa has remained at around 8 kg/ha of cultivated land over the past 40 years (Lal 1998, Stocking 2003). Enriching the soil is thus the key to tackling hunger in the continent (Gilbert 2012).

To develop and disseminate appropriate soil management recommendations, detailed, up-to-date and spatially explicit information about the condition and trend of soil health is necessary (Sanchez *et al.* 2009). Against this background, the CIAT led Africa Soil Information Service (AfSIS) project funded by the Bill and Melinda Gates Foundation (<http://www.africasoils.net/>) aimed to collect, process and analyse soil and ecological constraints to agricultural productivity, lay the basis for monitoring soil health, and to design, develop and operationalize a framework for evidence-based, spatially explicit soil management recommendations.

2.3. Data collection and processing approaches

To achieve these goals, a hierarchical, spatially stratified, random sampling framework was designed such that statistically representative points considering variability in climate, topography and vegetation are collected. The new approach replicates soil and other biophysical measurements at different spatial scales, linking consistent, geo-referenced ground observations to laboratory measurements, agronomic field trials and remote sensing data. The hierarchical sampling design involved sentinel sites that are 10,000 ha in size (Figure 5). Each sentinel site was stratified into 16 clusters of 100 ha, and sampling cluster centroids were randomly located within grid cells. Within each sampling plot, 4 subplots of 0.01 ha each were established and geo-referenced. In these subplots soil samples were taken at two depths (0-20 and 20-50 cm) and various landscape attributes were measured, such as terrain, land cover and use, woody vegetation abundance, soil surface

characteristics, root depth restriction, erosion prevalence and type and soil conservation practices, existent. The soil fertility status of 10 % of the soil samples was analysed using conventional laboratory methods. Analyses included soil organic carbon, total nitrogen, extractable phosphate, pH, sum of cations and soil texture. All samples (~20,000) were analysed by near- and mid-infrared spectroscopy (MIRS), x-ray fluorescent spectroscopy and x-ray diffraction (Shepherd and Walsh 2002). Analysing the MIRS signal and comparing it against the chemical characteristics of soil, contributed to the development of MIRS libraries that, once well established, allow for a rapid, comprehensive, but nevertheless cheap assessment of soil fertility by MIRS.

Simultaneously, detailed agronomic fertilizer response trials were carried out at farmer's field within the clusters of the sentinel sites. The response trials tested different combination of fertilizer types, liming, the additions of multi-nutrients (sulphur, iron, magnesium, and a mix of the most important micro-nutrients) and manure, in part omitting one of the major elements N, P, or K. This allowed quantifying the yield-limiting impact of omitting these elements.

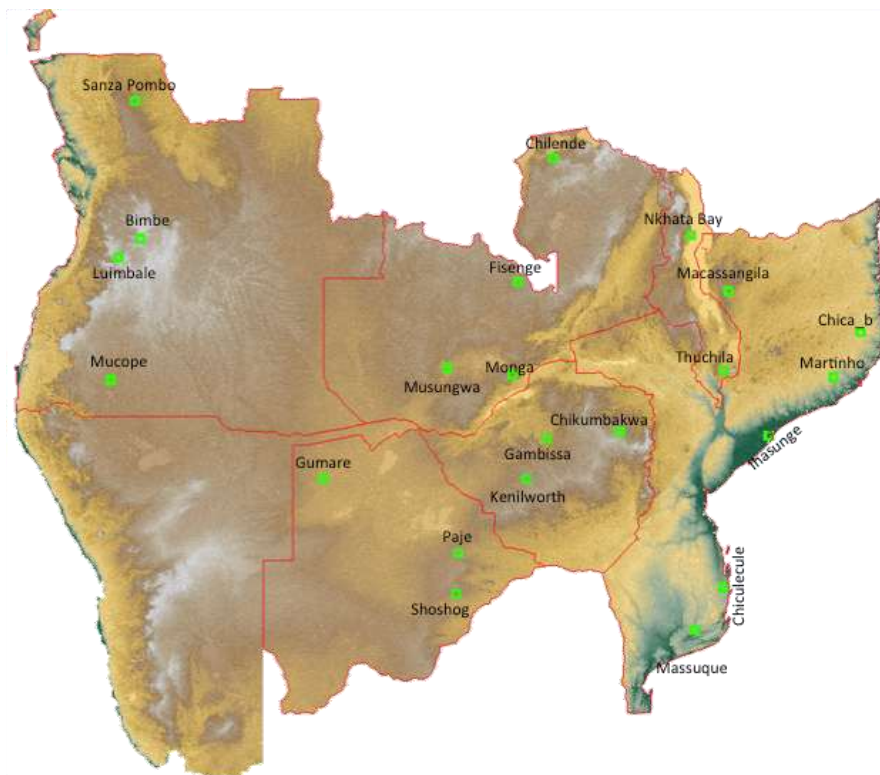


Figure 5: Location (green dots) of some of the AfsIS sampling sites in Southern Africa.

2.4. Major soil health constraints

2.4.1. Landscape

The major attributes that can be used to evaluate overall soil health and quality include a combination of land conditions and soil fertility status. Texture, infiltration, root depth, erosion prevalence, trees/shrubs in cultivated areas can be used to evaluate landscape condition and pH, SOM, N, P and sum of cations are the basis to assess soil health status (Dalal and Moloney 2000, Karlen *et al.* 2003; Allen *et al.* 2010).

Root depth restriction (RDR) is the depth at which root penetration is strongly inhibited by physical and/or chemical characteristics of the soil. Knowledge of this parameter is useful to assess whether

the landscape restricts the capability of plant roots to penetrate and acquire necessary elements and moisture, as well as if the area enhances or restricts the capacity of runoff to infiltrate into the soil layer. Areas with RDR are generally associated with moisture deficit and are also difficult to utilize and manage. These indirectly affect plant growth and development and management option and ultimately are detrimental to crop yield. RDR limits were defined as areas where auguring is restricted. Assessment of topsoil (0-20 cm) RDR showed that there was less than 4 % probability of observing root depth restriction in all the eleven sites. That means there was no significant problem of RDR in the studied sites. In addition, RDR is observed less in cultivated areas compared to non-cultivated and semi-natural areas. This may be because either farmers selectively focus cultivating areas with no depth restriction (areas with no problem of hard pan etc.), tillage could break a hardpan (if in the first layer), or areas with high RDR have been degraded and thus abandoned from being cultivated. The later may be the more plausible reason, as areas with severe root depth restrictions are also more prone to erosion by water, and thus easily degraded.

Land degradation in the form of soil erosion is severe problem in the agriculture-dominated regions of SSA. Erosion removes the topsoil and reduces the soils ability to hold moisture and nutrients and also results in the removal of essential nutrients. In addition to its on-site effects, erosion has also significant effects off-site such as sedimentation and pollution. Knowledge of the extent and severity of erosion can help plan mitigation measures. In the AfSIS project, prevalence and types of erosion were assessed within each subplot. There was about 50 % probability of observing soil erosion in all sites with a range varying from 36 % Chikumbakwa (Zimbabwe) to 70 % (Chica (Mozambique)). There was a higher probability of encountering erosion in the Zimbabwe sites compared to the others. Variability of erosion prevalence within the different clusters of sites was huge. This can be attributed to distinct land use and management practices within sites.

2.4.2. Soil functional properties

Soil Organic Carbon (SOC) is one of the key soil properties that reflect overall soil health and productivity. Among the reported sites, SOC was highest at Monga (Zambia) with on average 2.2 % followed by Nkhata Bay (Malawi) with 2.0 %. However, these values were not significantly different from the other sites. Some sites such as Inhasunge, Monga and Chica-b showed high variability of SOC between clusters while Chelende, Massuque and Chiculecule showed low variability. Generally, when SOC is less than 2 %, it is considered low and there may be a need to add organic matter to increase SOC and soil health (PVFS 2004). In this case, all sites sampled in the three countries show organic matter deficiency.

Total soil nitrogen is another critical element for many functions of plants such as photosynthesis. Total nitrogen concentrations of soils of the study sites were generally low with an average amount of only 0.05 %. Nkhata Bay (Malawi), which has a diverse land use and management, showed relatively higher total nitrogen compared to Massuque and Chiculecule sites (Mozambique).

Extractable phosphate is involved in root production, plant reproduction, and many other reactions necessary for growth. Unlike SOC and total nitrogen, the landscape assessment revealed that extractable phosphate, with an average of 16 mg/kg, did not seem to be a critical limitation in the study region. Nevertheless, fertilizer response trials revealed that applying P-fertilizer significantly increased maize grain yields and rendered profitable (> break-even) in 53 % of the cases. Detailed analysis will be needed to evaluate the reasons for the observed variability and especially for the relatively highly elevated values observed in some of the sampling plots.

The pH values of most sites sampled in the three countries ranged between 5.5 to 7 which is the optimum range for most plants. Only two sites in Zambia (Fisenge and Chilende) showed relatively high acidity and require lime to enhance crop growth and yields.

2.4.3. Fertilizer response

The fertilizer response/omission trials revealed that N and P were not the only yield constraining factors. K-deficiency was common and multi-nutrient deficiency observed in 15 % of the sites. Mbinga in Tanzania was one of the sites with significant responses to the application of the multi-nutrient mix and the addition of manure (Figure 6).

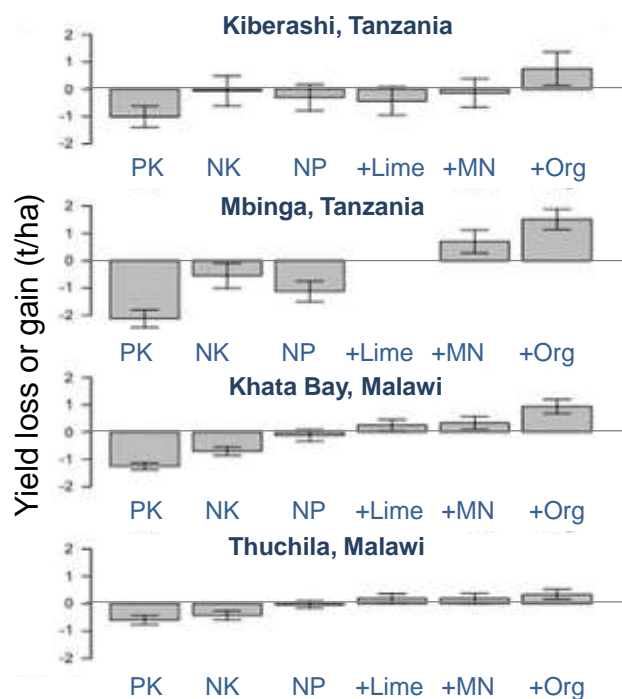


Figure 6: Crop responses to nutrient application (using NPK as reference) at Kiberashi and Mbinga in Tanzania and Khata Bay and Thuchila in Malawi; +lime = NPK + Lime; +MN = NPK + Multi-nutrients; +Org = NPK + Manure; bars are confidence limits

Thuchila in Malawi, on the other hand, was one of the examples with soils that showed only limited response to the applied fertilizers and other inputs. In line with observations on the soil pH at landscape level (see above), liming provided only very limited (not significant) responses, indicating that soil acidity was not an issue in the observed fields. The thus obtained responses allowed clustering of sites into distinct groups, and deduction of basic soil fertility management recommendations:

- **Cluster 1 (11 %):** highly responsive soils especially to N
→ business-as-usual fertilizer recommendation (probably based on nutrient extraction rates) may suffice for the time being
- **Cluster 2 (31 %):** only low response to fertilizer application, representing SOC-depleted soils
→ organic matter management (residue retention, manure application) is key to increasing productivity levels, mineral fertilizer application alone is not a viable short-term strategy
- **Cluster 3 (34 %):** soils that respond to N but also to P and manure notably improve yields

- > combination of N and P fertilization is key, manure application desirable
- **Cluster 4** (24 %): Non-responsive fields to any form of fertilizer; fertile soils or fields heavily affected by other biotic (water, heat) or abiotic stresses (pest and diseases)
- > further research required to disentangle yield limitations

Figure 7 illustrates the within site variability in terms of crop grain yield and response to fertilizer application for Thuchila (Malawi). The notable differences at short distance are obvious, indicating the need for site-specific assessment of soil nutrient constraints.

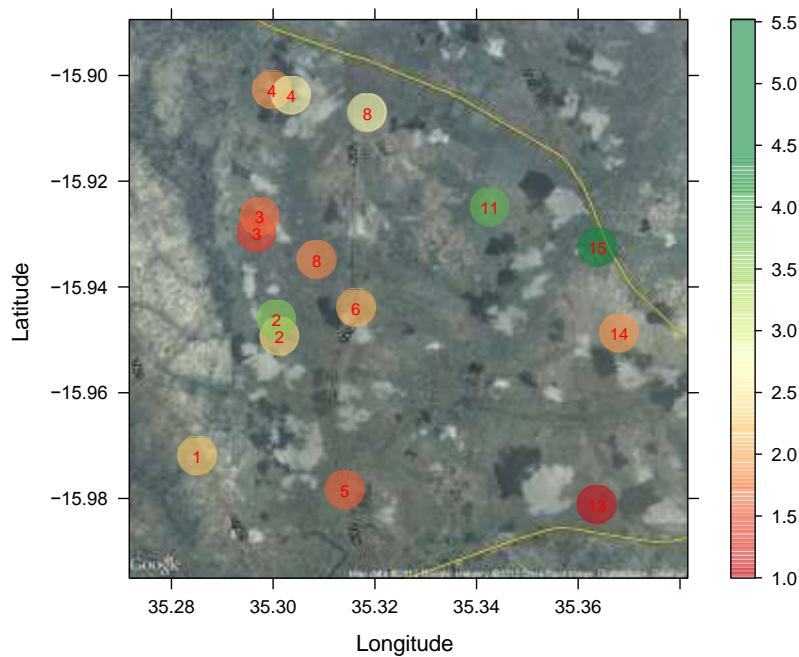


Figure 7: Grain yield (t/ha) at each of the NPK + manure treatments at Thuchila (n=15). Label numbers indicate the cluster

2.4.4. Scopes for MIRS to derive site-specific fertilizer recommendations

One of the biggest arguments against site-specific nutrient management, however, is the amount of soil sampling and analysis that would exceed the budget and capacity of any African national agricultural extension program. Soil sampling and subsequent wet-chemistry analysis at field level at the scale of sub-Saharan Africa is simply not a viable option. An assessment of soil fertility by MIRS has the potential to bypass this step and to provide a rapid soil fertility signal (Figure 8).

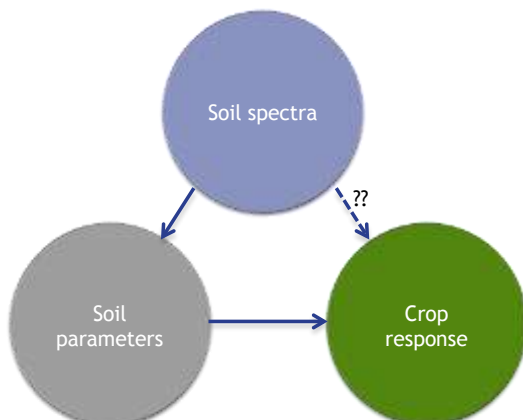


Figure 8: Can soil spectra derived by mid-infrared spectroscopy (MIRS) substitute time-consuming and expensive soil chemical analysis to predict crop response to fertilizer application?

The AfSIS project started a first attempt to address the issue. MIRS spectra were used as independent variables in a multivariate analysis with the aim to predict crop yields observed under control conditions, i.e. without applying any fertilizer, lime or manure. The established multivariate model could explain observed yields well, achieving a root mean square error of 0.67 t/ha (Figure 9).

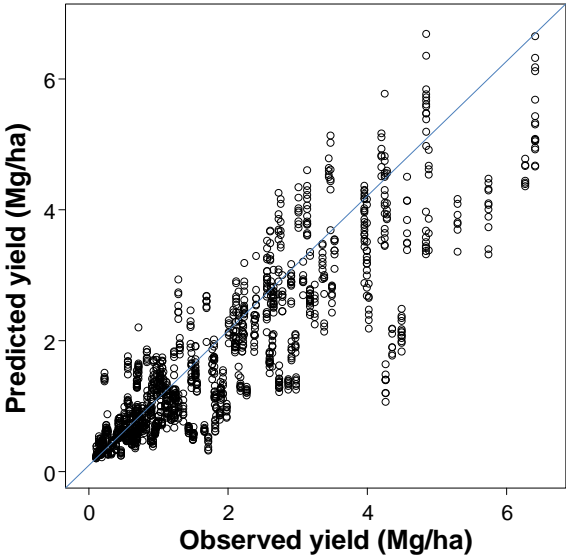


Figure 9: Plotting MIRS-based predicted (unfertilized control) against observed maize grain yields; 1:1 line in blue

Work is in progress to move this assessment one step further, by a) including rainfall data to cover this potential abiotic stress that may limit crop yields, and b) to model yield response to the individual levels of fertilizers applied. Once such a model is well established and verified at larger-scale (beyond the AfSIS focus countries), MIRS analysis needs to become mainstream and equipment available at affordable price, in a mobile form (rather than lab based), and extension service trained to use such, yet nowadays, cutting-edge high-tech tool on a daily basis.

2.5. Conclusion

Knowledge of land condition and soil health constraints is necessary to plan management options and apply necessary soil-fertility enhancing interventions. It is therefore necessary to undertake detailed analyses of soil health considering representative sites. AfSIS project results presented above show that the majority of the sites have soil nutrient deficiency and requires mineral and/or organic fertilizer input to enhance productivity. There were considerable difference in terms of soil fertility between sites and regions that omit blanket recommendations at broader scale without in-depth knowledge of land/soil health. MIRS, still in its infancies these days, offers a huge potential to overcome the overwhelming task of deriving site-specific nutrient management recommendations, that nowadays still rely on comprehensive chemical analyses of soils and related field-sampling.

3. Fertilizer Markets in East and Southern Africa

3.1. Summary

The optimal technical approach of East and Southern African countries to increase the use of mineral fertilizer is likely to be a function of a number of location-specific, agro-climatic, demographic and economic variables. The most important factors explaining fertilizer use increases before and during structural adjustment programs were pan-territorial crop and fertilizer prices, subsidized fertilizer, a high share of donor-funded fertilizer imports, fertilizers provided on a credit basis, and the devaluation of currency in some countries. In most SSA countries the private sector was not able to stop the decrease in total fertilizer consumption after market liberalisation and abolishment of subsidies. After the re-introduction of targeted fertiliser subsidies in the 2000s, some East and Southern African countries have realised increased fertiliser consumption growth, notably Malawi, Zambia and Tanzania. Realistically, it must be recognized that fertilizer subsidies are often implemented because of their political popularity, and exit strategies are absent. We believe that key policy measures for the establishment of well-functioning fertilizer markets are: the establishment of a consistent and predictable price (subsidized, if warranted) and trade policy; introduction of risk-sharing financial mechanisms; investment in human capital development (farmers and private sector); development and enforcement of fertilizer legislation and regulatory framework.

3.2. Introduction

There is ample evidence from experience outside of sub-Saharan Africa (SSA) that increased use of mineral fertilizers has been responsible for an important share of worldwide agricultural productivity growth. Some argue that fertilizer was as important as seeds in countries where a Green Revolution has taken place (Tomich *et al.* 1995), contributing 50 % of the yield growth in Asia (Hopper 1993). Others have found that one-third of the cereal production worldwide is due to the use of fertilizer and related factors of production (Bumb 1995). The growing contrast between the productivity role played by fertilizer in other regions of the world and the very limited use of fertilizer in SSA has stimulated a great deal of debate about what the role of fertilizer should be in SSA and what types of policies and programmes will be most likely to help SSA farmers realize the benefits of fertilizers.

Part of the problem is that most African soils are sub-optimal in terms of fertility, acidity, and drainage. Furthermore, land use practices during the past several decades have exacerbated the situation through nutrient mining by crops, leaching, and inadequate erosion control (FAO 2008 Minot and Benson 2009, Vanlauwe *et al.* 2010 and FAO 2011). Low fertilizer use rates per hectare translate into small fertilizer markets and hence, a small share of global fertilizer consumption for Africa as a whole and for SSA in particular. Thus, experts and policy makers agree on the urgent need to increase the use of inorganic fertilizer in the region. However there is little consensus on how to address this issue, and currently there are marked differences in policies and programs pertaining to fertilizer among African countries.

We take the position that increased fertilizer use is a desirable objective for the countries of SSA and that the optimal technical approach for a given situation is likely to be a function of a large number of location-specific, agro-climatic, demographic and economic variables. This chapter provides a historical overview of the fertilizer market in East and Southern Africa, components of well-functioning fertilizer markets, and summarizes the current status of fertilizer markets in general vis-à-vis these components.

3.3. History of fertilizer programs in East and Southern Africa

The period starting from 1986 was characterized by a gradual withdrawal of interventions from SSA governments in fertilizer markets due to structural adjustments programs from the World Bank. The idea behind this was that the private sector could perform better in fertilizer markets than governments and make fertilizers more available to farmers at the right time and at a reasonable market price. Countries like Malawi, Zimbabwe and Tanzania, that implemented structural adjustment measures in fertilizer markets, such as the phasing out of fertilizer subsidies and gradual government withdrawal from fertilizer importation and distribution, had negative growth figures in total fertilizer consumption from 1986 onwards. On the other hand, West Africa countries like Benin, Burkina Faso, Senegal and Togo, that did not really comply with the liberalization guidelines from the World Bank had positive growth figures in total fertilizer consumption in the two decades to follow (Meertens 2005). Clearly other factors than compliance with liberalization policies in fertilizer markets play their part in explaining why fertilizer use increases or decreases in SSA countries. These factors differ from one country to another due to their differences in fertilizer policy histories and their differences in agro-ecological, economic and political circumstances. A brief description of the specific circumstances in eight of the main fertilizer consuming countries in East and Southern Africa will be given in the following section to get a better view of which type of factors have significant impact on fertilizer consumption.

3.3.1. Tanzania

With help from donors, Tanzania had started its own production of fertilizer in 1972, and until 1981 this production contributed around half of Tanzania's total fertilizer consumption (World Bank 1994). The other half of the total consumed fertilizer was provided by donors in the form of aid. In 1975 the government started the National Maize Program with the support of international donors. The objective of this program, which focused on smallholder maize production, was to come closer to the goal of domestic self-sufficiency. For that matter inputs such as hybrid seeds, fertilizers and pesticides were provided at pan-territorial, subsidized prices in ten selected regions. A system of pan-territorial producer and consumer food crop prices was installed in 1974-75 to encourage production in potentially productive but remote areas and to guarantee a more equitable distribution of welfare. Inputs were furthermore distributed on a credit basis by government controlled cooperatives in combination with a government purchasing guarantee from the National Milling Corporation (NMC). The pan-territorial pricing system was an indirect subsidization of maize production in the more remote Iringa, Mbeya, Ruvuma and Rukwa regions in the Southern Tanzanian Highlands, since transport costs were paid in the end by the government (Geier 1995). As a result maize production increased sharply in the Southern Highlands, which provided a large share of the maize purchased by NMC (Delgado and Minot 2000). The Southern Highlands consumed about 60-70 % of total fertiliser in the country of which more than 70 % was used for maize production (Hawassi *et al.* 1998). The remaining fertilizer was consumed in tobacco, cotton, tea, rice and coffee at the same pan-territorial subsidized prices. Apart from rice these fertilizers were also supplied on a credit basis.

Structural adjustment measures from 1984 onwards with the devaluation of the Tanzanian Shilling gradually reduced government interventions in food crop and inputs markets. At the end of the 1980s the pan-territorial producer prices were abandoned and the NMC was not able anymore to buy maize from farmers due to financial problems. At the same time the inputs credit program of the regional cooperatives had to be abandoned due to poor repayment and the absence of refinancing

options. Fertilizer subsidies, which had amounted to an implicit level of 80 % in the 1988/89 season, were gradually phased out and finally reached zero in the 1994/95 season. During 1994 the subsidy on fertilizer imports by the parastatal Tanzania Fertilizer Company (TFC) was eliminated and pan-territorial pricing was discontinued. Technical problems, increasing with time, caused a reduction in Tanzania own production of fertilizers and finally it became zero in 1996. International donors, apart from Japan, stopped the provision of fertilizer in the form of aid. Tanzania was the second largest African recipient of the Kennedy Round 2 (KR2)¹, a Japanese aid program, in the form of fertilizers, pesticides and machinery in 1996 (Townsend 1999). However, in those years the absolute quantities of this aid program were much lower as they used to be (MAC 1997). An optimistic view on the role the private sector could play in fertilizer distribution caused some to believe that the removal of the fertilizer subsidy would eventually lead to a net increase in total fertilizer use and reach 200,000 t of gross fertilizer (World Bank 1994). However, that total fertilizer nutrient consumption declined from 46,800 t in 1990 (70 % implicit subsidy) to 35,900 t in 1994 (zero subsidy; FAOSTAT 2005). The government had created an artificial demand for fertilizers in many parts of the country due to the pan-territorial, subsidized prices. When the private sector entered the fertilizer market, many farmers were not interested anymore in buying fertilizers due to the sharp increased price and the fact that private traders were generally not supplying fertilizers on credit. Moreover, private traders could not profitably supply fertilizers to more remote villages due to high transport costs (Meertens 2000).

Market Organization

Before the liberalization and privatization of the early 1990s, all fertilizer production, import supply, and distribution were handled by the Tanzania Fertilizer Company (TFC), a government parastatal. Distribution to smallholder farmers was largely through cooperative unions, which were also government institutions. This system included government subsidies, credit facilities, and producer and fertilizer price controls, which resulted in increased fertilizer consumption but at an unsustainable cost. With market liberalization the private sector has been slow to take over the former state role. However, fertilizer importation and distribution have now become the responsibility of the private sector. Farmers have not benefited much from the current fertilizer marketing system, mainly because the private sector has been more active in responding to trading opportunities offered by the liberalized output markets rather than input markets. Historic Tanzanian annual fertilizer consumption in the period 2002-2010 is presented in Table 2.

Table 2: Tanzanian annual fertilizer consumption (t; FAOSTAT 2013)

Products\Years	2002	2003	2004	2005	2006	2007	2008	2009	2010
Nitrogen	22,192	26,590	34,469	33,530	39,222	41,448	43,426	66,942	58,341
Phosphate (P ₂ O ₅ equivalent)	5,281	6,390	9,725	16,825	11,552	8,992	9,264	14,951	8,055
Potassium (K ₂ O equivalent)	4,345	5,070	6,053	5,463	1,583	276	276	4,640	9,859
Sum	31,818	38,050	50,247	55,818	52,357	50,716	52,966	86,533	76,255

¹ The Kennedy Round 2 (KR2), now known as the Grant Assistance for Underprivileged Farmers, is a grant facility of the Government of Japan designed to assist developing countries striving to achieve food sufficiency to carry out their food augmentation plans.

Market Structure

The structure of the fertilizer market in Tanzania consists of overseas suppliers, importers, wholesalers, retailers, stockists, and farmers (small, medium, and large-scale farms). In 2006, 11 companies imported fertilizer, of which 8 were private companies, 2 were tobacco companies and 1 State Owned Enterprise (SOE; IFDC 2007). The majority of these companies are based in Dar es Salaam, with distribution channels at regional town centres. As in many other African countries, there is no clear demarcation between importers and wholesalers, and almost all importers have wholesaler and/or retail operations at regional trading centres.

Market Conduct

The fertilizer market in Tanzania can be characterized as a hybrid oligopoly due to the strong influence of the state on quantity and allocation decisions. The agricultural sector, including the input industry, falls under the scope of the Ministry of Agriculture, Food Security, and Cooperatives. The government has been directly involved in the fertilizer market for decades, and became fully engaged in a subsidy program during 2003-2004 (IFDC 2007). The government establishes the total amount of fertilizer to be subsidized and provides allocations to importers, distributor-wholesalers, and retailer-stockists. Farmers are given permits that instruct them on the exact amount and type of fertilizer to purchase under the subsidy program, and further specify the particular stockist from whom to purchase.

3.3.2. Zambia

In the early 1980s Zambia had a highly overvalued exchange rate, providing a large implicit subsidy on imported goods such as fertilizer that could count on foreign exchange allocations (Kherallah *et al.* 2002). Similar measures as the ones in Tanzania were taken by the government to increase domestic maize production with the objective of self-sufficiency in white maize. The expansion of state buying stations in remote areas under pan-territorial pricing encouraged a notable increase in smallholder maize production. Fertilizers and other inputs were supplied at subsidized, pan-territorial prices on a credit basis (Jayne and Jones 1997). At that time almost all fertilizer consumed in Zambia was applied to maize (Kherallah *et al.* 2002). Structural adjustment programs in the mid-1980s led to a huge devaluation of the national currency, the abolition of pan-territorial prices, the elimination of fertilizer subsidies and a gradual liberalization of food crop and input markets. As a result fertilizer consumption started to decrease since the late 1980s (Jayne and Jones 1997). The private sector's response to the reforms, in terms of new entry and investment in fertilizer markets, had been limited (Jayne *et al.* 2003). During the 1990s Zambia was, however, still one of the main African recipients of the Japanese KR2 aid program (Townsend 1999).

In the early 1990s, the Zambian government initiated a process of fertilizer market reform, as part of the economy-wide structural adjustment programs (SAPs; Hans 1988, Seshamani 1999, Shawa 2002). These reforms have evolved in five diverse phases. The first phase which took place from 1991 to 1993, the government assigned several state-affiliated banks and credit unions to dispense fertilizer to farmers on credit. Low repayment rates of as little as 5% led to the abandonment of the programme. (Govereh *et al.* 2002). The second phase was from 1994 to 1996, where the government appointed a few large private firms to be Credit Managers with Cavmont Merchant Bank Ltd. and SGS Ltd. Being the lead to import and deliver fertilizer on loan to "credit coordinators," who were private retailers tasked with forwarding the fertilizer on credit to farmers. Cavmont and SGS did not have

ownership of the fertilizer but rather they were paid management fees for their role of dispensing fertilizer to designated credit coordinators on behalf of government. Government made the designation of both credit managers and credit coordinators. The amount of fertilizer supplied through this approach was determined by availability of donated fertilizer from donors and local production (Govere et al 2002). This approach was marred by failure of the credit coordinators to account for the fertilisers sold as most of them were engaged in illegal selling of fertiliser instead of forwarding it to designated farmers on loan (Govere et al. 2002). Pletcher (2000) further states that as a result of this, government introduced another distribution system which provided selected private agents with the possibility for major financial gains and a protected market. This led to the private agents to be co-opted into the government system and their advocating a transparent open market system was weakened. Cavmont and SGS exited the market only after the government insisted that performance contracts be signed and this meant the absorption of some of the repayment losses being incurred. The government responded by introducing the state-run Food Reserve Agency (FRA) to carry out the responsibilities of importing and distributing fertilizer to the agents. This was the third phase, which lasted from 1996 until 1999. In this phase, the FRA also appointed private sector “agents” to distribute fertilizer to farmers and cooperatives on its behalf. This approach was apparently related to past repayment history and collateral, hence the system was again vulnerable to political interference. Evaluations of the program again concluded that a large proportion of the in-kind credit, designed to assist farmers afford fertilizer, was diverted before reaching them (Pletcher 2000, Govere et al. 2002).

The fourth phase was introduced in the 1999/2000 farming season. Under pressure from donors to restrain the state’s distribution of fertilizer on credit, the government contracted several large private firms to import and distribute roughly 45,000 tons of fertilizer especially to smallholder farmers through the cooperatives. The private firms operated on a commission basis on behalf of FRA. In 2000, there were four main importers and wholesalers of fertilizer in Zambia: Omnia, Sasol, Norsk Hydro, and Farmer’s Friend, with 85% of the volume concentrated in the hands of the two firms that the government chose to distribute fertilizer to selected cooperatives under its credit program. Evaluations once again indicated that a large proportion of fertilizer acquired on loan from FRA (through Omnia and Farmer’s Friend) was sold by implementing agents before it got to farmers (Govere et al 2002). During the decade of the 1990s, covering these first four phases of relatively limited fertilizer subsidy programs in Zambia, national fertilizer use and maize production actually declined (ibid 2002). Unfortunately, instead of prompting the production of local fertiliser, the government opted to import fertiliser citing high costs of production of the only fertiliser plant in Zambia. The fifth and current phase of Zambia’s experience with fertilizer subsidies since liberalization in 1990 is marked by the Fertilizer Support Programme (FSP), which was introduced the 2002/2003 farming season. Zambian 2002-2010 fertilizer consumption is presented in Table 3.

Table 3: Zambia annual fertilizer consumption (t; FAOSTAT 2013)

Products\Years	2002	2003	2004	2005	2006	2007	2008	2009	2010
Nitrogen	40,335	42,816	60,177	51,637	49,225	55,754	53,215	64,145	77'617
Phosphate (P ₂ O ₅ equivalent)	13,470	14,559	11,414	4,790	8,553	11,587	8,889	6,226	8'425
Potassium (K ₂ O equivalent)	13,520	17,846	13,996	19,885	19,587	28,013	55,876	21,140	13'148
Sum	67,325	75,221	85,587	76,312	77,365	95,354	117,980	91,511	99'190

3.3.3. Malawi

Among the countries studied, Malawi presents one of the most important and interesting hybrid markets for fertilizer. In terms of value, fertilizers make up one of the four largest markets in the country. Agricultural inputs, including fertilizer, represent the only sector among the top four that primarily comprises private actors (Government of Malawi 2011). The role of the state in the fertilizer market is still evolving in Malawi, which is in the forefront in the use of voucher systems, with logistical support from DFID. One could say that the Tanzanian market is moving toward what Malawi is today. However, there is some tension regarding the appropriate role of the state in the marketplace, and how government actions can inadvertently create the wrong incentives for the private sector. Malawi is also interesting because of the importance of producer associations that are organized by output crop (e.g., tobacco, cotton, coffee, tea) and input products such as fertilizer.

In Malawi the government was actively involved in promoting smallholder maize production during the 1970s and 1980s. Pan-territorial pricing was used to encourage production in the more remote Northern districts and maize producer prices and fertilizer were subsidized through taxation of smallholder cash crops (Jayne and Jones 1997). All fiscal and economic subsidies on fertilizer were removed in 1995/96 leading to an increase in fertilizer prices varying between 200 and 300 %. As a result fertilizer consumption started to decline despite the fact that one third of it was distributed for free by the government (Townsend 1999). At the end of the 1990s the commercial fertilizer market was dominated by a few private sector importers/wholesalers and an expanding network of small stockists but government institutions still continued to import fertilizer (Townsend 1999). Moreover, the parastatal maize marketing board continues to exist in Malawi (Kelly et al. 2005).

In 2002 Malawi liberalized its agricultural input markets, but the public sector continues to participate in the fertilizer market. Government participation at the procurement and distribution levels varies from year to year, depending on subsidy program decisions. The strength of the government network is its ownership of 58 Smallholder Farmers Fertilizer Revolving Fund (SFFRFM) depots and more than 600 Agricultural Development and Marketing Corporation (ADMARC) market units. The latter have not been active since 2005, apart from distributing subsidized fertilizer in 2005-2006 and 2006-2007 seasons, which significantly undermined the private stockists (small retailers) emerging under the AISAM and CNFA networks. In parallel with these two agricultural campaigns, about a dozen firms were involved in fertilizer procurement— primarily imports, with some processing. These importers supply a formal network of more than 400 retail outlets in Malawi (public and private sector combined), in addition to an informal network of independent agro dealers with an estimated 226 active dealers. Many of these smaller dealers were driven out of business in the two agricultural campaigns by the government's subsidy program.

Fertilizer Cost Chain Analysis

The Malawi market in 2006-2007 was estimated to be almost 260,000 metric tons of fertilizer products, representing a 16 % increase over the previous year (IFDC 2007). This is mainly due to a subsidized fertilizer program initiated by the government, amounting to 170,000 metric tons. The annual market over the past 10 years has fluctuated between 167,000 and 224,000 metric tons due to shifting government policies and periodic drought conditions (FAOSTAT 2011). Inconsistent government policies have frustrated the vibrant private sector procurement and marketing of fertilizer.

Market Structure

With its subsidy programs, the structure of the Malawian market resembles that of Tanzania. However, the Malawian market is more advanced in its liberalization and reform process than Tanzania. In Malawi, market subsidies are applied directly at the farmer level, and private sector importers compete via public tender to supply fertilizers through the subsidy program. While the tender bidding process is open to any participating entity, it is not an integrated approach. Locally established companies with the ability to service the market have no advantage in their bids. This situation opens opportunities for additional businesses to bid on the fertilizer procurement process and to create gaps in supply when new players fail to deliver the contracted goods.

Market Conduct

The Malawian fertilizer market is an oligopoly, with the government playing an active role —from importation to final delivery — through a public tender to receive private sector bids to procure subsidized fertilizers. Players include international companies with country offices (Yara Malawi, Export Trading Co), importer producers (Optichem, Farmers World, Agora), and independent traders (Sealand Investment, Agricultural Trading Company, Simama General Dealers Company). Many importers are vertically integrated, which contrasts with fertilizer markets in the other countries studied. While importers in the other countries are often wholesalers, few are also distributors and retailers, as is the case in Malawi. Another difference in Malawi is that the government can still play a role anywhere along the market chain, from importer all the way to the level of retailer. The uncertainty surrounding government intentions from year to year causes this marketplace to be riskier for private sector investment and market development. Experience in the last three years has influenced the government's thinking on its proper role, as have donor nations, which fund the subsidy (voucher) program. Subsidy policy uncertainties include annual timing, volume allocations, tender currency choice, validity of quoted prices, and payment delays.

3.3.4. Zimbabwe

A factory for phosphate fertilizer in Zimbabwe started already production in 1927 followed by a factory for nitrogen fertilizer in 1969. From that moment until now total annual production has been around 100,000 metric tons of fertilizer nutrients. In the 1970s the fertilizer produced by two state enterprises was distributed mainly to large-scale commercial farmers by a cooperative and a state enterprise. In the 1980s the government stimulated maize production by smallholders through channelling inputs, credit and extension to this group. As a result maize production doubled (Kherallah *et al.* 2002). Just as in Tanzania and Zambia state buying stations in remote areas under pan-territorial pricing were used for that matter. From 1986 onwards this government maize policy was gradually dismantled by market liberalization and privatization. As a result maize production and fertilizer consumption in the smallholder sector started to decline in the 1990s (Jayne and Jones 1997). However, despite structural adjustment program Zimbabwe has retained its parastatal maize marketing board to stabilize maize prices (Kelly *et al.* 2005). Moreover, own production of fertilizers is protected against importation of fertilizers and this had negative effects on private sector development in the fertilizer market (Townsend 1999). Zimbabwe's historic annual fertilizer nutrient consumption is presented in Table 4.

Table 4: Zimbabwe annual fertilizer consumption (t; FAOSTAT 2013)

Products\Years	2002	2003	2004	2005	2006	2007	2008	2009	2010
Nitrogen	70,742	77,499	51,594	48,403	60,543	57,419	51,871	65,707	71,197
Phosphate (P ₂ O ₅ equivalent)	48,087	44,403	20,406	20,766	45,301	30,289	35,184	40,639	48,079
Potassium (K ₂ O equivalent)	11,481	24,130	14,352	15,849	26,817	20,433	17,040	10,719	18,341
Sum	130,310	146,032	86,352	85,018	132,661	108,141	104,095	117,065	137,617

The Case of Nitrogen Production

Nitrogen fertilizer production in the country has been characterized by fluctuating trends. In 1969, N fertilizer production was 23,000 t and this rose sharply to around 60,000 t in 1971. Production levels fell down during the period 1977-1979, and Desai and Gandhi (1989) attributed this to the widespread droughts, deteriorating terms of trade and civil unrest. The period of stagnation was followed by a period of extremely rapid growth which restored fertilizer production above 60,000 t in early 1980s. This growth was facilitated by good weather, better support services and fast post war recovery in the country (Rukuni 2006). Following this there was however a period of stagnation and this is partly associated with the drought of 1984 and foreign currency constraints due to debt crisis (Desai and Gandhi 1989). The drought of 1992 may have also been behind the drop in production levels. Production levels dropped again sharply from 1999 and never recovered till today even though production rose to 16,000 t in 2008 and close to 34,000 t in 2010. The drop coincided with the chaotic implementation of the land reform programme and the macro economic challenges the country started to face like foreign currency shortages, power and fuel shortages. As a result fertilizer companies failed to finance production and import raw materials and spare parts.

The performance of fertilizer supply systems varied depending on climatic, economic and political factors. Nitrogen fertilizer imports fell sharply from 47,000 t in 1966 to 10,000 t in 1971. This was as a result of sanctions imposed on the country in 1965. Imports were high during the period 1980-83 and this was powered by the maize revolution in the country during the 1980s (Byerlee and Eicher 1997). The period where consumption was exceedingly higher than local production, the demand for nitrogen fertilizer imports grew.

Nitrogen fertilizer consumption rose significantly to above 60,000 t for the period 1971-75, followed by a drastic drop in 1977. Consumption rose again sharply and reached a peak of 100,000 t in 1981, and this was partly due to an increase in smallholder maize production driven by extension, research and conducive credit policies (Rukuni and Eicher 1994). Nitrogen consumption for the period 1980 to 1993, i.e. the period before the Economic Structural Adjustment Programme (ESAP), was higher than for the periods 1966 to 1979 and 1994 to 2007. During the drought of 1992, consumption levels fell by about 50 % compared to 1991. From 2000 onwards fertilizer consumption stagnated or even slightly declined, which must be associated with widespread poverty stemming from disruptions in the farming sector due to agrarian reform and recurrent droughts.

3.3.5. Kenya

The Kenyan fertilizer market is one of the few African success stories that demonstrate how input markets can function under fully liberalized conditions. Competition, vertical integration within the

fertilizer supply chain, economies of scale and overall growth in the sector have resulted in significant efficiency gains and cost reductions. During the period 1990–2006, marketing costs and margins have declined by about 40 % (IFDC 2007). The success of the Kenyan fertilizer industry has been attributed primarily to a stable policy environment since 1990 (Hernandez and Torero 2011). For example, import licensing quotas were eliminated, and foreign exchange controls and retail price controls were removed during that time. Importantly, no large subsidy programs have been implemented, and market distortions caused by artificially low fertilizer prices offered by donors or government have been kept to a minimum. This has undoubtedly boosted the confidence in the market by the private sector. Regrettably, in 2008, the Kenyan government decided to engage directly in the market by importing fertilizers.

Fertilizer subsidies were already phased out by the mid-1970s in Kenya, but price controls continued to hold prices below market levels. Maize production by small-scale producers was stimulated by the government through pricing and market support policies (Jayne and Jones 1997). During the late 1980s donor aid was in fact accounting for over half of total fertilizer imports (Jayne *et al.* 2003). In 1990 fertilizer prices were finally de-controlled, and in 1993 fertilizer import restrictions were eliminated (Kherallah *et al.* 2002). Donor imports declined to 5 % of total fertilizer consumption, and small-scale farmers relied exclusively on the private sector and cooperatives for fertilizer. By 1996 there were twelve major private importers, about 500 wholesalers and 5000 retailers distributing fertilizer in the country. It is estimated that the number of retailers rose to between 7000 and 8000 by 2000 (Jayne *et al.* 2003). However, Kenya was still the largest African recipient of Japanese KR2 aid in 1996 (Townsend 1999).

The increase in fertiliser consumption in Kenya can be attributed to market liberalization which saw the increase of private market players in fertiliser marketing. Figure 10 shows the fertiliser consumption trends in Kenya between 2001 and 2010.

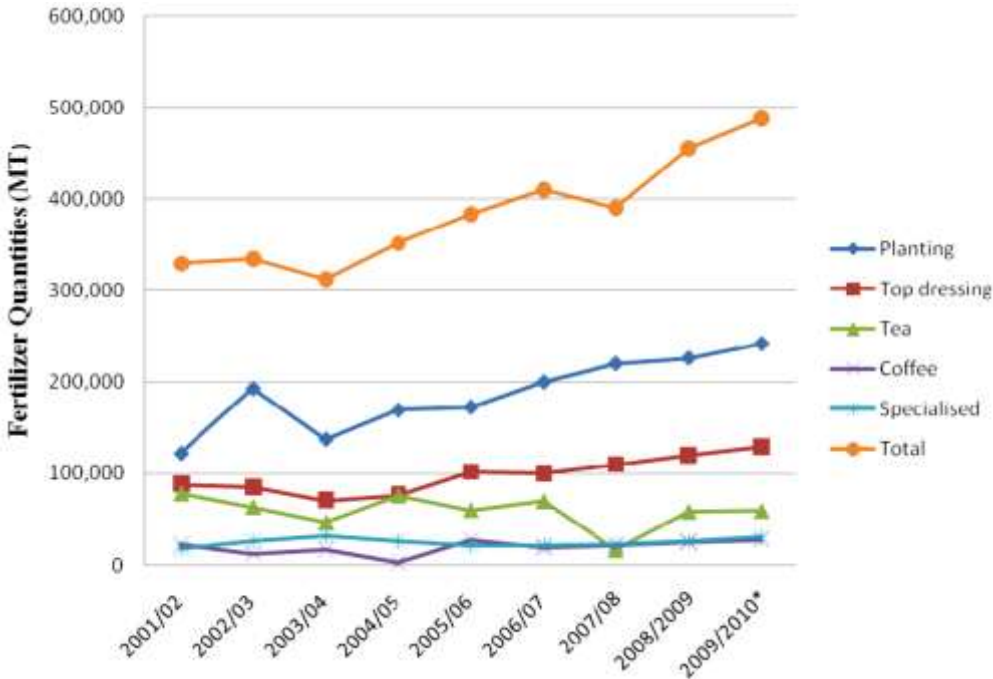


Figure 10: Fertilizer consumption trends by type for 2001-2010 (Kenyan Ministry of Agriculture, Farm Inputs Division 2011)

3.3.6. Ethiopia

Total fertilizer consumption increased gradually in Ethiopia since 1970 when the fertilizer market was totally controlled by the state owned parastatal. In 1992 fertilizer subsidies and pan-territorial prices had been removed and, with the currency devaluation, fertilizer prices increased sharply (Townsend 1999). However, total fertilizer consumption increased sharply from 1994 onwards. In 1993 Sasakawa Global 2000, an international NGO, had successfully introduced the use of improved maize technologies involving improved seeds and fertilizer on credit. In 1994 the government extended this concept nationally through the introduction of government-guaranteed credit at low interest rates with the National Extension Program as major buyer and distributor of fertilizer (Kherallah et al. 2002). Moreover, Ethiopia was the third largest African recipient of Japanese KR2 aid in 1996 (Townsend 1999). Credit repayment had been initially very high (usually > 98 %) due to the government's very strong stand on repayment, with arrests or confiscation of assets where necessary (Kelly et al. 2005). However, Kherallah *et al.* (2002) mentioned that the National Extension Program was later plagued with unrecoverable debts and favouritism in procurement. Ethiopia's historic annual fertilizer nutrient consumption is presented in Table 5.

Table 5: Ethiopian annual fertilizer consumption (t; FAOSTAT 2013)

Products\Years	2002	2003	2004	2005	2006	2007	2008	2009	2010
Nitrogen	97,647	34,075	81,860	80,503	84,628	106,019	111,773	118,364	156,141
Phosphate (P ₂ O ₅ equivalent)	69,977	28,240	45,604	59,300	64,483	119,149	122,253	127,990	162,062
Potassium (K ₂ O equivalent)	no data available								
Sum, N+P	167,624	62,315	127,464	139,803	149,111	225,168	234,026	246,354	318,203

3.3.7. Uganda

The development of Uganda fertilizer markets has taken a completely different path from the countries discussed above. When the governments of these countries were heavily involved in the fertilizer distribution in the 1970s and the early 1980s, the Ugandan government was deeply involved in civil conflicts and unable to implement any meaningful agricultural policies.

By the time the Museveni government took over in 1986, the structural adjustment programs had started in other African countries, and the Uganda government quickly adopted such policies. Indeed, the Ugandan government was considered as a leading example of market reform policies for other countries to follow. However without a basic market structure to build upon, the scale of fertilizer market has never been large enough to capture any scale economies. Omamo (2003) found that the fertilizer market structure was dominated by small-scale trade, high prices, and low net margins in the early 2000s. This is likely due to the poor transportation infrastructure and the country's remoteness from the major ports. There is no sign of expansion of the fertilizer market for decades. The total fertilizer consumption (in nitrogen fertilizer) remains at a low level: the 5-year average in Uganda is only 3,842 t, which is about 5 % of the Kenyan fertilizer consumption and 12 % of the Ethiopian fertilizer consumption (FAOSTAT, 2010). The fertilizer policy debate in Uganda has been centered around the question of whether Uganda should follow the pathway of Kenya or rather the one of Ethiopia. Uganda's historic annual fertilizer nutrient consumption is presented in Table 6.

Table 6: Ugandan annual fertilizer consumption (t; FAOSTAT 2013)

Products\Years	2002	2003	2004	2005	2006	2007	2008	2009	2010
Nitrogen	3,651	4,328	3,951	2,578	4,389	3,968	10,644	7,046	6,366
Phosphate (P ₂ O ₅ equivalent)	2,126	2,976	3,298	2,018	2,172	2,171	5,493	4,152	2,811
Potassium (K ₂ O equivalent)	1,686	2,027	1,509	1,160	1,091	1,358	2,839	2,548	2,429
Sum	7,463	9,331	8,758	5,756	7,652	7,497	18,976	13,746	11,606

Market Structure

The Uganda market procures from Kenya based importers, who purchase from international exporters (traders and/or producers). The in-country structure involves the Uganda importer servicing distributors, who then service retailers, and finally farmers. In terms of the market conduct, the fertilizer market in Uganda is best described as an oligopoly. The largest volume of fertilizer (70 %) is imported by independent agribusiness companies engaged in integrated production of specific crops throughout grower programs. The remainder is imported by a group of private sector enterprises selling fertilizer in an open-market environment.

3.3.8. Mozambique

Mozambique's market is characterized by low volumes of domestically consumed fertilizers (30,000 t/yr) despite the large quantities of imports that transit through the ports of Beira and Nacala (Kelly and Crawford 2007). The domestic market is dominated by one major importer wholesaler and is the closest to a monopoly among the countries studied. Mozambican ports are used to service the demand for fertilizer among neighbouring landlocked countries, namely Malawi, Zambia, and Zimbabwe. There is a potential for Mozambique to decrease the costs of domestic fertilizer by "piggy-backing" small domestic orders to those of the larger landlocked countries. Similarly, warehouse storage for the landlocked countries could be positioned in Mozambique for subsequent sale and delivery throughout the region, and could include release of sufficient stocks to meet local demand. There is not much history regarding fertilizer marketing in Mozambique as the country suffered a protracted civil war for a long time. Even after the war it took quite a long time to establish the required institutions that could deal with fertilizer marketing.

Immediately after the war, all agricultural functions were controlled by the government, and state owned companies were in charge of all production decisions and agricultural extension through a physical presence in each province (Jayne *et al.* 2002). Despite a later start than most African countries, Mozambique has fully liberalized and privatized all agricultural input markets. The transition to a private sector-led economy has left many unattended villages and farm areas due to the absence of a retail network for agricultural inputs. Distrust remains between the previous public sector monopolists and emerging private sector actors in the agricultural input supply system. Mozambique's historic annual fertilizer nutrient consumption is presented in Table 7.

Table 7: Mozambican annual fertilizer consumption (t; FAOSTAT 2013)

Products\Years	2002	2003	2004	2005	2006	2007	2008	2009	2010
Nitrogen	17,700	1,836	3,414	6,400	17,168	11,464	41,860	15,133	43,385
Phosphate (P ₂ O ₅ equivalent)	2,000	1,360	3,473	439	2,835	1,079	10,363	4,678	2,587
Potassium (K ₂ O equivalent)	6,900	117	3,508	298	2,748	1,293	9,430	2,373	355
Sum	26,600	3,313	10,395	7,137	22,751	13,836	61,653	22,184	46,327

Market Structure

The fertilizer market is dominated by one major importer, AgriFocus that services the open market. As in most African countries, the export crop estate sector often imports directly. Estates are unwilling to depend on the local agricultural input supply system due to the high costs incurred if the fertilizers are not delivered on time, in the appropriate amounts, and with the correct formulations. Despite its cost in terms of time, labour, and money, auto-procurement is more attractive and less risky to the estates. In Mozambique, the sugar and tobacco estates auto-procure their fertilizer needs, which represent 80 % of the country's total fertilizer imports (IFDC 2007).

In terms of market conduct, aside from the plantation companies (sugar and tobacco), which import approximately 80 % of the total fertilizer volume to service their own farmers, the open market presents itself as oligopolistic due to approximately six active importers. The open market volume is mainly serviced by one importer, *Agrifocus*. The latter began operations with plantation producers (cotton, sugar, and tobacco) in the late 1990s (Jayne et al 2002). It has since gained access to higher-volume procurement, established international creditworthiness, and obtained lower-priced fertilizers from international manufacturers (Baltzer and Hansen, 2012). *Agrifocus*' import volumes decreased when large sugar and tobacco companies started importing their own fertilizers, but its access to more affordable fertilizers remains intact. In addition to road imports from South Africa, the main importation of fertilizers into the country is conducted through the Maputo, Nacala, and Beira ports. As additional imports have taken place through Maputo, fertilizer availability and use has increased, as reflected in increasing sales by importer-retailers in the Maputo region (ibid).

3.4. Fertilizer Trade in East and Southern Africa – an overview

With regards to trade, trade of total nutrients (imports and exports) increased between 1995/96 and 2005/06 for Africa as a whole and for East and Southern Africa. Total imports for Africa increased from 1.4 Mt of nutrients to 2.2 Mt of nutrients, an increase of 57 % (Africa Fertilizer 2012). The increase for SSA was 25 %, from 0.8 Mt to 1 Mt. Total exports from Africa increased from 2.7 Mt to 3.1 Mt (an increase of 16 %). The increase for SSA was 6 %, from 0.078 Mt to 0.825 Mt (ibid). Therefore, Africa as a whole is a net exporter; it exports more fertilizer than it imports. However, SSA is a net importer of fertilizers.

SSA's almost exclusive reliance on imported fertilizer for its supply was not an inherent disadvantage before 2007 since there was ample supply of fertilizers in the global fertilizer market at relatively stable prices (Bumb et al. 2008). However, the unprecedented increase in fertilizer prices between January 2007 and mid-2008 was of extreme concern to African governments, and renewed interest in exploring the viability of national and regional fertilizer production in Africa. The US Gulf price of

di-ammonium phosphate (DAP), a popular basal fertilizer for the production of maize in many African countries, increased by approximately 365 % from \$262/t in January 2007 to \$1,218/t by April 2008. Similarly, between January 2007 and August 2008, the price of urea in the Arab Gulf tripled from \$272/t to \$815/t (Africa Fertilizer 2012).

These unprecedented fertilizer price increases were due to a number of factors, including oil prices at over \$100 per barrel and the increased demand for fertilizers to produce grain-based substitutes such as biofuel in Europe, the United States and Brazil; an increase in energy and freight prices; increased demand for grain-fed meat from the expanding middle-class societies of China, India and Brazil; and an increase in the price of natural gas, a major input for the production of urea for nitrogen fertilizers. However, farmers could not afford to purchase fertilizers at these astronomical prices, resulting in a drop in fertilizer quantity demand, leading to stock accumulation and drastic price declines: by mid-December 2008 the price of DAP had fallen to \$469/t and the price of urea was lower than pre-2007 levels at \$247/t (ibid).

Although prices have since returned to pre-2007 levels due to the market correction, this experience clarified for African governments how vulnerably the continent is to global price volatility and has solidified interest in pursuing fertilizer production in Africa.

Having said this, an investment in fertilizer production is only economically viable if it is for production of 0.3 to 0.5 Mt, which requires a capital investment of over \$500 million. One option to pursue in the long-run is to invest in fertilizer production in one country for local and regional consumption and export markets. However, in the short-term Africa will continue to import the majority of its fertilizer from the world market.

In view of the aforementioned, the retail price of fertilizer in Africa is determined by three factors: the world market price; exchange rate; and domestic marketing costs. Since Africa is a consumer in the global market its response options in regard to reducing the price paid on the world market are limited. In this era of free trade and globalization, governments are also limited in regard to the extent by which they can manipulate the exchange rate to mitigate the impact of these price increases on farmers. Consequently, the key policy response has been a surge in the number of countries with subsidy programs. However, this response is expensive and in many cases unsustainable, and more importantly, it is typically implemented in a manner that eschews and undermines the private sector due to market distortions. A more viable alternative is to develop sustainable and competitive private-sector led fertilizer markets that will make available to farmers the appropriate fertilizers of high quality, at affordable prices, in a timely manner.

3.5. Basic Fertilizer Market Conditions in East and Southern Africa

Small-scale farmers produce the majority of agricultural products in SSA, but they use little or no chemical or organic fertilizers to do so. More fertilizer is applied to staple foods than to export crops; 40 % of the fertilizer consumed in SSA is used on maize, followed by other cereals (wheat, barley, teff, sorghum and millet). Fruits and vegetables and sugar cane account for 15 % of fertilizer use, and rice, tobacco, cotton and traditional tubers account for 2-3 % each (Morris *et al.* 2007).

Average fertilizer use in SSA is 8.7 kg/ha, less than one-tenth of the world average (100 kg/ha). Consequently, national fertilizer markets are small, with the majority of countries in SSA consuming less than 10,000 t of nutrients per annum (FAOSTAT 2013). These markets are characterized by too

many products relative to market size. For example, Malawi has 20 fertilizer products in use. Many are compound fertilizers, typically NPK with minor variations in content. Because these are low-analysis fertilizers, the nutrients are more expensive than the same nutrients found in straight high-analysis fertilizers, because it is more expensive to manufacture smaller amounts of specific types of fertilizers. As a result, there is poor availability of fertilizers in rural areas and high prices for fertilizers that do reach the farm-gate. The seasonality of demand for fertilizers and the low purchasing power of smallholders which is typically characterized by small and frequent purchases increase transportation, storage and transaction costs.

3.6. Constraints to Market Development

3.6.1. Supply-Side Constraints

A key supply-side constraint is policy uncertainty and inconsistency. Many African governments are unclear about their role in a liberalized fertilizer market; specifically, what they should do to support the fledgling private sector. At the same time, governments have little faith in the capability of the private sector.

The result is two extremes in the governments' approach to the fertilizer market. One extreme is a 'hands-off' approach whereby the government has withdrawn completely and left the private sector unsupported in terms of providing an enabling policy, regulatory and institutional environment. The other extreme is 'government intervention' – government involvement in the importation and/or distribution of fertilizer via the reinstatement of old parastatals, typically implemented in the form of an unclear and inconsistent subsidy policy which eschews the private sector (Kelly and Crawford 2007).

Where the subsidy programs do not involve the private sector, the result is market distortions due to the sale of subsidized fertilizers by the government parastatals and the displacement of commercial sales, which discourages the private sector (Minot and Benson 2009). Even where the private sector may be requested to import on behalf of the government, the information regarding quantities and timing is not always clear or provided in a timely manner, and the terms of participation can pose risks for private importers who decide to submit bids. For example, tenders can be unrealistic as they require physical stocks to be positioned in-country prior to tendering which poses a huge risk for importers as they have no guarantee their bid will be successful.

Therefore, despite the liberalization of fertilizer markets in Africa, continued government involvement to varying degrees is creating an unequal playing field and disrupting the development of the burgeoning private sector.

Other supply-side constraints are weak market information systems and fertilizer regulatory systems that are either non-existent or ineffective where they do exist. Many countries either do not have a legal and regulatory framework regarding quality, standards, measures, safety in use and business ethics vis-à-vis the importation, distribution, marketing and use of fertilizer products in the country (Kelly 2006) Where these frameworks exist, the quality control systems are weak and implementation capacity is limited. Laboratory testing facilities are absent or out-dated and the majority of countries have no inspectors or there are less than 10 inspectors for the whole country; hence inspection at the point of sale, where the risk of adulteration is highest, is limited.

Well-functioning markets require regular and accurate information about prices, quantities, stocks,

deliveries and transaction costs. However, while in some countries information about output markets (commodity prices) is published in the daily newspaper, information collection and dissemination remain weak for input markets. The ministries of agriculture in many African countries do not have the human and/or financial resources to collect and disseminate market statistics and information. Consequently, importers, agro-dealers and farmers do not have sufficient, up-to-date information about market conditions to make intelligent decisions about where and when to buy and sell their fertilizers and other agricultural inputs.

3.6.2. Demand-Side Constraints

These consist of constrained fertilizer adoption due to the absence of stable output markets for increased production, outdated fertilizer recommendations, and weak or non-existent extension systems. The existence of reliable and stable output markets provide the incentive for farmers to use productivity-enhancing technologies like fertilizers by providing reliable outlets for their marketable surpluses. However, while the markets for cash and export crops are well-developed in SSA, the markets for food crops are poorly developed. Consequently, at harvest farmers are often faced with low prices which reduce the incentive to use modern inputs.

Second, small-scale farmers in SSA lack knowledge about the correct and safe use of fertilizers (Kelly 2006, Africa Fertilizer 2012). Very few farmers use basal fertilizers, some use basal (NPK) fertilizers for topdressing, or they may use a mixture of both, due to limited knowledge and economic constraints. Moreover, even where farmers attempt to use fertilizers correctly their efforts are hampered by out-dated fertilizer recommendations; consequently, they use fertilizer grades and quantities that are not suitable for their soils and/or crop mix. Such continuous cultivation without proper and adequate use of fertilizers has resulted in severe soil infertility and degradation problems in SSA. Consequently, crop yields and profitability are much lower than what is required to achieve food security and increased incomes.

3.7. Conclusions

In this chapter, we have shown that the majority of East and Southern Africa countries have modest and some even impressive annual growth levels in total fertilizer consumption during the past 20 years. The most important factors which explain fertilizer use increases before and during structural adjustment programs are pan-territorial crop and fertilizer prices, subsidized fertilizer prices, a high share of donor-funded fertilizer imports to total imports, fertilizers provided on a credit basis to farmers, and the devaluation of currency in some countries. The removal of pan-territorial prices, fertilizer subsidies and credit opportunities due to liberalization has caused a decrease in fertilizer consumption in Tanzania, Zambia, Malawi and Zimbabwe. The private sector was not able to stop this decrease in total fertilizer consumption. In fact only in Kenya's private sector involvement in the fertilizer market seems to be an important factor in explaining fertilizer consumption growth. However with the re-introduction of targeted fertiliser subsidies in the 2000s, some East and Southern African countries have realised increased fertiliser consumption growth, notably Malawi, Zambia and Tanzania.

Despite a history of disappointing results, fertilizer subsidies are now attracting renewed attention in East and Southern Africa. Recently there has been considerable debate about the desirability of using fertilizer subsidies to achieve not only economic growth targets but also welfare goals. Although it is difficult to support the use of fertilizer subsidies on efficiency grounds, realistically it must be

recognized that fertilizer subsidies are likely to be implemented in some countries in the region, if for no other reason than because of their political popularity.

Further we have shown that the establishment of well-functioning fertilizer markets in East and Southern Africa will require the implementation of a set of appropriate policy, regulatory, institutional, and market development measures which will attract private sector investment and engagement by establishing a level playing field for all market actors while enabling government to ensure market access for poor farmers. The key policy measures are: the establishment of a consistent and predictable price (subsidy, if warranted) and trade (tariffs, taxes) policy; introduction of risk-sharing financial mechanisms to share risk among stakeholders thus increasing access of affordable finance for importers and agro dealers; investment in human capital development for farmers and the private sector, (marketing and technical skills); development and enforcement of fertilizer legislation and supporting the regulatory framework.

On the demand side, measures should be implemented to improve the prices received by farmers and dramatically increase output market demand. Output market demand can be increased by scaling-up and replicating output markets on different fronts – out grower schemes, peri-urban agriculture, niche markets and non-traditional exports.

The prices received by farmers can be improved by promoting the development of producer associations, dissemination of market information, introduction and enforcement of grade and standards for quality produce, improved storage and agro-processing facilities and warehouse collateral to facilitate the purchase of agricultural produce at harvest time.

There is a need to educate farmers about the proper use of fertilizers and management practices. Extension systems should be revived, and redesigned and capacitated to reach the widely dispersed farming community in Africa. Farmers need to be educated about correct fertilizer use and improved agronomic practices through fertilizer trials and demonstrations.

4. Use of chemical fertilizers

4.1. Summary

Fertilizer consumption of sub-Saharan Africa is stagnating at 8-12 kg/ha/yr since at least ten years. In 2010, only six countries surpassed the 10 kg/ha/yr bar and none reached the 50 kg/ha/yr target set by the Abuja Fertilizer Summit in 2006 to be reached on average for SSA in 2015. It is thus highly unlikely that the goals of the Abuja Fertilizer Summit will be met. Lack of enabling policies for the private industry, poor infrastructure (access to fertilizer), and low demand by fertilizer consumers, especially in rural areas of sub-Saharan African countries, are three major causes of low consumption. Because of the relatively high fertilizer price at farm gate, the low market price of food crops like maize and the high variability of the agronomic efficiency of fertilizer applied, the benefit-cost ratio often is too low to encourage farmers to apply fertilizer. An overestimation of the risk of failure to break even when applying fertilizer by farmers adds to the dilemma. Furthermore, fertilizer recommendations developed in the past often ignore differences between soils and are highly incompatible with smallholders' resources.

4.2. Trends

The most comprehensive recent report on the use of chemical fertilizers in Africa is that of The World Bank (Morris *et al.* 2007). In this report the authors present data on fertilizer consumption for sub-Saharan Africa of the year 2002. They calculated an average annual total mineral fertilizer application of merely 8 kg per hectare cultivated land. Eight years later the average figure has changed only little. Total mineral fertilizer consumption in 2010 was less than 12 kg/ha or 3.2 kg/person (Figure 11).

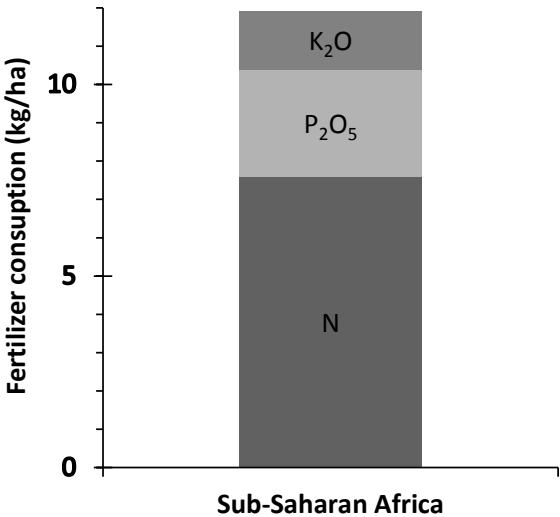


Figure 11: Average mineral fertilizer consumption (N, P₂O₅ and K₂O equivalent) per arable and permanent crop land of sub-Saharan Africa in 2010; calculated with data from IFA 2013 (fertilizer) and FAOSTAT 2013 (land area)

This is far below fertilizer consumption of similar agro-ecozones of e.g. eastern, southern and south-eastern Asia – as far as such comparison is valid when averaging data across an entire sub-continent. For example, the average fertilizer consumption of India in 2010 was 166 kg/ha (24 kg/person) and that of Vietnam 239 kg/ha (26 kg/person; Table 8).

Table 8: Mineral fertilizer consumption (sum of N, P₂O₅ and K₂O equivalent) per arable and permanent crop land or per capita of sub-Saharan Africa and a few selected countries in 2010; calculated with data from IFA 2013 (fertilizer), FAOSTAT 2013 (land area) and OECD 2010 (population)

Country/Sub-continent	Per hectare consumption (kg/ha)	Per capita consumption (kg/person)	Total consumption (Mt)
Sub-Saharan Africa	11.9	3.2	2.72
Indonesia	113	20	4.79
India	166	24	28.12
Vietnam	239	26	2.30
Egypt	369	17	1.36
Germany	206	31	2.51

Per hectare fertilizer consumption for sub-Saharan Africa as a whole stagnated since more than a decade. However, as far as single country fertilizer consumption data are accessible – for the majority of countries of Sub-Saharan countries they are not, and such countries are simply lumped together – quite some variability across countries can be observed. South Africa and Kenya, with 44 and 30 kg/ha, respectively, are the two sub-Saharan African countries with by far the highest per hectare fertilizer consumption in 2010 (Figure 12). Nigeria, Ethiopia, Zimbabwe and Zambia follow with fertilizer consumption rates between 13 and 16 kg/ha. The remaining sub-Saharan countries (unfortunately largely lumped together by IFA) do not pass 10 kg/ha; (former) Sudan is at the low end (4 kg/ha). Per capita fertilizer consumption approximately follows this trend (exception Zimbabwe), in terms of absolute numbers amounting to ~30 % of per hectare consumption.

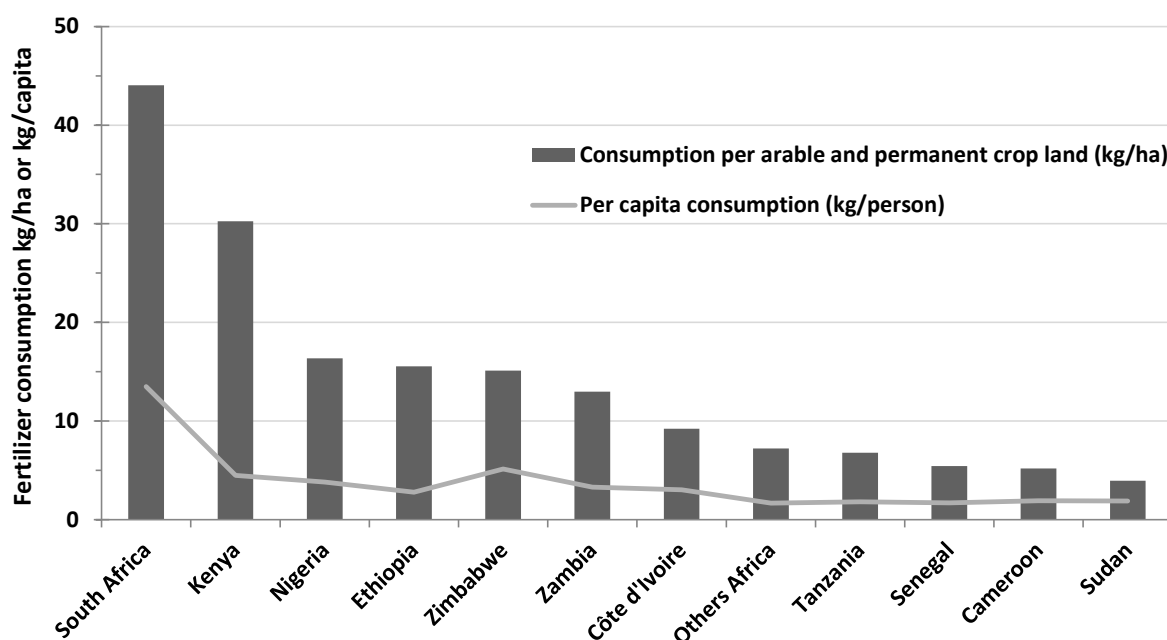


Figure 12: Mineral fertilizer consumption (sum of N, P₂O₅ and K₂O equivalent) per arable and permanent crop land or per capita of selected sub-Saharan countries in 2010; calculated with data from IFA 2013 (fertilizer), FAOSTAT 2013 (land area) and OECD 2010 (population); arable and permanent crop land area are data from 2009; 'Others Africa' – lumped together by IFA – are: Central African Republic, Chad, Comoros, Democratic Republic of the Congo, Congo, Djibouti, Equatorial Guinea, Eritrea, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Mozambique, Namibia, Niger, Rwanda, Sao Tome and Principe, Seychelles, Sierra Leone, Somalia, Swaziland, Togo and Uganda

Across years, Kenya and Ethiopia managed to gradually increase per hectare fertilizer consumption at a modest pace (Figure 13). Tanzania on the other hand, stagnated at a mere 5 kg/ha over the last 35 years. Zimbabwe, the African figurehead of reasonable fertilizer use during the 80's and 90's, reduced consumption sharply beginning 2001, soon after the *Land Reform and Resettlement Programme Phase II* was forced into full-fledged implementation.

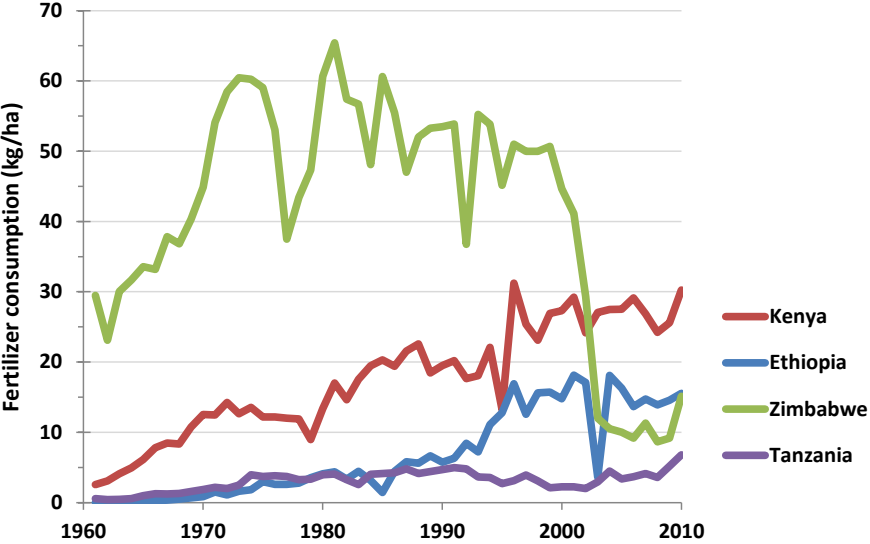


Figure 13: Mineral fertilizer consumption (sum of N, P₂O₅ and K₂O equivalent) per hectare of arable and permanent crop land of Ethiopia, Kenya, Tanzania and Zimbabwe from 1961 to 2010; calculated with data from IFA 2013 (fertilizer) and FAOSTAT 2013 (land area); 2010 arable and permanent crop land assumed to equal that of 2009; arable and permanent crop land of Ethiopia of 1961-1992 assumed to equal that of 1993

Total fertilizer consumption in sub-Saharan Africa increased steadily from 1960 to 1980 but then leveled off at around 2 Mt/yr for the subsequent 25 years (Figure 14).

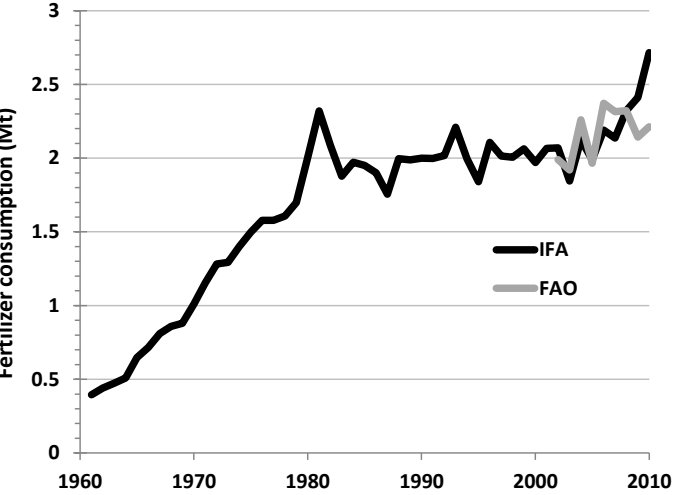


Figure 14: Total fertilizer consumption (Mt; sum of N, P₂O₅ and K₂O equivalent) of sub-Saharan Africa from 1961 to 2010 (based on data from IFA 2013 and FAOSTAT 2013)

Only in 2005 consumption increased again, which however was almost exclusively due to the increase in fertilizer consumption of Nigeria alone. It should be noted, however, that especially for

Nigeria, latest IFAD and FAO data deviate considerably, leading to the differences in total fertilizer consumption in Figure 14 between the two. South Africa (25 %, 0.67 Mt) and Nigeria (22 %, 0.61 Mt) used almost half of the total fertilizer consumed in 2010. Ethiopia (0.23 Mt) and Kenya (0.18 Mt) used another 9 and 7 %, respectively. Thus, more than 60 % of all fertilizer consumed in sub-Saharan Africa went on the account of these four countries alone.

4.3. Reasons for low mineral fertilizer consumption

4.3.1. Fertilizer markets and access

Well developed and functioning fertilizer markets backed up by a strong commercial fertilizer industry are the key to increased inorganic fertilizer use. Despite considerable efforts in the past, such markets and accompanying industries have yet to emerge in most of sub-Saharan Africa, even though the problem had been identified some decades ago and since then repeatedly emphasized in a range of publication (Miracle 1966, Vlek 1990, Crawford *et al.* 2003, Poulton *et al.* 2006, Hernandez and Torero 2011) and global initiatives, such as the Abuja Fertilizer Summit in 2006 (see below).

Lack of enabling policies for the private industry, poor infrastructure (access to fertilizer), and low demand by fertilizer consumers (farmers), especially in rural areas of sub-Saharan African countries, are three major causes of the dilemma. To some extent this is creating a “chicken-egg” problem, i.e. low consumption triggers little market development and vice-versa. Additionally, it leads to a considerable increase in fertilizer prices along the market chain *producer – wholesaler – retailer – farmer*, augmented by the fact that a) often only a single firm is operating in a country (risk of monopoly), and b) large amounts of fertilizer in many African countries is imported rather than produced in the country itself with locally available reserves (Hernandez and Torero 2011).

Farmer’s physical access to the fertilizer market is thus one constraint – fertilizer might simply be out of reach for a farmer. Lacking financial means (cash constraints) is another, probably even more import, reason for low mineral fertilizer consumption. Many resource-poor farmers in sub-Saharan Africa do not have enough money in cash at hand to buy high-priced fertilizers (see following chapter) when required, especially when cash-income after crop harvest and the subsequent season is months apart with a dry season in-between. A poorly developed output market, i.e. little opportunities for farmer’s to sell surplus yields or cash-crop at reasonable price adds to the cash constraints, besides providing a big disincentive to increase production of staple crops above the mere subsistence level; fertilizer use would be crucial to accomplish this.

4.3.2. Fertilizer costs

In view of the constrained market situation, it is not surprising that fertilizers in Africa are more expensive compared to Europe, North America, or Asia. Sanchez (2002) estimated that cost of fertilizer in Africa is between two to six times more than in the other continents. A metric ton of urea costs about \$90 in Europe, \$120 in Mombasa (Kenya) or Beira (Mozambique) – both seaports – and increases to \$400 in Western Kenya (700 km away from Mombasa), \$500 across the border in Eastern Uganda, and \$770 in Malawi when transported from Beira (Sanchez, 2002). Nevertheless, break-even responses calculated from the SIMLESA’s baseline survey show that, even with rather high fertilizer prices, the use of fertilizers across eastern Africa, should be economical and the way forward to start developing more sustainable and profitable farming systems.

4.3.3. Fertilizer value-cost ratio

One of the basic parameters defined by agro-economists to assess the viability of fertilizer use is the ratio of unit fertilizer price to unit crop price (P_F/P_Y). This, for example, would be the dollars per kg fertilizer spent divided by the dollars per kg yield earned. Furthermore, the fertilizer efficiency (Y/F) is defined as kg extra yield (Y) produced per kg fertilizer (F) applied. Finally, the value-cost ratio (VCR) is the amount of money earned per amount of money spent, which is, within the aforementioned context, equal to $(Y/F) / (P_F/P_Y)$.

Figure 15 displays the relationship between VCR and P_F/P_Y for three different fertilizer response levels. Morris *et al.* (2007) invoke a few rules-of-thumb that have proven to describe well in very general terms the market situation of Latin America and Asia. From 1980 to 2004, assuming no subsidies on fertilizer, P_F/P_Y ranged between 0.8 and 4.5, depending very much on the crop and year considered. As rice usually achieves a higher market price, P_F/P_Y (~1.1) is at the lower end. P_F/P_Y of wheat is around 2.2 and of maize around 2.9 with considerable variation over the years (indicated by the light color shades in Figure 15). A second widely held convention is that VCR should be greater than 2 (*lower* threshold in Figure 15) in a developing economy to provide incentives for fertilizer use overcoming risks and costs of capital (CIMMYT 1988). VCR may have to be as high as 3 or 4 (*secure* threshold in Figure 15) to provide sufficient incentives for adoption in risky production environments.

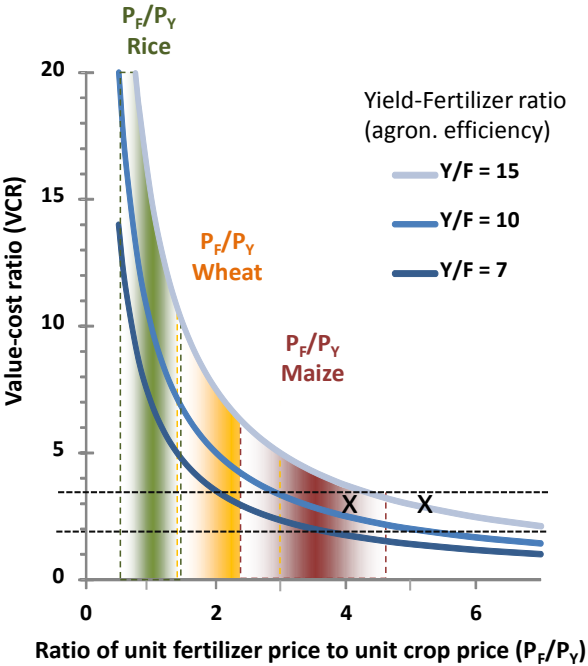


Figure 15: Value-cost ratio (VCR) in response to the ratio of unit fertilizer price to unit crop price (P_F/P_Y) for three different levels of fertilizer response (kg yield [Y] per kg Fertilizer [F]; blue curves); value-cost ratio is the amount of money earned per money spent; based on data from Morris *et al.* 2007; left X = maize, West Africa; right X = maize, East and Southern Africa (Kelly 2006)

For the given ranges of P_F/P_Y , VCR of a high value crop like rice is always above the secure threshold, even at low level of fertilizer response ($Y/F = 7$), making it likely for farmers to invest in fertilizers. Similar applies to wheat when $Y/R > 10$. For maize, on the other hand, the secure VCR threshold is only surpassed when $Y/F > 15$. If Y/F is between 7 and 10, the lower VCR threshold is frequently surpassed but not the secure threshold, and thus only farmers in non-risky environments would be inclined towards investing in fertilizer.

The immediate question arises: what is the usual fertilizer response for a staple crop like maize in Eastern and Southern Africa? Data for West Africa and East and Southern Africa have been provided by Kelly (2006; see X in Figure 15). The median observed VCR for both regions was 2.8. The fertilizer response was higher in East and Southern Africa (~14) than in West Africa (~11). The opposite was true for P_F/P_V (East and Southern Africa ~5.2, West Africa ~4). As VCR is smaller than 3-4, fertilizer application may be perceived as (too) risky by farmers in challenging environments.

CIAT data on N-fertilizer use efficiency are on average much higher than those presented above. For example, within the AFSIS project (<http://www.africasoils.net/>), fertilizer response trials were carried out in a number of sub-Saharan African countries (see also chapter 2). Results for maize at four sites in Malawi (two years of data) and one site in Nigeria (one year) that received sufficient P-fertilizer (40 kg P/ha) and increasing levels of N-fertilizer (45, 90, 120, or 150 kg N ha⁻¹) are shown in Figure 16.

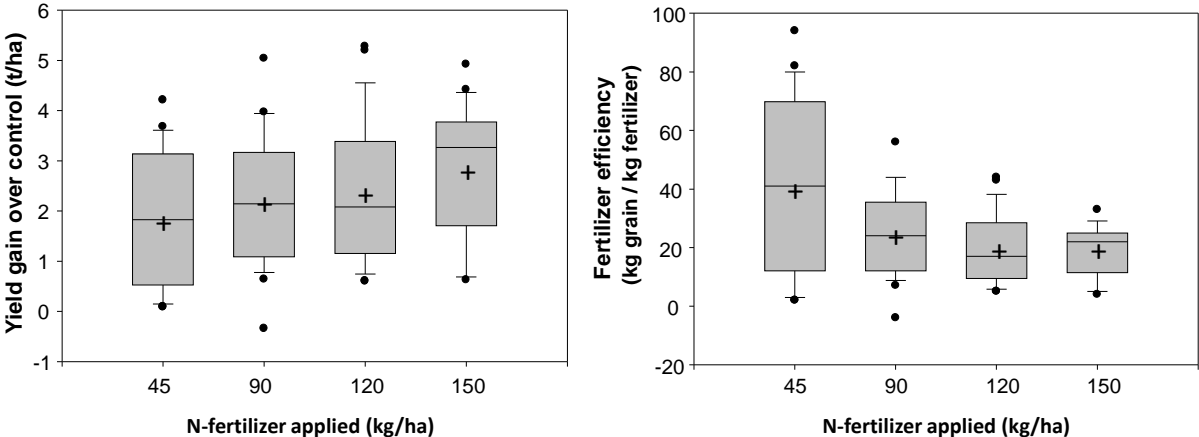


Figure 16: Box-Whisker plot (left) of yield increases (t/ha) in response to N-fertilizer application at four sites in Malawi and one site in Nigeria, and corresponding fertilizer efficiency (right); boxes display the 25th and 75th percentile, lines within boxes the median, + within boxes the average, whiskers the 10th and 90th percentile, and dots outliers (N = 23); all sites and plots, including the control treatment, received 40 kg P/ha; data from CIAT’s AFSIS project (Kihara *et al.* unpublished)

Fertilizer efficiency at all N-levels was on average larger than 20 (median >17), with the 45 kg N/ha treatment reaching even 40. The overall average O/N was 26 (median 23). Furthermore, O/N of 75 % of the data was greater 10. However, it should be noted that these data are only valid for the N-fertilizer applied with sufficient phosphate base fertilization. If this phosphate fertilizer was budgeted in, i.e. assessing the N *plus* P fertilizer efficiency, the overall O/N average (26) would drop to 17 and the 25th percentile from 12 to 8. With P_F/P_V ratio equal 5-7, the average O/N (17) would still yield a VCR equal to 3.4-2.4, and thus significantly above the lower threshold of farmers’ “interest-to-invest”. However, the rub lies in the 25th percentile: At O/N equal 8, fertilizer application becomes unattractive, as the VCR is below 2 unless the P_F/P_V ratio is less than 4 – which according to Kelly (2006) is hardly the case in East and Southern Africa. In other words, in at least 25 % of the observed cases, fertilizer application is likely to be perceived unattractive by farmers. Furthermore, if O/N is equal are less than 7 (21 % of the aforementioned N+P fertilizer efficiency cases) and the P_F/P_V ratio equal 7, VCR would not surpass 1, i.e. a farmer selling the extra maize grain achieved with the fertilizer applied would not even get the money back that he/she had invested in fertilizer.

In conclusion, merely looking at economic figures, investing in fertilizer to grow maize in east and southern Africa is not a straight forward, 100 % attractive thing for farmers to do.

4.3.4. Farmer's perceived risk

The actual risk that an investment in fertilizer does not pay-out, as has been detailed above, and the farmer's perceived risk may vary substantially. This has a range of reasons, in a nutshell boiling down to the differences in subjective perception between farmers and scientists, "shaped by their knowledge of fertilizer technologies, skill in using fertilizer, and capacity to evaluate potential returns to fertilizer use, given climatic and other natural risks, output price risk, perceptions of potential returns to alternate uses of available resources, personal risk preferences, and possibly other factors." Morris *et al.* (2007 p. 64)

One of the recommendations to overcome an overly risk-averse attitude of farmers is to provide farmers with financial tools to better manage risk, for example, by introducing innovative insurance instruments tailored to the needs of farmers, such as weather-indexed crop insurance (Morris *et al.* 2007). Another entry point is the use of participatory systems simulation approaches (Meinke *et al.* 2001).

4.4. Fertilizer recommendations

In most countries fertilizer recommendations have been developed based on practical considerations for extension to communicate uniform messages rather than based on site-specific needs or the socio-economic circumstances of poorly resourced farmers (Table 9).

Table 9: Selected blanket N and P fertilizer recommendations for maize

Country	Blanket fertilizer recommendation (kg ha ⁻¹)		Source
	N	P	
Malawi	92	40	Snapp <i>et al.</i> (1998)
Mozambique	105	30	Goujard <i>et al.</i> (2011)
Zambia	112	40	Xu <i>et al.</i> (2009)
Zimbabwe	60-107	40	ZFCL, Gono (1996)
Kenya	60	26	Okalebo <i>et al.</i> (2006)
Ethiopia	60	20	Stepanek (1999)

These recommendations ignore differences between soils and are highly incompatible with smallholders' resources (Kumwenda *et al.* 1996). In Malawi, the fertilizer recommendations are only given for N and P. Tanzania has developed a more sophisticated set of recommendations considering 20 ecological zones, 13 of which have their own maize recommendations. Still these recommendations ignore local socio-economic, market settings, and ignore alternative sources of nutrients. Establishment of agro-ecological zones were based on dominant soil type, length of growing season, and annual rainfall, distribution and reliability, so that the major environmental conditions which affect fertilizer response were taken into account (Harrop and Samki 1984). Having said so, smallholder Tanzanian farmers have one of the lowest rates of fertilizer use in eastern Africa.

In Zimbabwe, the recommended basal compound fertilizers contain K and in some cases Zn. The spatial heterogeneity within smallholder farms will need to be recognized in order to design more effective fertilizer recommendations targeting existing soil fertility niches such as poorly responsive

fertile fields, responsive fields and poorly responsive poor fields (Tiftonell *et al.* 2007). There is need for capacity building of extension workers to assist smallholder farmers in the identification of such variability and its effect on the performance of different management interventions.

4.5. The 2006 Abuja Fertilizer Summit

Looking at the tripling of fertilizer consumption in Nigeria from 0.18 Mt in 2004 to 0.61 Mt in 2010 (IFA 2013), one could be inclined to say that it requires hosting an international fertilizer summit to create the awareness of African states to start efforts to increase fertilizer use.

From 9 to 13 June 2006 heads of states and politicians of African countries, farmers, donor agencies, and agricultural scientists from various parts of the world met in Abuja, Nigeria, at the first-ever Africa Fertilizer Summit. The challenges of reaching and maintaining food security in Africa as well as the importance of increasing mineral fertilizer use to achieve this goal was discussed. Participants unanimously acknowledged that *“African farmers face a variety of constraints, including low productivity of cultivated lands, limited access to new agricultural technologies and the lack of markets for their products. Without adequate inputs, farmers cannot meet the food needs of their own families, much less those of a rapidly growing population. Regarding food security in Africa, farmers will need to shift from low yielding, extensive land practices to more intensive, higher-yielding practices, with increased use of improved seeds, fertilizers and irrigation.”* (AfDB, 2013)

In view of this, African Union Ministers of Agriculture endorsed *“The Abuja Declaration on Fertilizers for an African Green Revolution”*. In a nutshell, this declaration recognized that fertilizer is crucial in the face of rapidly rising population and declining soil fertility, and that there is an urgent need for a strategic investment program to increase the availability and use of fertilizer. The African Union Member States resolved to increase the level of use of fertilizer from the current average of 8 kg/ha to an average of at least 50 kg/ha by 2015. They furthermore committed themselves to reduce the cost of fertilizer procurement, to improve farmers’ access to fertilizers by developing and scaling up input dealers’ and community-based networks across rural areas or granting targeted subsidies in favour of the fertilizer sector, to facilitate measures to improve output market incentives, and to accelerate access to credit at the local and national level.

For the purpose to meet the financing requirements of the various actions agreed upon by the Summit, the African Development Bank (AfDB), with the support of the United Nations Economic Commission for Africa (UNECA) and the African Union Commission (AUC) in 2007 established the (Secretariat of the) Africa Fertilizer Development Financing Mechanism (AFFM). The AfDB’s Board of Directors was put in charge of overseeing general operations and approves all financing, including the annual budget and financial statements of AFFM itself. The AFFM relies on a Governing Council (GC), which includes representatives of donors, African farmers unions, fertilizer industry experts and representatives of African Ministers of Agriculture. AFFM key activity areas were defined as:

- Facilitation of activities including policy formulation, technical assistance, information dissemination, law reform, and project preparation
- Development of Africa’s fertilizer manufacturing capacity
- Provision of credit guarantees for fertilizer importers and distributors
- Support for the establishment of regional fertilizer procurement and distribution facilities
- Development of financing mechanisms in support of fertilizer production, distribution, and agriculture generally

AFFM started work in 2008 and developed a plan of action for 2009-11, among others scheduling an official AFFM launching and first GC meeting. This was held in November 2009, i.e. more than 3 years after the Abuja declaration was endorsed. In 2008 it had been anticipated that by that time AFFM funds would be fully operational (AfDB 2008).

Four years later, in March 2013 the 2nd AFFM GC meeting took place. At the meeting it was stressed that AFFM was facing lack of funding. One of the specific objectives of the meeting was to agree on joint actions, which should lead to the operationalization of the AFFM.

Further major achievements of AFFM so far are:

- AFFM’s operational strategy and manual on rules of procedure were prepared and endorsed
- Administrative, governance and budgeting structures and arrangements were defined
- Communication tools, including a brochure and a logo were developed
- A draft resource mobilization and advocacy plan was developed
- Proposals were developed and submitted to AfDB for consideration for funding, such as a:
 - Feasibility study to establish a fertilizer production plant for the East African Community
 - Fertilizer Procurement Facility Pilot for the East African Community
 - Exploitation of phosphate rock deposits in DRC and Mali
 - Bio-fertilizer production in Cameroon

The current (Jan. 2013) volume of the fund amounts to US\$ 5 million from Nigeria (50 % of their pledge) and US\$ 150,000 from IFAD (75 % of their pledge). Thus, a considerable gap exists for AFFM to reach the US\$ 10 million to be declared legally operational (Allana Potash News, 2013).

The New Partnership for Africa's Development (NEPAD), an African Union strategic framework for pan-African socio-economic development, in July 2011 reported “*substantive improvement in the implementation of the Abuja Declaration on Fertilizers by the countries and Regional Economic Communities (RECs) since June 2006.*” (NEPAD 2011). The East African Community (EAC), for instance, had identified low usage of fertilizer as a constraint to food security, and, to address the issue had started the development of responsive projects and programs. The Economic Community of West African States (ECOWAS) member states, on the other hand, in 2010 had adopted a “National Agricultural Investment Program” (NAIP) under the Comprehensive Africa Agriculture Development Programme (CAADP, administered by NEPAD). Most of the NAIP included programs for fertilizer improvement. Finally the Southern African Development Community (SADC) had developed simple harmonized system of labeling fertilizer in the region. The NEPAD 2011 report than provides a list of indicators and the status of implementation, without detailing further examples (Table 10). It is particularly interesting to see that NEPAD judged status of implementation of *Increase in the proportion of farmers using chemical fertilizers* as good, even though national fertilizer consumption data would not back up this assumption.

Table 10: Status of implementation of Abuja Summit resolutions at country level in July 2011 (NEPAD 2011)

Indicators	Status of implementation
Establishment of policy and regulatory frameworks	Unsatisfactory
Capacity for quality control	Satisfactory
Elimination of taxes and tariffs	Unsatisfactory
Development of agro-dealer networks	Satisfactory
Distance traveled to purchase fertilizers	Good
Increase in the proportion of farmers using chemical fertilizers	Good
Increasing market size	Partially Satisfactory
Introducing targeted subsidies	Satisfactory
Introducing national financing facilities for importers and agro-dealers	Good
Introducing regional procurement initiatives	Satisfactory
Improving access to complementary inputs	Satisfactory
Establishment of the Africa Fertilizer Financing Mechanism (AFFM)	Unsatisfactory

NEPAD (2011) identified the following issued to be tackled by the AU Member States:

1. Immediate commitment of **funds** from national budgets to bridge the funding gap required to make the African Fertilizer Financing Mechanism operational.
2. Implement targeted, **smart subsidies** by using input vouchers and using the private sector to import and distribute fertilizers for government fertilizer subsidy programs.
3. Explore alternative sources of revenue to facilitate the **elimination of taxes** and tariffs on fertilizer and on fertilizer raw materials.
4. Increase and expand programs to develop **agro-dealer networks**.
5. Increase the availability of **risk-sharing financial facilities** for importers and agro-dealers.
6. Develop and implement **policy and regulatory frameworks** for the fertilizer industry.

All of these demands are not much different from those in the original Abuja declaration. In other words, progress must have been little if the same issues are raised again five years after the Summit.

In conclusion, preparatory work including hosting and operationalizing of AFFM, as well as mobilization of support for the mechanism through consultation with stakeholders has been achieved, and AFFM has strong support from the political leadership. However, obviously AFFM as the major funding mechanism is not yet legally operational for kicking off strategic investment programs to increase the availability and use of fertilizer, and facilitate and assist in related goals. Notwithstanding, individual countries have made progress in increasing fertilizer use, such as Kenya (Figure 13) or Nigeria, even though the direct influence of the Abuja Summit remains to be proven, and the per hectare consumption rates are still far below the 2015 target of 50 kg/ha. It is quite unlikely that in the coming two years this target will be reach; neither on average nor by any of the sub-Saharan states.

5. Sustainable, intensified nutrient management concepts

5.1. Summary

Two sustainable, intensified nutrient management concepts that have been proven successful in farmer's field are Integrated Soil Fertility Management (ISFM) and Conservation Agriculture (CA). ISFM includes the combined use of mineral fertilizer and organic resources management with the aim to improve agronomic efficiency and crop yields. These components and others (e.g. improved varieties) can be adopted stepwise. Thus, ISFM is perceived as a strategic goal rather than a dogma with fixed components. CA, on the other hand, is advocated as a package that the farmer should preferably adopt as a whole. Also, CA is stricter than ISFM in regard to the must-have key components, above all minimum tillage and surface residue retention. Both systems face some challenges in regard to the wider-scale adoption by farmers in Africa. Even though proven profitable in the long-run, the attractiveness is often impaired by smallholders' limited resources (money, labour) as well as the delayed responsiveness in terms of improved yields. In mixed crop-livestock systems it is primarily the competition for crop residues that vitiate the farmer's willingness to adopt. Farmers keeping livestock see little value in leaving residues on top of the soil (CA) or incorporating it into the soil (ISFM). Feeding residues to the animals is considered a much better investment. Both systems intend to move farmers out of subsistence and therefore depend on access to input (credit, fertilizer, herbicides, and modern varieties) and output markets (selling surplus production). They also are knowledge intensive as far as management of residues, fertilizer, herbicides and (zero-tillage) direct seeding of crops is concerned. We believe that the combination of ISFM and CA which we named ISFM+ — i.e. working towards full adoption of CA but using the step-wise approach of ISFM — allows for easier, smoother and faster adoption, as farmers can implement improved management components at the pace they feel comfortable with.

5.2. Integrated Soil Fertility Management

5.2.1. Concept

Integrated Soil Fertility Management (ISFM) is a concept that had been developed in the late 1990s - early 2000s, among others, by the Tropical Soil Biology and Fertility (TSPF) Institute of the International Center of Tropical Agriculture (CIAT), Nairobi, as the major ISFM-advocating international agricultural research centre. The concept emerged out of the so-called *Second Paradigm* formulated by the renowned soil scientist Pedro Sanchez who, beyond sole application of mineral fertilizer, acknowledged the importance of organic inputs and input use efficiently (Sanchez 1994; Table 11).

ISFM built on this approach, however also embracing social, cultural and economic processes regulating soil fertility management strategies (Bationo *et al.* 2012b). Yet, this was not seen as an obstacle (complicating the issue) but rather strength: *“One of the greatest strengths of ISFM is its ability to integrate local sustainability, economic profitability, adoptability, and sustainability in developing improved land management recommendations.”* (p. 10 in Sanginga and Woomer 2009) TSBF scientists – as did Sanchez (1994) – considered mineral fertilizer application as an entry point to ISFM furthermore requiring improved, fertilizer-responsive germplasm. Thus, they defined ISFM as:

‘The application of soil fertility management practices, and the knowledge to adapt these to local conditions, which maximize fertilizer and organic resource use efficiency and crop productivity. These

practices necessarily include appropriate fertilizer and organic input management in combination with the utilization of improved germplasm.' (Sanginga and Woomeer 2009, p. 13).

Table 11: Soil fertility management paradigms as have been evolving throughout the last four decades, the role of inputs and experiences in Africa (after Vanlauwe *et al.* 2006, modified)

Period	Paradigm	Role of		Experiences in Africa
		Inorganic fertilizer	Organic inputs	
1970s	1 st External Input Paradigm	Sole use will improve and sustain yields	Play a minimal role	Limited success due to shortfalls in supply infrastructure, policy and adoption
1980s	Organic Input Paradigm	Plays a minimal role in land quality maintenance	Are the main source of nutrients and substrate	Limited adoption because of excessive land and labor requirements
1990s	Sanchez's Second Paradigm	Is essential to alleviate main nutrient constraints	Serve as an entry point offering functions other than nutrient release	Adoption hampered by difficulties in accessing organic resources
2000s	Integrated Soil Fertility Management	Is a major entry point to increase yields and supply needed organic resources	Access to has social and economic implications	Ongoing, broad-scale success outstanding

Numerous papers about ISFM have been published in journals and books throughout the last 12 years (FAO 2001, Defoer 2002, Place *et al.* 2003, TSBF 2005, Vanlauwe *et al.* 2005, Bationo *et al.* 2006, Bationo *et al.* 2007a, Bationo 2008, Tittonell *et al.* 2008, Vanlauwe *et al.* 2010 and 2011).

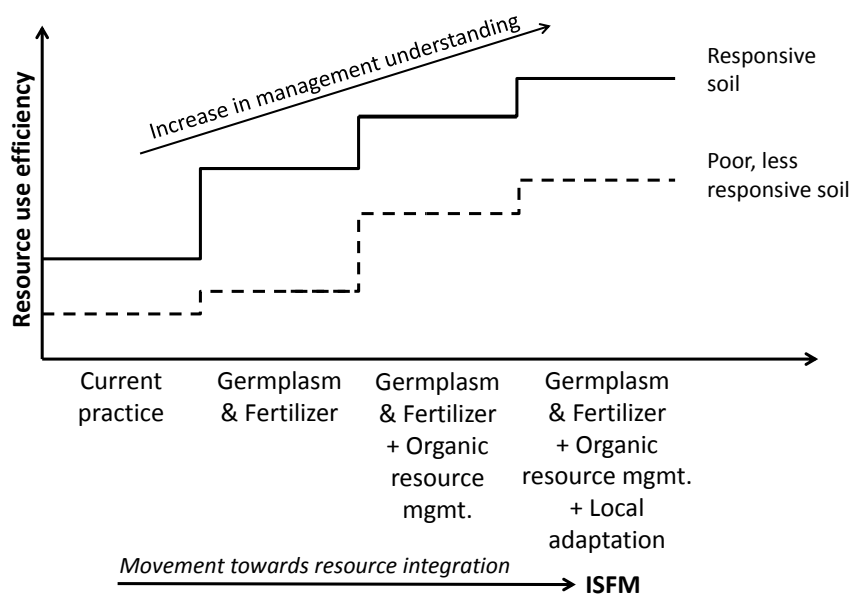


Figure 17: Conceptual relationship between the resource use efficiency and soil fertility management practice (after Sanginga and Woomeer 2009)

ISFM is perceived as a strategic goal rather than a dogma with fixed components; the latter is a trait more common to the concept of Conservation Agriculture (CA; see next chapter). Increasing the understanding of soil fertility/agronomic management is part of this strategic goal as a farmer moves towards ISFM (Figure 17). Thus, adoption can be all at once or step-wise, whereas the order of adopting components is not necessarily fixed (as could be falsely interpreted from Figure 17), and for instance adoption of organic resource management could be first and improved germplasm subsequently.

It is important to note that the y-axis of Figure 17 displays resource use efficiency and not, for instance, crop yield, economic revenues or farmer's well-being. This notwithstanding that resource use efficiency and crop yields – less so economic revenues – are in the majority of cases positively correlated. Resource use efficiency is often expressed as agronomic efficiency (AE), which is the increase in crop yield per unit applied nutrients. AE is an important measure of the success of a particular ISFM technology. The ISFM concept builds on the notion that the combined application of inorganic fertilizers and organic residues increases AE by providing for better nutrient retention, release and crop recovery. Uptake efficiency and utilization efficiency are two important aspects in terms of turning nutrients in the system into crop production and yield. ISFM claims that both can be improved by specific practices, as for instance amount, timing, form and placement of fertilizer or by increasing soil health when applying organic residues to the soil, improving soil organic matter and soil micro- and macro-fauna.

In regard to mineral fertilizer application, ISFM recommendations are toward optimizing returns per unit input and not per unit area. As a consequence, resource-poor farmers seem to be better off spreading the available fertilizer thin – certainly not too thin – rather than applying larger amounts to only part of their fields. Thus, optimum fertilizer rates recommended elsewhere are suggested to be adjusted downwards to levels better affordable by small-scale farmers (Sanginga and Woomer 2009, p. 30).

Figure 17 does not include “attractiveness” or any other measure of farmer's content with the suggestions. It also is not 100 % logical, as a poor less responsive soils, even though at a lower productivity level, may nevertheless have similar levels of native resource use efficiency than a responsive soil.

Sustainability of nutrient management is an intrinsic part of ISFM. Sanginga and Woomer (2009) suggest that fertilizer and organic residues application should follow the *sufficiency* concept, where nutrient requirements are calculated based on defined production targets. An alternative is the *build-up and maintenance* concept in which first nutrients are added to reach critical soil tests values for certain crops and subsequently nutrients are replaced as they are lost over time. The latter, however, seems little practical for some of the inherently low-fertile soils in Africa that would require massive amounts of initial fertilizer addition. For such soils the *sufficiency* concept, however, is also short off clear, soil chemistry-based recommendations. A low-pH, P-fixing soil, for instances, requires P-fertilizer addition that exceeds production target-related P-uptake by far; to determine exact quantities requires soil chemistry knowledge, even more so when inorganic fertilizers are applied together with organic residues.

For acquiring site-specific quantitative information on crop nutrient requirements and fertilizer addition, ISFM scientists suggest, rather than carrying out expensive laboratory soil testing, to rely on farmer's field test diagnosis. This could be a farmer setting up small fertilizer-cop-response test strips

in which different levels of common NPK fertilizers (and micronutrients, if applicable) are tested side-by-side with strips where single nutrients are omitted.

Farm mechanization and use of machinery suitable for smallholders is not mentioned as part of the concept of ISFM – in contrast to CA, where special direct-seeding machinery (hand-held, oxen- or tractor-drawn) is a crucial component of the concept. Likewise, little is said about herbicide or (no-) tillage requirements. The beneficial effect of no-till is acknowledged by Sanginga and Woomeer (2009) when outlining the concepts of CA, while at the same time criticizing that “*many of its [CA] technologies are not available or well-suited to small-scale farmers*” (p. 118, Sanginga and Woomeer 2009). This plain rebuke is surprising given the unquestionable successes and large-scale adoption of CA in other (tropical) countries (Derpsch and Friedrich 2009). The asserted notable adaptive capacity of ISFM should allow for embracing CA as one form of ISFM that fits well into certain social/cultural/economic environments. Contrarily to expectations, TSBF scientists rebuff CA suggesting “*that ISFM serves as an alternative, more practical approach towards achieving many of the benefits from CA...*” (Sanginga and Woomeer 2009, p. 120).

5.2.2. Site-specificity

The inclusion of social, cultural and economic issues into the ISFM concept inevitably increases its site-specificity, as soil and climate are no longer the only drivers of soil fertility management. It is therefore not surprising that site specific or local adaption is one of the pillars of ISFM (compare Figure 17). The added complexity is significant, and a full account of site-specific ISFM is beyond the scope of this review. Only a brief insight is provided.

For sub-Saharan Africa, ISFM technologies were categorized by major climatic zones (dry to semi-arid, sub-humid to humid) as well as altitude, leading to some five Agro-Ecological Zones (AEZ) clearly distinguishable in terms of appropriate ISFMs (Table 12).

Table 12: Selected characteristics of agro-ecological zones in sub-Saharan Africa and examples for appropriate ISFM technologies; LGP = length of growing period (from Sanginga and Woomeer 2009 based on FAO 1995 and FAO/IIASA 2000 data)

Agro-Ecozone, (%) of the area	LGP	Appropriate ISFM technology	Major Soil Order (FAO classification)	Major nutrient-related constraints
Lowland (< 800 m) dry savanna (36 %)	< 150 d	Micro-dosing, agro-pastoral interaction, rock phosphate	Arenosols, Lithosols, Regosols	Low available soil P, soil acidity, low water holding capacity
Lowland (< 800 m) moist savanna (17 %)	150-270 d	Cereal-Legume rotation and intercrops; Conservation Agriculture	Lithosols, Ferralsols	S, Zn deficiency under intensive cultivation, low available N and P
Lowland (< 800 m) humid forest (15 %)	> 270 d	Cassava-legume intercrops, understorey & lowland rice management	Ferralsols, Acrisols	Soil acidity, low available P
Mid-altitude (800–1200 m) moist savanna (7 %)	150-270 d	Cereal-Legume rotation and intercrops; Conservation Agriculture, slope management	Ferralsols, Nitisols	Soil acidity, low available N and P
Highland (> 1200 m) moist forests (7 %)	> 270 d	Intercrops and rotations, slope management	Ferralsols, Andosols	Soil acidity, low available P

Table 12 gives a glimpse of possible ISFM systems, but certainly falls somewhat short of reality.

Further adjustment are suggested for regions with mono-modal or bimodal rainfall regimes, slope landscapes, sandy soils, poorest households, farming on forest margins, agro-forestry systems, or organic farming systems.

Quite often in small scale farming systems in Africa a marked soil-fertility gradient is visible between home-fields and outer-fields, and ISFM practices must take these into account (Tittonell *et al.* 2005, Vanlauwe *et al.* 2006, Tittonell *et al.* 2013). It may thus well be that home-fields have a positive nutrient balance at the cost of more distant outer-fields from which such nutrients are withdrawn either in the form of residues from crops, pruned trees or the like, or manure from livestock grazing in these outer fields. Soil fertility declining with distance from the homestead may not be a deliberate form of ISFM, but probably inevitable as long as nutrient resources are limited (Vanlauwe and Giller 2006).

5.2.3. Requirements and accompanying developments

New technology or concepts with the aim to improve the livelihoods of smallholders in developing countries in the majority of cases rely on a set of supplementary accompanying technological, biophysical, economic or social assets or developments to provide the basis for successful technology introduction. ISFM is not an exception. Broadly speaking, two major influential domains can be distinguished, 1) a domain related to policies and markets, and 2) a domain where researchers, extensionists, farmers and related actors come together (Figure 18).

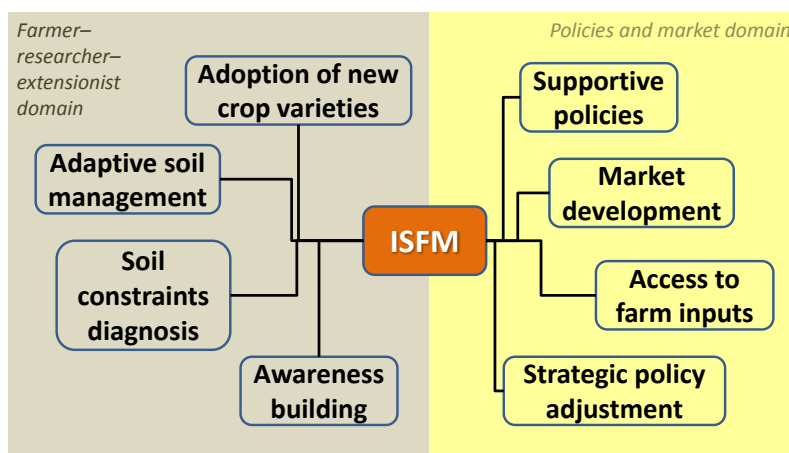


Figure 18: Integrated Soil Fertility Management (ISFM) and its immediate influencing domains

The farmer-researcher-extensionist domain comprises aspects of awareness building (of the importance of maintaining a healthy soil) of concerned farmers, improved capacity in farmer diagnosis of soil constraints, (subsequent) adaptive soil management, and adoption of improved (responsive) crop varieties. The policy and market domain, on the other hand, covers the necessity of strategic policy adjustments that stimulate institutional and market response toward ISFM and its resulting crop surpluses, supportive policies in terms of agricultural inputs (attractiveness for businesses, judicious prices), market development, and (subsequent) greater access to farm inputs and commodity markets by small-scale farmers. In short, “farmers must be provided incentives to invest in ISFM technologies” (Sanginga and Woomeer 2009, p. 70). Furthermore, “these technologies must be packaged into products and field operations that are recognizable, available and affordable to farm households” (ditto, p. 13).

5.2.4. Constraints and challenges

It is without doubt the necessary accompanying aspects that pose the greatest challenge to larger-scale adoption of ISFM. This not to say that ISFM only works in a ‘perfect world’, but still after some 10-15 years, ISFM did not have the overwhelming breakthrough it ought to have.

Table 13 summarizes the aforementioned accompanying development aspects, their basic support functions and consequences of failure to implement them properly. It becomes obvious that at least three of them are crucial in terms of successful introduction and adoption of ISFM, and failing to address them is fatal. Another four aspects are at least critical. We assume that lack of availability or adoption of new crop varieties might have at least a notable influence on the success of ISFM. If farmer’s varieties (landraces) are not actually responsive to increased nutrient inputs, it is certain that the investments in mineral fertilizer will not pay off and the farmer will stop applying it, besides facing a significant economic loss.

Sanginga and Woomeer (2009) identified the inability to deliver appropriate recommendations of accompanying inputs in the right form to smallholders as a major problem for effective utilization of fertilizers and ISFM practice in Africa. As a first step to overcome this, they recommend to provide for better diagnosis of soil and plant constraints. This would put farmers in a position to move away from blanket fertilizer recommendations – as far as these have been established – that often have limited applicability/attractiveness to their environment.

Table 13: ISFM supporting aspects, their functions and consequence of failure to address them

Aspect	Basic (support) function	Consequence of failure
Supportive policies	Provide attractiveness and access; remove barriers	Fatal!
Market development	Absorb increased & diversified production	Critical!
Access to farm inputs	Basis of ISFM (fertilizers)	Fatal!
Strategic policy adjustment	Incentive for adoption	Critical!
Awareness building	Provide options to farmers	Fatal!
Diagnosis of soil fertility constraints by farmers	Fine-tune ISFM towards maximum effectiveness	Critical!
Adaptive soil management	Re-establish soil fertility	Critical!
Adoption of new crop varieties	Increase effectiveness in terms of yields	Notable!
Mechanization, machinery	Unknown	Unclear

Furthermore, organic matter management and manure application poses some management challenges: In many crop-livestock mixed farming systems, especially when operating at low-productivity level, organic matter is scarce and used as animal feed, fuel or fiber (McDowell 1988, Lule *et al.* 2012, Jaleta *et al.* 2012, Valbuena *et al.* 2012). Alternatively, manure might serve as the major fuel source for cooking. Thus, competition for nutrients is often large, and especially the feed value might be high – sometimes as high as, or even higher than the primary crop yield itself (Magnan *et al.* 2012). There has been only little success so far in addressing the issue in a practical and farmer-attractive manner.

Additionally, the nutrient contents and quality of organic matter may be low, and timing the release of nutrients from organic matter is a challenge. Low quality organic matter may rather lock up nutrients stemming from inorganic fertilizer in the short term – in the microbial biomass, growth of which is stimulated by organic matter addition – rather than adding nutrients (Braakhekke *et al.* 1993, Kato *et al.* 1999, Bationo *et al.* 2007b). Finally, organic residues can potentially stimulate harmful pests and diseases (Vanlauwe and Giller 2006).

In terms of balancing farm-level nutrient balances, organic residue management must take into account that organic matter produced on-farm does not constitute an input of nutrient, except for atmospheric N fixed by legumes. Organic matter management merely improves on-farm nutrient recycling and use efficiency by improving availability and diminishes losses. Thus, ISFM may still be exposed to the risk of nutrient mining, as long as nutrient exports out of the farm in the form of marketed crops is not compensated by imports of nutrients in the form of chemical fertilizer or, as far as nitrogen is concerned, by atmospheric deposition or fixation of N₂ by legume crops or trees.

In environments where rainfall is variable and crop growth is repeatedly affected by water stress – which indeed applies to at least 86 % of the African land (Bationo *et al.* 2012a) – soil fertility is not always the major yield limiting factor. Thus, there is a considerable risk that the investment in inorganic fertilizer, improved seeds and extra labour for organic residue management is diminished or even annihilated by drought. Most of the smallholders in sub-Saharan Africa with limited (financial) resources are not in the position to compensate for such losses, unless insured against such risks, or with access to continued micro-credits.

In conclusion, it is not surprising that Kanyama-Phiri *et al.* (2000) acknowledged for Malawi that “*to date virtually no farmers have adopted them [ISFM technologies].... The most significant blocks to farmers’ acceptance of the new methods seem to be the high labour requirements, the need for skilled management and the limited profitability in the short term.*” Apparently little progress has been made since. Almost a decade later TSBF-CIAT scientists concluded that the level of success of ISFM is modest (Sanginga and Woomer 2009, p. 10), which they also attribute to the fact that any such success might be little visible within heterogeneous setup of livelihood strategies encountered and that for instance crop breeding had a comparably much stronger breakthrough.

5.2.5. Examples

Murehwa, Zimbabwe, soil texture and management history

This research was initiated in 2002 under the Integrated Soil Fertility Management framework (<http://www.aglearn.net/isfmHome.html>), to determine the potential to improve crop yields through the strategic application of N and P fertilizers. The general objective of the long-term trial was to identify pathways to restore soil fertility of degraded fields using a combination of mineral fertilizers and manure. The experiment was established on contrasting soils (Manjonjo, sandy soil; Ruzvidzo, red clay soil), having contrasting previous fertilization managements. Fields closer to the homestead (< 50 m; homefields) were relatively more fertile than those far away from the homestead (100-500 m; outfield). Nitrogen fertilizer was applied at a rate of 100 kg N ha⁻¹ and maize yields were evaluated at different levels of P supply (Figure 19). Up to 35 kg grain per kg N applied, when combined with up to 30 kg of P/ha, could be harvest on the clay soil home-fields.

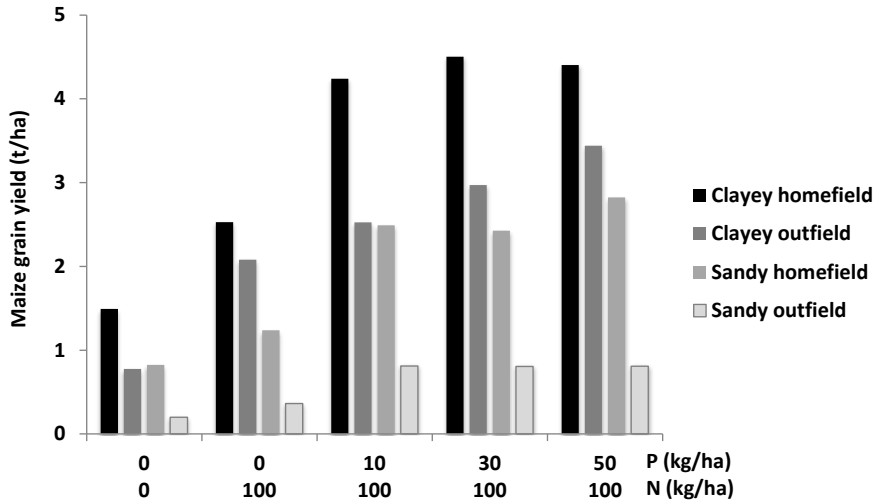


Figure 19: Maize grain yield response to N and P fertilization on sandy and clay soils of different previous management regimes; points are averages of seven seasons

Up to 20 kg grain per kg N combined with up to 50 kg P/ha were harvested on the clay soil outerfields. Smaller responses were observed on soils further away from the home, an indication that other factor than N or P might be limiting yield.

Central Mozambique, intercrop strategy and fertilizer management

The objective of this research was to evaluate the suitability of maize-legume intercropping systems to alleviate the biophysical and socio-economic constraints faced by smallholder farmers in Ruaca, central Mozambique. Two intercropping strategies were tested on a sandy soil i.e. (a) an additive design of within-row intercropping in which a legume was intercropped with alternating hills of maize within the same row (maize plant population was the same as sole crop maize); and (b) a substitutive design with distinct alternating rows of maize and legume (local practice). Fertilizer treatments were: (i) no fertilizer, (ii) 20 kg P ha⁻¹, (iii) 20 kg P ha⁻¹ + 30 kg N ha⁻¹, and (iv) 20 kg P ha⁻¹ + 60 kg N ha⁻¹. Results showed that the response to N and P fertilizer was weak, which was mostly because of poor rainfall distribution. In the third season, maize in rotation with pigeon pea and without N fertilizer application yielded 5.6 t ha⁻¹, i.e. eight times more than continuous maize (0.7 t ha⁻¹) which was severely infested by striga (*Striga asiatica*; Figure 20).

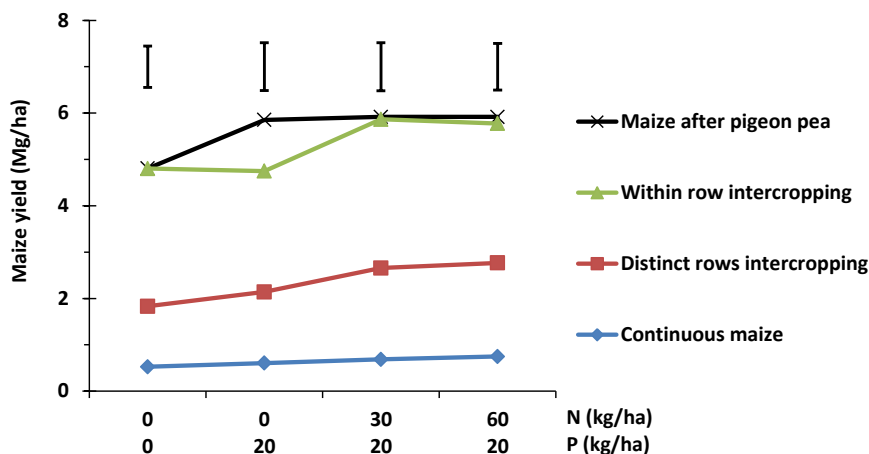


Figure 20: Effect of intercropping, rotation, and N and P fertilization on maize grain yield in Ruaca, central Mozambique, in the third (2010/11) season (Rusinamhodzi *et al.* 2012); Bares on top indicated the LSD

5.3. Conservation Agriculture

5.3.1. Concept

Conservation agriculture (CA) is a crop management system which was developed and improved in the Americas and Australia during the last four decades. Its term has been coined to describe the differences between the CA system and other (tilled) agriculture systems. CA is based on three main principles: a) minimum soil disturbance, which implies no inversion tillage; b) crop residue retention with living or dead plants or plant material; c) diversified crop rotations or associations (Kassam *et al.* 2009).

CA is not a completely new agriculture system or package but rather a set of principles that have different site specific applications. CA aims at removing the unsustainable parts from the existing conventional systems and replacing it by sustainable components: the tillage that leads to erosion and soil degradation is replaced by no-tillage; the monoculture by diversified crop rotations and the removal of organic material by retaining crop residues as protecting mulch on the soil surface (Wall, 2007). CA, like all other agriculture systems, is not a low tech or low input system and to be successful needs good management, adequate nutrient supply, timely operations and good weed control.

CA has been advanced mainly on large commercial farms using tractor drawn direct seeding implements, and the bulk of hectares under CA are in Brazil, Argentina, Paraguay, the United States of America, Canada and Australia (Friedrich *et al.* 2012). Only recently, the systems has been tried and tested to adapt it to the conditions of smallholder farmers in America, Africa and Asia. Currently more than 100 Mha worldwide are under CA with an increasing trend (Friedrich *et al.* 2012). The main drivers on large commercial farms are fuel reductions, time saving and reduced off-side damages of conventional tillage-based agriculture systems. Drivers for small-scale farmer are very different and are dependent on site specific socio-economic situations, resource endowment, mechanization level and biophysical challenges.

In sub-Saharan Africa mostly manual or animal traction CA system are used and some seeding equipment to plant into un-tilled land have been developed in the recent years (Johansen *et al.* 2012). For manual farming the use of a pointed stick, manually dug planting basins and manual hand-held, so-called jab-planters, have been successfully tried and tested (Haggblade and Tembo 2003, Mazvimavi *et al.* 2008, Thierfelder *et al.* 2013c). In areas where animal traction is common, the use of animal traction equipment such as the Magoye chisel-tine furrow opener, animal traction sub-soilers, deep rippers and animal traction direct seeders are currently used (Thierfelder and Wall 2012).

Combinations of CA with other associated technologies like the use of manure, green manure cover crops, the use of drought-tolerant and low N tolerant cultivars and agroforestry are common and are successful attempts to adapt the system to the local farming context. As such, CA has a wide applicability which ranges from sea level to above 3000 m a.s.l., from heavy clay to very sandy soils, and for most agriculture crops grown in sub-Saharan Africa such as maize, sorghum, millet, legumes, vegetables and to a certain extent also root crops, although their harvest inevitably leads to soil disturbance. Nevertheless, CA has its limitations in waterlogged situations, on soils that are too sandy for crop production, and in very cool climates.

5.3.2. Advances of CA in Africa

Since the late 1990s, CA has become a major part of the research agenda in Africa. Development organizations have spent considerable efforts to promote this crop management system and to adapt CA to the local farming context.

Giller *et al.* (2009) and Andersson and Giller (2012) criticized the widespread promotion of CA to large farming areas without scientific proof of concept. Evidence has therefore been generated in recent years to support the usefulness of CA to the majority of farming systems in Africa. In a regional study on the yield advantages of CA systems in contrasting environments and across many farming systems Rusinamhodzi and Thierfelder (2013) found out that CA generally outperforms the conventional farmers' practice in equally fertilized and managed plots (Figure 21). In 76 % of the cases, CA gave a positive response in comparison to the control treatment.

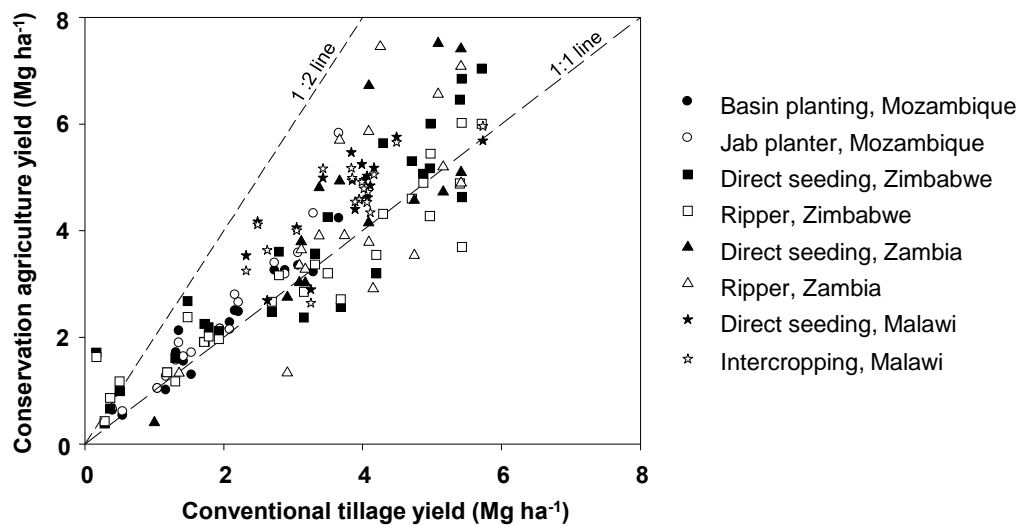


Figure 21: Plotting yields achieved under various conservation agriculture practices against corresponding conventional tillage across sites and seasons in Southern Africa. Data points on or below the 1:1 line do not show a relative advantage of conservation agriculture, and those on the 1:2 line show that CA yields were double those of conventional tillage (adapted from Rusinamhodzi and Thierfelder 2013)

Results from the region further show that CA has immediate biophysical and economic benefits such as increased water infiltration into the soil due to the protection of surface structure by mulch (Thierfelder and Wall, 2009), reduced water run-off and loss of top soil (Figure 22) by maximizing the capture of rainfall and resulting increased infiltration from the ponding effect of the residues (Thierfelder and Wall 2010a and b), reduced evaporation of soil moisture as the crop residues protect the surface (Lal 1974), improved crop water balance (Thierfelder and Wall 2009), less frequent and intense moisture stress because of increased infiltration and reduced evaporation (Mupangwa *et al.* 2008, Thierfelder and Wall 2010a), reduced traction and labour requirements for land preparation and for weeding if herbicides are used, hence saving costs of manual labour, animal draft and fuel (Mazvimavi *et al.* 2008, Johansen *et al.* 2012, Ngwira *et al.* 2012a and b). Long-term effects of CA, such as increased soil organic matter, enhanced biological activity, better soil structure, improved nutrient availability, and greater water-holding capacity have also been reported (Thierfelder *et al.* 2012, Thierfelder *et al.* 2013b and c) and are key benefits of the system. However, in some cases stratification of nutrients in the systems on the first soil horizons can be a problem when the soil is not turned anymore.

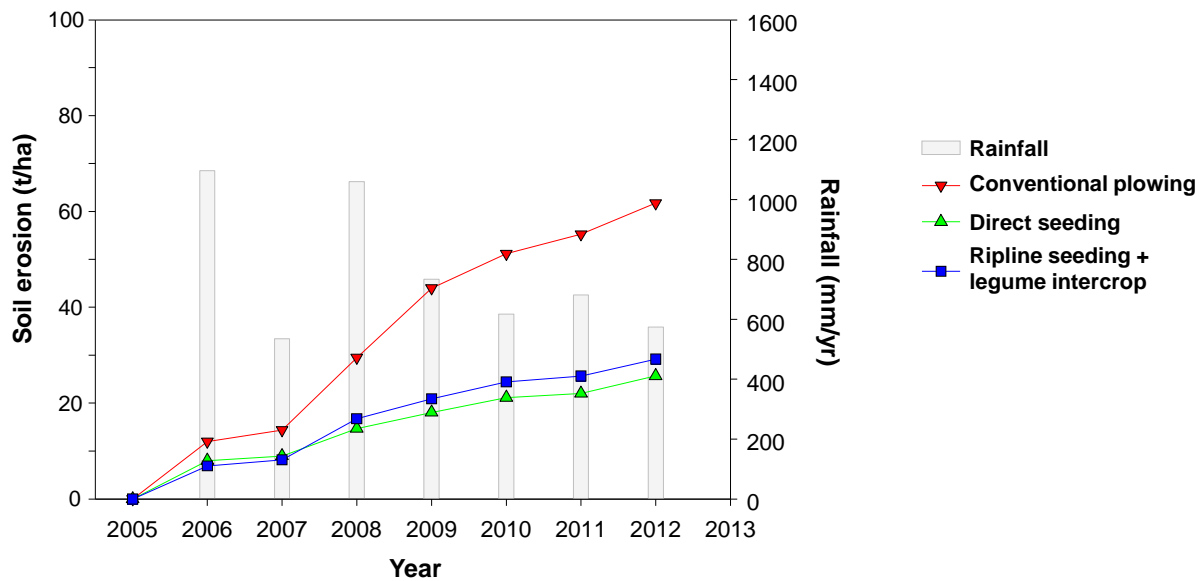


Figure 22: Cumulative soil erosion and rainfall in two CA treatments (direct seeding and ripline seeding) in comparison with a conventionally ploughed control plot, Henderson Research Station, Zimbabwe, 2005-2012 (adapted from Thierfelder *et al.* 2012)

Long-term results from the region show that yield increases cannot be expected immediately and appear normally after 3-5 cropping seasons (Figure 24). This lead time can make it difficult for farmers to adopt CA, especially if no other economic benefits of the system can be attained.

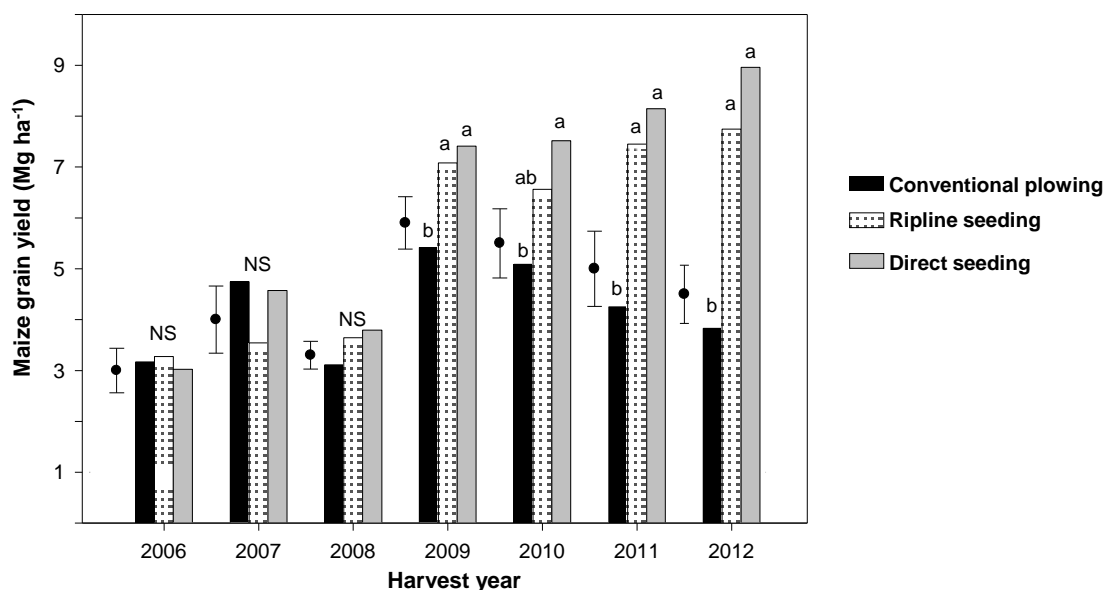


Figure 23: Long-term maize grain yield in two CA and one conventionally ploughed system in Malende, Monze, Zambia 2006-2012 (adapted from Thierfelder *et al.* 2013c)

5.3.3. Requirements and accompanying developments

CA, like any other agriculture systems, needs an enabling environment for the up- and outscaling, which differs at different levels and scales. Farmers who want to practice CA need access to critical inputs such as fertilizer, seed, herbicides and crop chemicals and adapted and tested equipment. The development of markets both for inputs and outputs, provision of credit to purchase critical inputs for cash constraint farmers, crop insurances for farmers against climate risk and crop failure are

crucial components for the success or failure of CA. Research from the region clearly shows that the quality of the enabling environment decided if CA was adopted to a large extent.

The promotion of CA systems cannot follow the linear approach of technology extension, where researchers develop technology packages on-station, test them on-farm, pass them on to extension officers in the hope that farmers will adopt. To the contrary, a different approach is needed for complex technologies involving multiple changes in the way farming is practiced. Participatory technology development and adaptation are therefore a pre-requisite of technology transfer and recent promotion of innovation systems where multiple players develop and adapt technologies have been one suggested way of promoting complex technologies such as CA (Ekboir 2002, Thierfelder and Wall 2011).

5.3.4. Constraints and challenges

The promotion of CA systems quickly shows that a flexible approach is required adapted to the farm context. What works in one area might not work in another, and there is need to work at different levels to overcome constraints to adoption. The main challenges highlighted in recent studies are summarized below:

- a) In mixed crop-livestock systems the retention of residues, one of the key components of a functional CA system can be very challenging and can lead to considerable conflicts between livestock keepers and crop producers. Feeding the residues to the soil or the livestock is a complex decision process and depends a lot on the farming system, the importance of livestock as insurance, source of nutrients and a sign of wealth in the community. Community agreements, fencing and growing of additional non-palatal residues may offer solutions to this, however little work has been done to better understand and overcome this constraint.
- b) When tillage is reduced, weeds may become a great challenge for smallholder farmers, especially when no herbicides are used for weed control. Persistence and combinations of different weed control technologies such as good ground cover, repeated manual and or chemical weed control, rotations with competing green manure cover crops and combinations of the above may offer solutions that need to be further explored.
- c) Rotations, another key component of the system, maybe be challenging if farmer size is small. In other areas where the land holding size is larger often no markets are readily available to pay farmers a reasonable price for the rotational crop. This hampers the widespread uptake of rotational crops, especially legumes, despite their huge potential for the farming system.
- d) When residues are applied, especially on sandy soils, the incidence of nitrogen lock-up has been observed especially if not enough nitrogen is fertilized to the growing crop. Nitrogen lock-up is a consequence of increased biological activity triggered by the surface residue retention – microorganisms take available N from the soil during population increase, which then is not available for the plants. However this is a temporary phenomenon, which can be overcome by appropriate N fertilization.
- e) A great limitation for the widespread use of CA like any other agriculture system is the available of critical inputs such as herbicides, crop chemicals, seed and fertilizers, equipment etc. Examples from Malawi however show that once this has been overcome, the adoption of CA was large.
- f) CA systems are more knowledge intensive than the traditional systems and involve multiple changes to the way operations are done (e.g. different seeding systems, residue management, rotations, different fertilization strategies, weed control, harvesting methodologies and equipment). Very critical to the successful outscaling of CA systems is the knowledge and

understanding about different components of the CA system. Capacity building for extension officers and farmers on different aspects of crop management under CA are therefore necessary and crucial for the success of any intervention.

5.3.5. Examples

An innovation systems approach with *Total LandCare* in Malawi

The development of CA systems in Malawi was facilitated using an innovation systems approach initiated in 2005 in Nkhotakota, Central Malawi with key stakeholders and NGOs (in this case *Total LandCare*). A range of partners providing complimentary skills were identified including research and extension organizations, the private sector and farmers. Discussions within target communities highlighted key constraints to crop production by farmers during the project implementation phase. The challenges mentioned by farmers contributed to the design of on-farm experiments that remained at the same site for the duration of the project. Experiments allowed agronomists and soil scientists to assess the effects and performance of different CA interventions on long-term crop productivity and soil fertility. Trials also served as a research platforms and learning centers for socio-economic and agronomic research and for farmer-to-farmer exchange activities.

Analysis of TLC's innovation network after four cropping seasons

A study of the innovation network using focus group discussions in 2009 identified organizations currently involved in the innovation network as actors to facilitate the adoption of CA in a pluralistic innovation support structure (Klerkx *et al.* 2009, Spielman *et al.* 2011). Most of the initial research and training was led by the governmental extension and the regional NGO *Total LandCare* (TLC). Organized discussions between local stakeholders and participating farmers promoted wider informal community discussions and feedback, which eventually provided a foundation for technology adaptation and adoption. Farmers and farmer groups near the validation trials were encouraged to participate in innovation network field days, discussion groups, and farmer-to-farmer exchange visits. After observing performance of CA on validation trials and conventional fields, farmers were encouraged to adopt, experiment with, and adapt CA oriented technologies on their own farms.

Survey results suggested that the main catalyst for the innovation network was the growing interest of farmers in herbicides to control weeds. Since input suppliers were initially not available in the study areas to supply herbicides, farmer access to herbicides was facilitated by TLC. Farmers interested in CA registered with the TLC field coordinators, where they paid a deposit of 14.5US\$ each with a commitment to pay the balance in 9 months. This amount included improved maize seed varieties and herbicides, which cost about 50US\$ per 0.4 ha of land. These deposits were used to estimate demand for maize seed and herbicides, which then were purchased by TLC and distributed to farmers. The repayment of the "soft" loans was estimated at about 90%, and was used as a revolving fund to support farmers on CA in the following season.

Interaction and information exchange between all relevant stakeholders was crucial for modifying CA system to local conditions. The process was supported by donor funds from the international donor community to initially create the necessary critical mass of successful examples of CA. Different from previous studies innovation networks were built around crop management systems instead of marketed commodities (Brooks and Loevinsohn 2011, Kilelu *et al.* 2011, Spielman *et al.* 2011). The main drivers in this innovation network were knowledge transfer and capacity building, adaptive CA

research, access and availability of critical inputs (herbicides), and an enabling environment for CA in Malawi. Adoption figures now provided by TLC support the effectiveness of this approach (Figure 24).

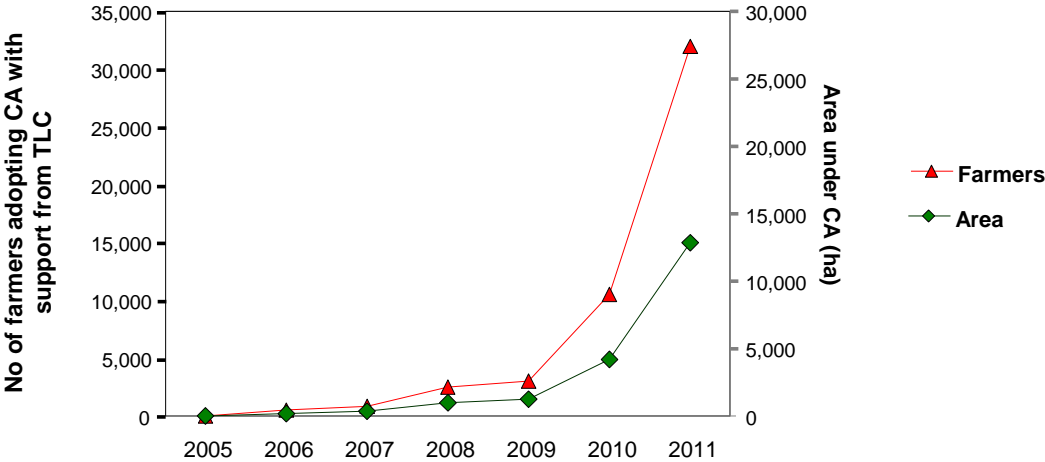


Figure 24: Extent of CA adoption facilitated by Total LandCare in Malawi, 2005-2011

5.4. ISFM+

The lessons-learnt from introducing ISFM and CA technologies into farmer’s field are that uptake and success of such sustainable intensification concepts to a large extent hinge on farmer’s (physical and financial) access to inputs (fertilizer, herbicides, improved varieties), the viability of fertilizer use, and adoption at the pace that a farmer feels comfortable with in terms of change of paradigms and acquirement of the required agronomic knowledge and experience.

We believe that the latter can be facilitated by a stepwise adoption of key-components of ISFM that, beyond the classical components of ISFM, also embraces the core principals of Conservation Agriculture (CA) minimum soil disturbance, surface residue retention/mulch and crop rotation, and which may thus be called ISFM+ (Figure 26).

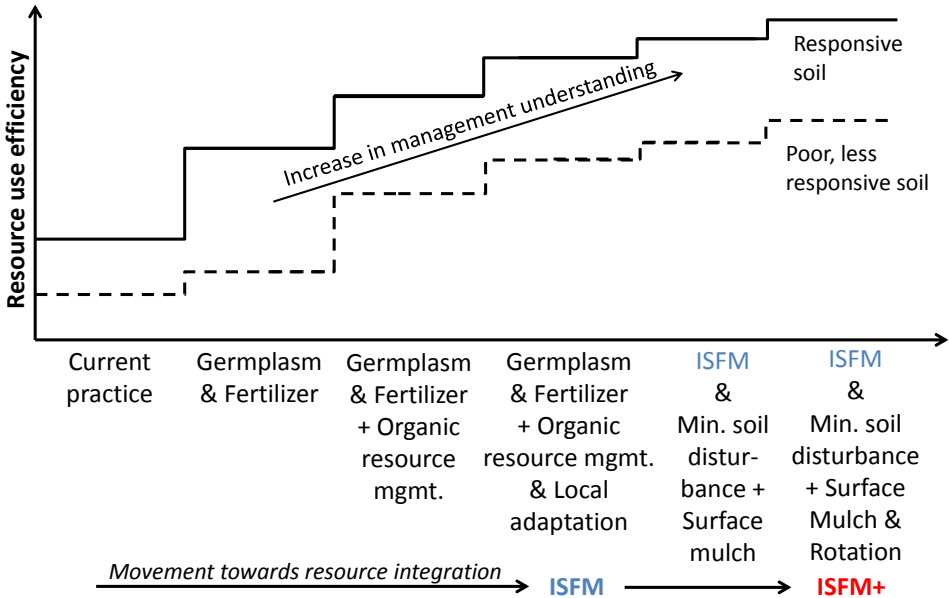


Figure 25: Extending ISFM by embracing the CA components minimum soil disturbance, surface residue retention/mulch and crop rotation

This approach has not yet been tested in farmer's field. It is an improvement over the classical CA implementation pathway in terms of farmer's participation, but, on the other hand, may violate CA principles such as minimizing tillage during the first years of adoption. It also does not alleviate the need for farmer's access to input and output markets and therefore requires flanking actions, such establishment of Innovation Platforms and probably access to various forms of credits for inputs.

6. Promising new opportunities, tools and initiatives

6.1. Summary

Farm-scale bio-economic models, like APSFARM, offer the possibility to quantify benefits from the adoption of alternative technologies, aiming at identifying “best-fit” pathways out of poverty. Results of such modelling analysis revealed that small investments in N fertiliser by western Kenyan farmers that had more responsive cropping systems had the potential to provide large increases in maize production. For the poorest farmers, on the other hand, investment in N-fertilizer would be difficult to finance and therefore, to increase nutrient inputs, they might need to initially rely on cheaper options, such as a rotation with N-fixing legumes. Modelling also exposed that the impact of keeping residues as ground cover was small in these highly N constrained environments.

Innovation Platforms offer a promising way to put farmers into the position to link with the fertilizer and agro-input sector, as well as to establish collaboration with the (micro-) finance sector, NGOs or (contract farming) companies that provide such services.

To reduce climate risk perception as a barrier to increasing investments, farmers need to be engaged directly on their subjective assessments of climate risk and comparisons made with more objective assessments, such as rainfall records, crop simulation outputs.

During the last 1-7 years a new generation of entrepreneurs has appeared in the agricultural development arena, with in part sizeable financial means, a clear goal-driven agenda and an impressive short-term track record. We believe that these players in combination with the renewed strong interest of the classic major stakeholders (such as The World Bank) in agricultural development provide reason for optimism that after some decades of stagnation there is now the time to achieve notable impact in sub-Saharan Africa for intensifying farming systems in a sustainable manner. Yet, most of these new players will require, and indeed explicitly ask for, scientific backup to make sure that their chosen intensification pathways are not only profitable in the short run, but also sustainable in the long run.

6.2. Ex-ante analysis of opportunities from addressing soil fertility constraints

Recent projections indicate that the FAO World Food Summit target of halving the number of undernourished people in developing countries (1990/1992 basis) by 2015 is unlikely to be achieved before 2040 (Alexandratos and Bruinsma, 2012). For this projection to be realised, food production will have to increase by 70 %, or even 100 % in some developing economies. In other words, between 2010 and 2050 more wheat and maize will have to be produced than over the last 500 years on nearly the same area of land, with higher energy costs, and under a changing climate. The challenge is particularly significant for sub-Sahara Africa (SSA) where population growth is expected to more than double between 2006 and 2050 (compared to a 38 % increase for the world as a whole). Adding to the constraints, most of the rural population has limited availability to production resources (cash, land and labour), and has limited access to input and output markets. Even though the challenge is significant, we should be able to feed the 9 billion people by 2050. Evidence for this can be found in the fact that over the last 50 years the increase in agricultural production fed an additional 4 billion people with only an 11 % increase in land area (Lenne and Wood, 2011); indicating the potential from adopting the right technologies and policies required to generate incentives, opportunities and economic growth in smallholder agriculture.

Here we present results of a quantitative analysis of benefits from the adoption of alternative technologies with the aim of identifying “best-fit” pathways out of poverty across five countries of east and southern Africa. The basic hypothesis of this research is that a better understanding of the diversity of household resources and livelihood strategies will allow us to more efficiently target adoptable interventions in a stepping stone approach to help poorly resourced farmers out of poverty (Figure 27).

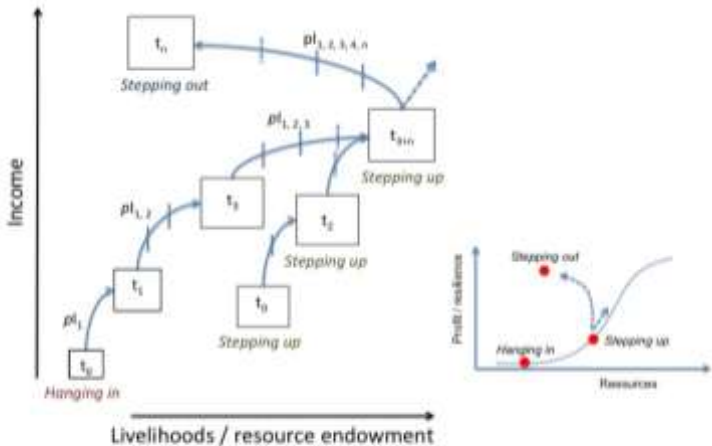


Figure 26: Stepping stone interventions towards an improved state in the relationship between income and resource endowment

Results from surveys, discussions with farmers, agri-businesses, local socio-economists and field agronomists, and the use of household modelling technologies were combined to: (i) describe the existing diversity in households; (ii) categorise such a diversity into classes of households having similar opportunities for economic development; and (iii) the use of a household model (APSFarm, Rodriguez *et al.* 2011) to quantify the benefits from alternative interventions.

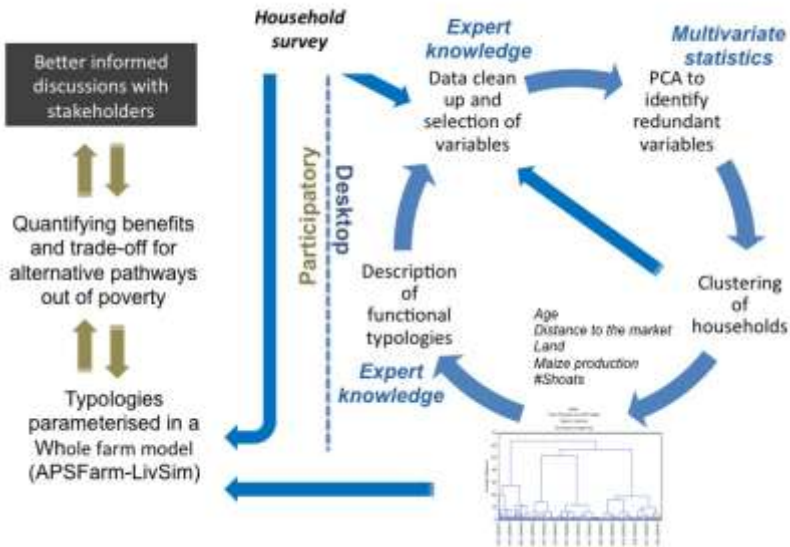


Figure 27: Steps in the development of household typologies and use of household models in the SIMLESA program

The socio-economic, physical and bio-physical characteristics of 3611 randomly selected households

was surveyed in Ethiopia, Tanzania, Malawi, Mozambique and Kenya. The household data within each country and agro-ecological region was then used to group households into 2 to 4 classes using multivariate statistics and local expert knowledge from the teams of socio-economists in each National Research System (Figure 27).

Labour availability and access to markets were the top two factors describing the variability in the dataset. Other important factors were the perceived level of soil fertility and ownership of livestock (Table 14). The detailed results of the clustering are shown in Table 15.

Table 14: Most important factors describing the variability of the dataset

Rank	Ethiopia	Tanzania	Malawi	Mozambique	Kenya
1.	Labour availability	Market access	Market access	Livestock ownership	Labour availability
2.	Market access	Labour availability	Labour availability	Labour availability	Perceived level of soil fertility
3.		Age of household head	Land ownership	Market access	Household assets
4.		Farmer’s education level	Ownership of sheep and goats	Perceived level of soil fertility	Kinship
5.		Farm assets	Fraction of farm income		Age of household head
6.					Off-farm income

Table 15: Results of the household clustering exercise for eastern and western Kenya

Structural household typologies: resource endowment		
	<p>C1: Hanging in 66 % population Land 1.8 ha Livestock 27,000 KSh Mostly male ME 2 Age 45 Income 77,000 KSh 45 % off farm Crop sales 16,000 KSh Lower soil fertility soils Fertilizer 14 kg/ha Manure 200 kg/ha Maize yield 1780 kg/ha Bean yield 620 kg/ha</p>	<p>C2: Stepping up 34 % population Land 2.4 ha Livestock 43,000 KSh Mostly male ME 2 Age 52 Income 146,000 KSh 39% off-farm Crop sales 36,000 KSh Higher soil fertility soils Fertilizer 14 kg/ha Manure 200 kg/ha Maize yield 1810 kg/ha Bean yield 670 kg/ha</p>
<p>C3: Hanging in 14 % population Land 1.5 ha Livestock 30000 KSh Female headed ME 2.8 Income 60700 KSh 73% off-farm Crop sales 1680 KSh Animal sales 950 KSh Low fertility soils Fertilizer 1.3 kg/ha Manure 21 kg/ha Maize yield 1700 kg/ha Bean yield 460 kg/ha</p>	<p>C2: Hanging in 69 % population Land 2 ha Livestock 32,000 KSh Mostly male ME 2.8 Income 79,300 KSh 72% off-farm Crop sales 0 KSh Animal sales 1,500 KSh Low fertility soils Fertilizer 5.6 kg/ha Manure 0 kg/ha Maize yield 2,200 kg/ha Bean yield 320 kg/ha</p>	<p>C1: Stepping out 17 % population Land 2 ha Livestock 35,000 KSh Mostly men ME 3.4 Income 111,000 KSh 91% off-farm Crop sales 1,960 KSh Animal 0 KSh Low fertility soils Fertilizer 21.5 kg/ha Manure 20 kg/ha Maize yield 2,300 kg/ha Bean yield 370 kg/ha</p>

The household model APSFarm (Rodriguez *et al.* 2011 and 2013) was parameterised using plot management data collected from the household survey, allowing for a 1:1 mapping of all the surveyed households. Figure 28 shows that the model was able to largely explain the observed distribution in household maize production.

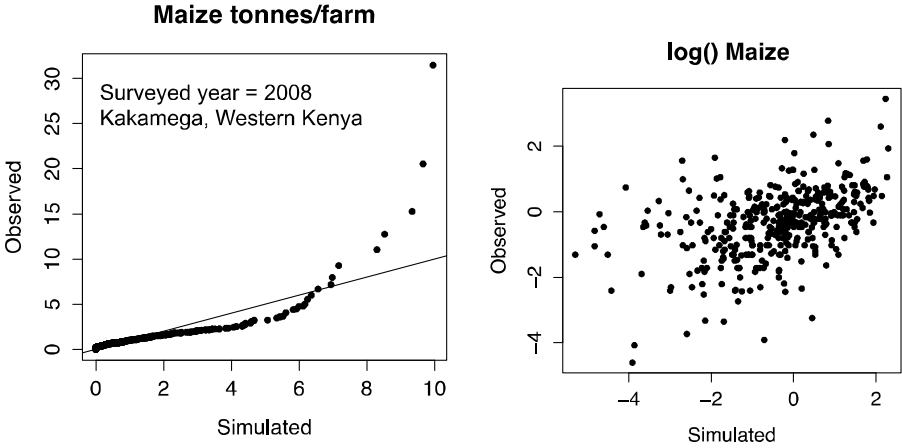


Figure 28: Model validation: plotting observed against simulated maize yields per farm (left; 1:1 line shown), exemplarily for Kakamega, Western Kenya for the survey year 2008, and a log:log graph (right figure) of observed (household data set) versus predicted (APSFarm simulation) household maize production for 2008

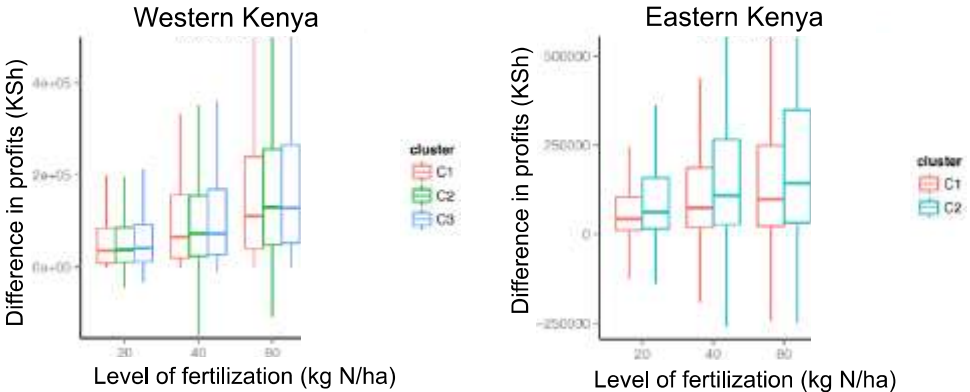


Figure 29: Simulated impact of topping up levels of fertilisation up to 20, 40 and 80kg N/ha on household profits (relative to baseline, i.e. present management). Different bars in different colour represent the household types in Table 15, for Western (left graph) and Eastern Kenya (right graph)

The model was then used to quantify the impacts of investments on alternative technologies in terms of levels of food security, risk, household profits, and environmental outputs. Therefore, the most representative households within each cluster was identified and ranked 1 in the matrix of similarities (smallest Euclidian distance from the geometric mean; Figure 30). Preliminary results indicate that across the five countries:

- Important factors driving differences across household types were: access to markets, labour availability, farmers’ perception on levels of soil fertility, livestock and land ownership, farm assets, age and level of education of the household head.
- Two to four typologies could explain the diversity of across regions within countries.
- The poorest households were usually female-headed households.

- Poorer households perceived higher frequencies of occurrence of droughts than better-endowed households.
- The household model was able to reproduce the observed values of household maize production and could be used to simulate intervention options.

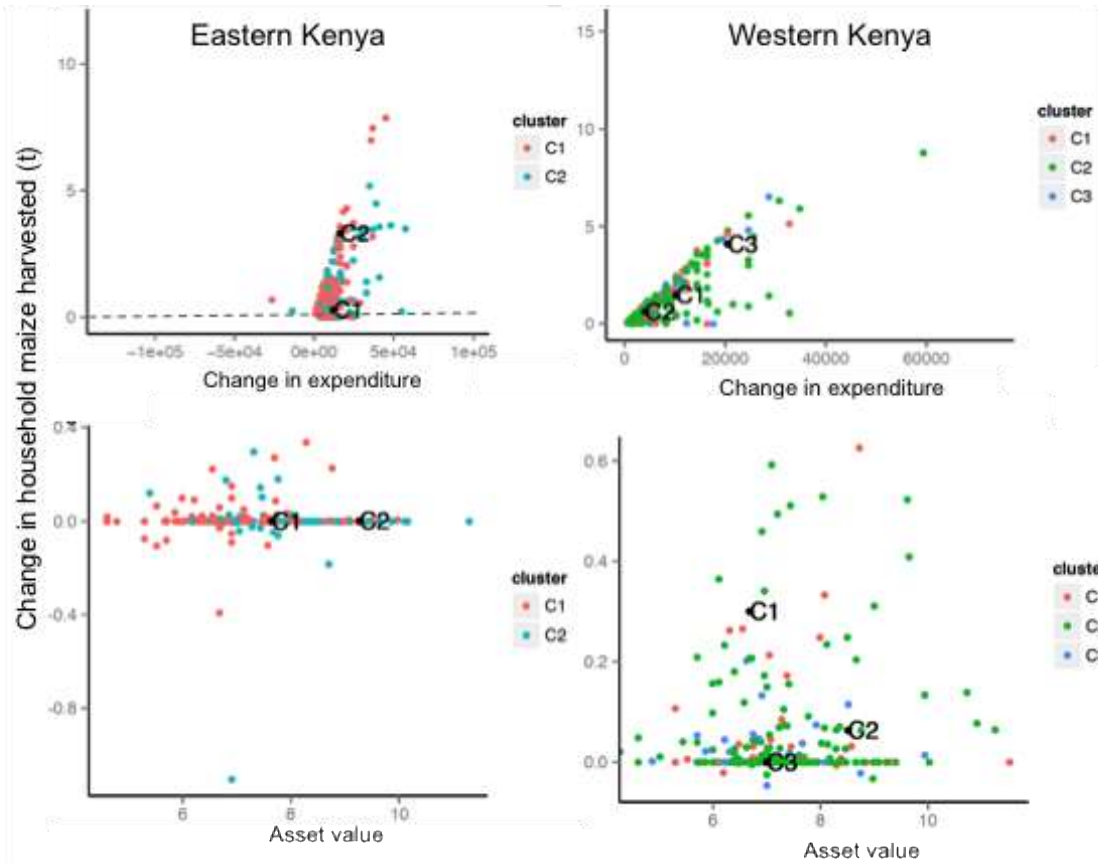


Figure 30: APSFarm simulated changes in maize production in response to the application of 40 kg/ha N-fertilizer (top) as a function of change in household expenditure for all households in cluster 1 and 2 in Eastern Kenya and cluster 1 and 4 in Western Kenya; and changes in household maize production from keeping crop residues as ground cover (bottom) as a function of an index of household asset ownership

- Simulated responses to interventions were different across different household typologies. For Eastern Kenya the model indicated that small investments in nitrogen fertilisers in households from Cluster 2 (that had more responsive cropping system) had the potential to provide larger increases in maize production compared to Cluster 1 (that had less responsive cropping systems, i.e. driven by the mixture of crops planted and the farm size).
- In Western Kenya significant improvements in maize production could be achieved in Cluster 3 (classified as a “hanging in” Dorward, et al., 2010), though at a rather large costs for these poorly resourced (female headed) households. This is because these farmers (Cluster 3) are not applying fertilisers or manure and the increase in cost reflects the fact that they required a significant increase in expenditure to achieve 40 kg N/ha compared to present practice. This also indicates that for the poorest farmers, to increase nutrient inputs, they might need to initially rely on cheaper options e.g. manure, composts and rotation with legumes.
- The impact of keeping residues as ground cover was small in these highly nitrogen constrained environments. Simulated results indicate that only the richest households that already are using

moderate amounts of fertilisers and produced larger crop yields (Cluster 1 in Western Kenya) would see benefits from this practice.

- The different responses to interventions indicate that the household typologies could be used to inform how to better target practices, and allocate household investments to maximise benefits while minimising trade-offs.

6.3. Innovation platforms to support multi-stakeholder collaboration

6.3.1. Introduction

The fact that the millennium development goals are not to be met is not due to lack of appropriate technologies or the lack of scientific expertise – but rather the very low rate of adoption of technologies (Van Rooyen and Homann 2007). Yet, as such the scientific community is not “off the hook” by blaming the small scale subsistence farmers for their lethargic adoption rates. Rather, it is most probably scientist’s limited understanding of the adoption/innovation process and the incentives for investment and production beyond the household’s immediate needs. To redress this, the Forum for Agricultural Research in Africa (FARA) has promoted an Integrated Agriculture Research for Development (IAR4D) approach based on an innovation systems framework (Adekunle *et al.* 2012). The driver of IAR4D is the Innovation Platform that brings together multiple actors along a commodity value chain to address challenges and identify opportunities to generate innovation. The approach creates a network of stakeholders or partners, who are able to consider the technical, economic, social, institutional, and policy constraints in an environment. The network facilitates research and learning that not only generates new knowledge, products or technologies, but also ensures the use of research products. Of importance in this process is the market.

Much of SSA small scale agriculture will continue to remain heavily biased towards low input low output extensive systems where subsistence is the primary objective, as long as we cannot improve market access and improve productivity. Increased investment in production and management will remain low as long as access to markets, and thus returns on investments are low. The fundamental hypothesis is thus that increased market access will lead to increased investment in production, and therefore increased adoption of technologies. Further developing these markets will facilitate the whole process and increase sustainability. In other words, the main driver of increased technology uptake leading to increased sale of agricultural produce is access to more efficient markets. This chapter presents the theoretical development of such a process as a working model for any project where we strive to improve crop production and markets by improving markets, partnerships and stimulating dialogue between local stakeholders in the agriculture sector.

6.3.2. The concept of an Innovation Platform

Innovation Platforms (IPs) are based on Innovation System thinking. IP has recently gained ground as a mechanism to stimulate and support multi-stakeholder collaboration in agricultural research for development (Pali and Swaans 2013). The terminology used is different in different contexts and sometimes the terms ‘innovation networks’ or ‘stakeholder networks’ or ‘multi-stakeholder platforms’ are used synonymously for various functions. Generally, an IP is a forum established to facilitate interactions, and learning among stakeholders selected from a commodity chain leading to participatory diagnosis of problems, joint exploration of opportunities and investigation of solutions leading to the promotion of agricultural innovation along the commodity chain (cf. Van Rooyen and Homann 2007, Adekunle *et al.* 2010, Nederlof *et al.* 2011, Pali and Swaans 2013).

With its roots in innovation systems theory, IP facilitates dialogue between the main local players in the value chain: farmers, input suppliers, traders, transporters, processors, wholesalers, retailers, regulators, and the research and development fraternity (Van Rooyen and Homann 2007). Innovation Platforms identify bottlenecks and opportunities in production, marketing and the policy environment. The process is galvanized through discussions on market requirements (quantity,

quality, and the timing of sales), followed by an analysis of existing production strategies. The IP then identifies and implements technologies to improve production to fulfil market demand. In a parallel and similar process the marketing system is analysed, and improvements to benefit all role players are tabled and tested within the local context.

6.3.3. The design and establishment of Innovation Platforms

This model should focus at grassroots level-functioning at the level of the local commodity market and its participants and associated interested parties. Results and impacts can be *up and out-scaled* from here. It is thus essentially a bottom-up approach, where planning and decision making are controlled by the target audience, but the process facilitated by the local R&D. Strong linkages to higher levels of decision making and policy development can be fostered from here.

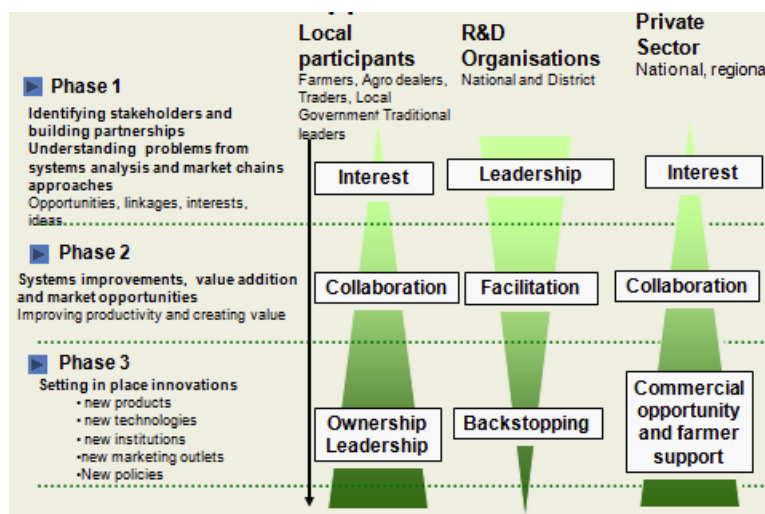


Figure 31: Conceptual Framework for Innovation Platform establishment and functioning; derived from Devaux (2005)

Figure 31 presents a conceptual framework for the establishment of an IP showing a three phase process with multiple steps, as has been outlined in detail by Mokwunye and Ellis Jones (2010) and CORAF/WECARD–CS (2012). This framework informs the creation of a researcher-managed knowledge generation and dissemination IP. A Researcher-managed IP is facilitated through the active participation of relevant interest groups and stakeholders at the early stages of development of practical and most cost effective technologies, innovations and best practices. The IP process for any given constraint or opportunity should be evidence-based analysis to determine the priorities that need to be addressed. Priorities which are segments of the system and or value chains are the entry point(s) of the stage(s) of the development process of IP technology or best practices. All the entry points are interconnected and linked throughout the innovation process through experiential learning and sharing. The IP should be dynamic and be able to facilitate interests, interactions, and relationships taking into account perceptions, competing interests, risks, access to resources, and incentives among the diverse social and economic interests of IP stakeholders. The process should ensure forward and backward linkages between each entry point or segment of the technology and/or best practices under development or dissemination.

The phased innovation platform process is illustrated in Figure 1 and is described as follows:

Phase 1 encompasses two main stages. During the **first stage**, the interested R&D institutions begin

the process of identifying and establishing a research theme and stakeholder roles. During this process, capacity strengthening of participating organizations is undertaken including researchers from NARS, International Agricultural Research Centres (IARCs) and subregional research organizations (SROs), development agencies (extension services), NGOs, staff of Ministries of Agriculture and representatives of National Farmer Organizations, where they exist, and wish to participate. Shortly thereafter, Task Forces (TFs) are identified in the geographical areas where interventions are likely to occur. During the **second stage** of Phase 1, local stakeholders including farmers and farmers' groups, agricultural extension agents, input dealers, NGOs, and district or local government authorities are invited to actively participate. This process seeks to achieve a common understanding of challenges/opportunities, existing linkages, interests and ideas for intervention through systems and value chain analysis and identification of opportunities for action.

Phase 2 confirms the roles of partners; bye-laws are agreed upon, and objectives are defined. This promotes deepening understanding of priorities and development as well as implementation of an action plan. Research activities, which ultimately result in technology development, are initiated on a participatory basis. Participatory learning through assessment of performance and progress also takes place. At the same time, input and output markets including financial opportunities are assessed and linkages established. During the IP process, continued learning occurs and becomes part of a monitoring and evaluation system that assesses learning from process and practice. Field days are organized for learning, and for assessment of performances.

Phase 3 allows IPs to assess the performance of innovations in terms of new policies, new institutions, capacity needs, technologies developed, market linkages, and information and knowledge flows.

During Phase 1 leadership is in the hands of the R&D organizations with local participants and those from the private sector showing interest. During Phase 2, R&D begins to play a facilitating role with increasing collaboration from local actors and the private sector. During Phase 3, ownership and leadership passes to local actors while the private sector plays a key role in farmer support but motivated by commercial opportunity. This allows R&D actors to play a backstopping and service function role.

6.3.4. Actors in the Innovation Platform and their roles

Participants in the IP fall into two main categories, firstly those who are the main beneficiaries from the process, those members of the value chain that would tangibly benefit from actively engaging in the process, i.e. farmers, market intermediaries, processors and those towards the consumer end of the value chain. Their participation in the process will ensure that the correct and relevant issues are captured, appropriate (site specific context) technologies and strategies are identified and implemented. This group will benefit mostly through becoming more competitive – through reduced transaction costs. The second group of stakeholders in the innovation platform can be broadly categorized as the R&D community or service providers. Traditionally these groups interact primarily with the producer and the communication is often only one way. This group will analyze the situation as described by the main role-players and together suggest technical and institutional interventions that will improve the efficiency of the production to market process making it more competitive. Local research and development organizations, government support services and NGOs will contribute to the IP as informed (outsiders) facilitators of the process. Within this group there may well be individuals/groups who will contribute from time to time, providing information,

guidance and technical support as required. Those within the policy environment may fall into this group. Thus, an IP has the following main actors:

- a. *Farmers and Farmer organizations*: as producers they have access to certain resources, they understand their limitations and challenges. Often there is a lack of skill and expertise with regards to certain technologies and improved farming strategies. Access to information (such as market related information) is often a limiting factor. Farmers often do not know what the market needs, when the market needs it, and can often not produce enough to make it worthy for a market intermediary to collect the produce. The farmer's role at the IP is to provide insight from the producers' perspective on the technology and information needs of farmers, their challenges in production and marketing.
- b. *Traders and other Market intermediaries*; similarly, small scale traders and transporters may not always be aware of the needs of the market, and often operate in the dark, buying, transporting and trying to sell to distant market places with limited knowledge of price structures, regulations and grades and standards. More importantly, their needs in terms of the variety of products, the quality and quantity of products may not be known or understood by farmers. Within the IP, the roles of market intermediaries are important to complete the process of information sharing. A clear understanding of what the market requires is crucial in providing the incentives for farmers to produce what the market requires. Moreover, there is an increasing role the trader can play in also supplying other types of information. This may include information regarding technologies or other commercial inputs such as fertilizer, herbicides, improved varieties, fungicides and improved agronomic management strategies. Building improved relations between market intermediaries and producers has proven to work elsewhere and this can be seen in even some of the most rudimentary markets, where buyers provide inputs and supply information.
- c. *The Market Place*: representatives of the market place should participate in the IP to understand the specific needs of farmers, traders and those who buy from them, this may be processors and/or retailers buying crop produce to be processed and then sold to the consumer. Improving the market place, its related institutions and infrastructure has the potential to greatly improve the efficiency of the market, its functioning and the role it plays in facilitating information flow between individual parties.
- d. *Processors and the consumption end of the Value Chain* – their role is specifically to provide inputs on market needs (type, quality, quantity and timing), its trends and issues of control and feedback to producers.
- e. *Research and Development community* – The main roles of this group is to provide the technical backstopping, assist with analysis and identify opportunities. Assess and negotiate the relative feasibility of IP actors objectives and gain focus in the discussion during the IP meeting, and identify relevant soil fertility interventions or other interventions that can help farmers increase yields and profits. A vast amount of information and experience are entrenched in these bodies. Previously these information/technologies were not fully appreciated, as it was so often 'disseminated' in the form of a sterile technology offered without the facilitating environment that would yield the real value of the intervention. The IP and the framework that it provides with the linkages to market development will thus allow interventions (fertilizers, conservation agriculture, organic manures, improved crop varieties) to be evaluated within the context of investment and the returns on investment. This is not only true for the producer, but also from

other role-players of the value chain. This will consist of national research and development agencies, agricultural support services, local policy makers and NGO's.

6.3.5. The role and functions of Innovation Platforms to generate incentives for investment

The basic principle of this approach is that increased communication between the various stakeholders will identify opportunities for improvement, both in identifying pressure points in the production to market system/process and also to allow for novel and more effective approaches to information exchange. Once all relevant parties have been identified and have "bought into the system", the main tasks for this IP would be to engage in the following five main activities (ICRISAT and ILRI 2008, Van Rooyen and Homann 2007):

a.) Improve Markets

Through deliberations and analysis the IP will identify ways and means to improve on existing markets or even develop new markets. These improvements may be at various levels:

i. *Improving Institutions* – improvements may be to develop more transparent markets, managed by more credible people or by improving the institutions around the marketplace that will improve the acceptability of the specific organization managing the market/market place. Improvement of local outlets for input supplies (voucher schemes for fertilizers) and other farm inputs.

ii. *Improving Infrastructure* – the IP will identify and facilitate improvements in the infrastructure of the market place. This may include facilities that improve the individual farmer's ability to display his crop produce or small packs of fertilizers, standard and transparent weighing scales and grading systems may well be identified as important improvements to be implemented.

iii. *Access to markets* - this important aspect has two main components which will be dealt with by the IP, namely the physical access, such as roads and access to transport to the market place, and the institutional access, such as those preventing farmers who are not members of the local farmer or market related institutions or in certain cases farmers may not have access to markets because of imposed quarantines or prohibitive by-laws.

iv. *Information* – improving market related information is quite often an important limiting factor inhibiting producer's participation and confidence in certain markets. Opening up such information and providing access to such information may well increase participation in markets.

b.) Identify and promote technologies

i. *Improved productivity* – these are technological interventions that are traditionally promoted to increase productivity. Examples of such technologies include conservation agriculture practices, fertilizers and organic manures, improved crop varieties etc. Promoted alone it will often have very little impact as adoption is normally low. However, done within the framework identified through an iterative process between all stakeholders may hold more value.

ii. *Aligning the requirements* of the production and demand – more importantly, some technologies/strategies may well bring producers closer to the demands of the market – this may be related to the type of product, its quality, quantity and the temporal requirement of the market/consumer. We hypothesize that technologies identified at this level, to align the farmers' production environment to that of the market demands, will well be first to be adopted, as this is

dictated by the market and therefore a direct incentive scheme is in place to account for the return on such investments.

c.) Providing a platform for improved information/input supply

Access to credible and reliable information is crucial in agricultural development. Effective pathways of information exchange are however limited and the traditional agricultural extension officer experience various challenges in the implementation of his/her traditional role. The IP can provide alternative pathways of information exchange and training. Channeling information through the IP, and evaluating and 'endorsing' information before dissemination, may render information more credible, reliable and site/context specific. Moreover, information that may be passed on by market intermediaries, for their, as well as the farmer's benefit may be more readily accepted. This is because both parties have a vested interest in the information. Similarly, input suppliers may well be more effective in providing information at appropriate places along the value chain. Traders that also act as input suppliers may well be very effective because they are the actual point where money is exchanged and thus the most likely "place" where cash is available for inputs. The IP will thus continuously:

- i. i. Evaluate alternative information using supply chains
- ii. ii. Evaluate alternative input supply chains using the IP and traders/market intermediaries.

d.) Policy analysis and development

Bringing about change in policies is often very difficult and involves long periods of lobbying to engage policy makers. Since the IP as it is described here already involves a range of stakeholders, their contribution to policy analysis and bringing about change can be vital. Moreover, if the IP already included policy makers, even at the local level, then the process to bring about change will be more probable. Through the iterative process of testing, implementation and evaluation the IP can implement changes to policies and evaluate the local impact. The IP may become a crucial role-player in changing policies and will:

- iii. Identify 'problem' policies
- iv. Develop appropriate policies
- v. Test and refine policies

e.) Monitoring Impact, evaluation and adaptation

By the nature of the functioning of the IP, it provides an elegant opportunity for it to become the major body to do the monitoring and evaluation. As the real stakeholders are present and they experience the impact, or the lack thereof in the implementation process of interventions or changes in strategies, it is in their interest to adapt and improve and re-evaluate. Such a body can therefore fulfil the crucial role of evaluating impact and also sharing successes.

6.3.6. Continuity and sustainability

The main assumption is that an IP would be established by a project, funded from outside and facilitated to the point where the process runs according to the work plans as defined by the platform itself. Initially the process would thus be driven by the project, but as the benefits of the IP are realized, the platform would become increasingly self-driven/stakeholder driven, or at least through a process of partnerships developed within the platform.

6.4. Climate-related risk and investment in soil fertility management

6.4.1. Introduction

Smallholder cropping systems in Africa are characterized by chronic low productivity due to a continuing lack of investment in soil fertility management. Fertilizer use in sub-Saharan Africa is extremely low (see Chapter 3 and 4, this publication), inputs of biological N fixation are limited by ubiquitously poor legume yields (Giller and Cadisch 1995, Giller *et al.* 2009) and farm yard manure is mostly of low nutrient content (Probert *et al.* 1995, Probert *et al.* 2005). While over 90% of crop lands in SSA is rainfed, Foley *et al.* (2011, see Figure 3) has shown that increasing maize yields (by 50% above baseline) across the sub-continent is overwhelmingly dominated by nutrient limitations, and for their analysis, water only limitations were identified in just two locations, south-west Zimbabwe and regions of South Africa. Keating *et al.* (2010) point out that unless ways are found to relieve the soil fertility constraint in Africa, eco-efficient use of other natural and human resources will remain low.

Increased fertilizer use in Africa's smallholder cropping systems offers the most promise for alleviating recurring food insecurity (at farm level) and providing the impetus for agricultural production to drive economic growth on the continent (Nature 2012, Gilbert, 2012). There are known reinforcing market-related (poor infrastructure, market development and marketing strategies) and socio-economic (widespread poverty, poor extension services, lack of incentives) factors contributing to farmers' low investment in fertilizer in Africa (Morris *et al.* 2007). However, because fertilizer use interacts strongly with crop water supply in determining returns on investment, coupled with its generally high proportion of variable input costs, fertilizer investments are a major production risk in rainfed agriculture. Hence, for Africa's smallholder farmers, promotion of higher investments in fertilizer use must assume farmers' willingness to take on higher production risk (Keating *et al.* 2010, Carberry *et al.* 2013). For risk-averse farmers, this is further complicated by a tendency to over-estimate the frequency of drought conditions (Rao *et al.* 2011), providing a strong dis-incentive to fertilizer investment.

Over-coming farmer's risk-aversion and risk perceptions is a major challenge for research and development, since risk management is the outcome of highly individualistic attitudes and circumstances feeding into the decision making process. Getting close to the bio-physical environment of farmers is perhaps the best we could expect to achieve. One option for engaging farmers directly on risk analysis and management is participatory modelling, whereby local soil, climate and farmer management is used in conjunction with a cropping systems model to explore alternative management options under variable rainfall conditions (Whitbread *et al.* 2010, Carberry *et al.* 2004). Here the experiences of conducting a participatory modelling exercise at a village in Eastern Tanzania, under the SIMLESA project (Mulugetta *et al.* 2011), is described.

6.4.2. Farmer perceptions on drought risk

SIMLESA survey results that include the Mandela region discussed below, show that 50 % of farmers rated 30% of seasons as drought affected (Figure 32), and 80 % of farmers indicated that the impact of these droughts on crop yield is severe (data not shown).

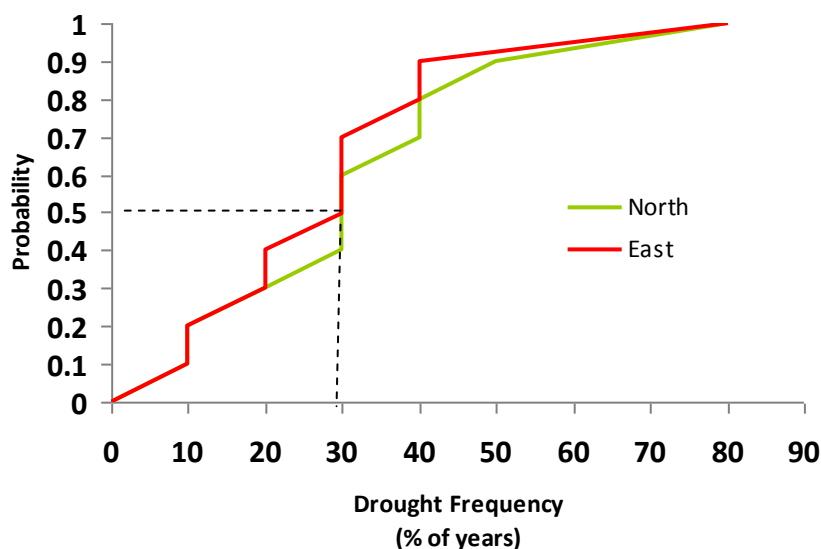


Figure 32: Probability distribution of farmer responses on drought frequency affecting crop production in eastern and northern regions of Tanzania. (Source: SIMLESA Baseline survey, eastern sample area includes Mandela village)

A 30% incidence of crop failure at Mandela is not evident in the farmer’s yields in Figure 4 below, while the simulated yields in Figure 6, suggest that the probability is less than 10%. Hence there is evidence here that farmers do over-estimate the frequency of unfavourable seasons.

6.4.3. An example of engaging farmers on climate risk

The SIMLESA project conducted a 3-day participatory modelling workshop at Mandela village, Tanzania, in November 2011. On day 1 of the workshop, the farmer group (10 men and 10 women) was visited for the first time. Half of the farmer group participated in a questionnaire in which farmers provided data on maize yields achieved across seasons. Four farmers provided yield estimates going back 13 seasons, and seven farmers provided estimates going back 5 seasons. The other 10 farmers and local extension officers participated in constructing resource allocation maps (RAMs), providing a description of farmer’s field soils, management practices (sowing dates, variety, row spacing, fertilizer use, and weeding dates) and yield outcomes in the 2011 cropping season (Figure 33).

Day 2 activities were conducted without farmers. Survey data was entered and yield data analyzed for water use efficiency. The cropping systems model, APSIM (Keating et al. 2010), was used to simulate maize yields for the period 1999 to 2011 at Mandela. Historical climate data from Ilonga Research Station (approx 50 km distant) and representative farmer management and soil descriptions were inputs to the model. Farmer management applied in 2011 to a maize field from one of the RAMs was also simulated (Fig 2). The model was calibrated to the farmer yield achieved in 2011, and his 2011 management was extrapolated across previous seasonal rainfall conditions, back to 1999.

On day 3, the farmer group was re-visited to share analysis results. Simulated yield outputs for the RAMs’ exercise were used with the farmer group to explore management changes in relation to fertiliser use, weeding frequency and interactions with seasonal rainfall.

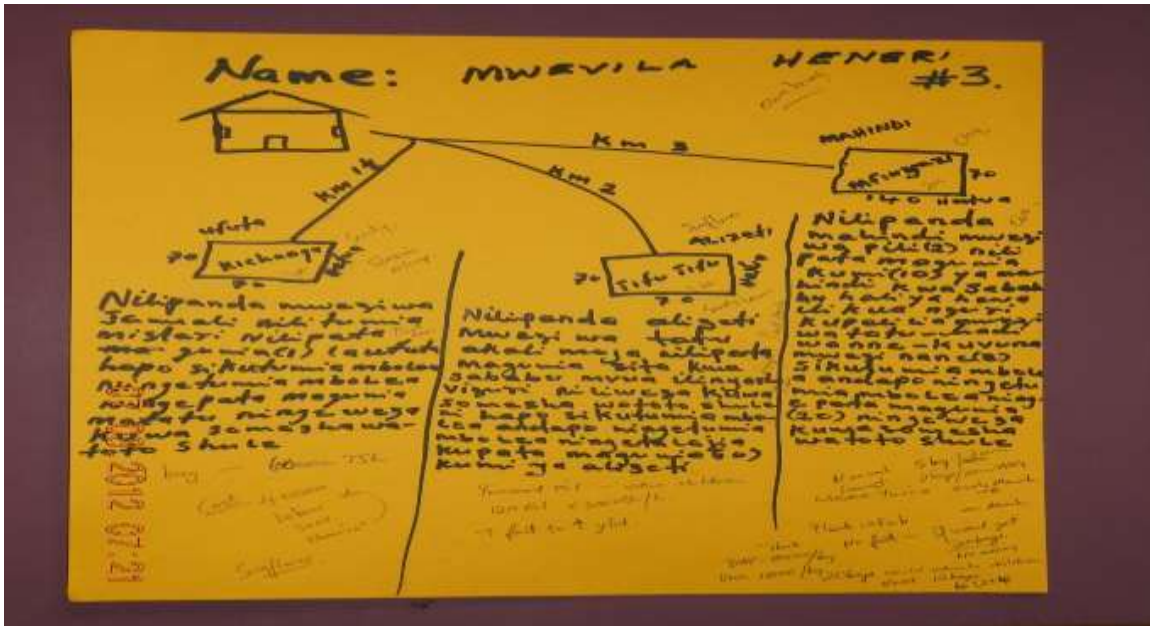


Figure 33: Farmer resource allocation map at Mandela

Farmers in Mandela village did not use fertiliser on maize or on cash crops (sunflower and sesame) and struggled to do more than 1 weeding during the season. They also used mostly recycled seed. Historical rainfall data for Ilonga (Figure 34) was shared with the farmers and its variability explored through farmer interactions with the data, leading to the general agreement that Ilonga provided an appropriate representation of the Mandela climate. The rainfall data showed that 1 season in 13 as drought affected (Fig.3, < 400mm in-crop rainfall), compared to farmer survey results.

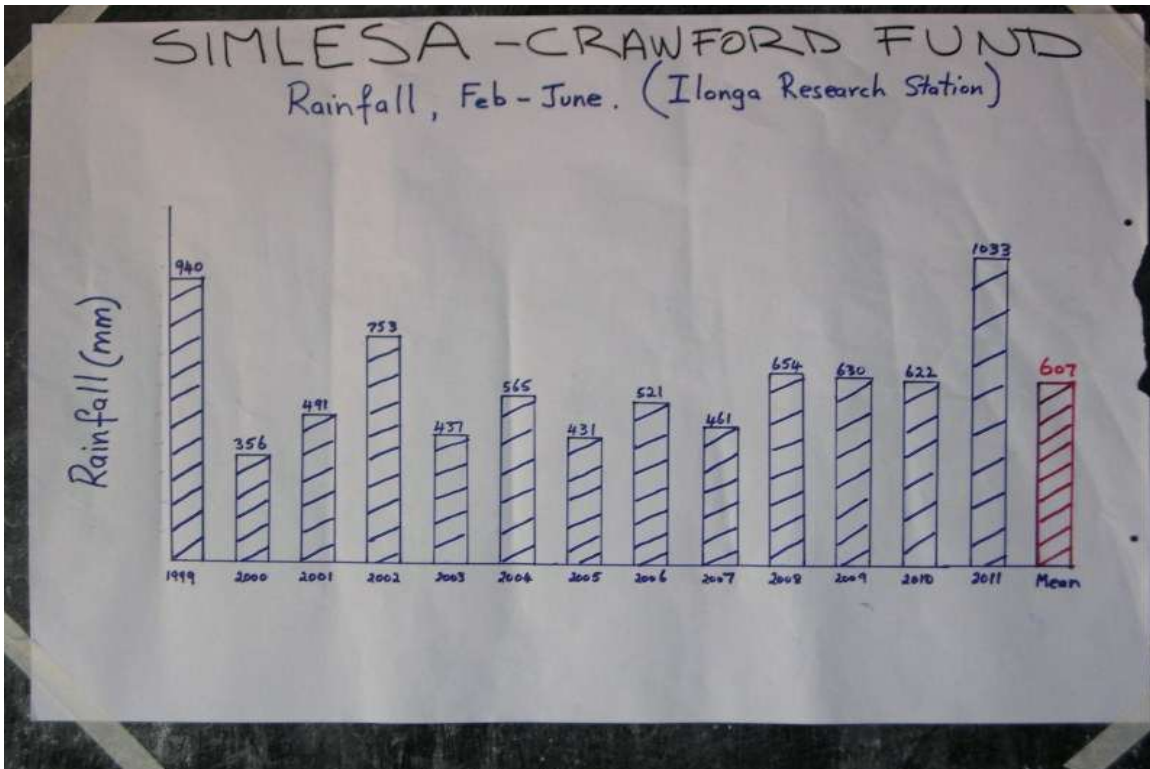


Figure 34: Seasonal (Feb-Jun) rainfall totals at Ilonga Research Station, 50km from Mandela village

The simulated yield outputs for the period 1999-2011, fairly closely reproduced the distribution of yields reported by the farmers at Mandela. (Figure 35, data not presented to farmers). For the RAM's scenario shared with the farmer group (i.e. Mr Mwevila Heneri, Figure 36), simulated maize yield was very close to the farmer's yield in 2011 (it having been provided in RAMs and used for model calibration) and his average for the field across years (solicited during the discussion, see asterisks in Figure 36).

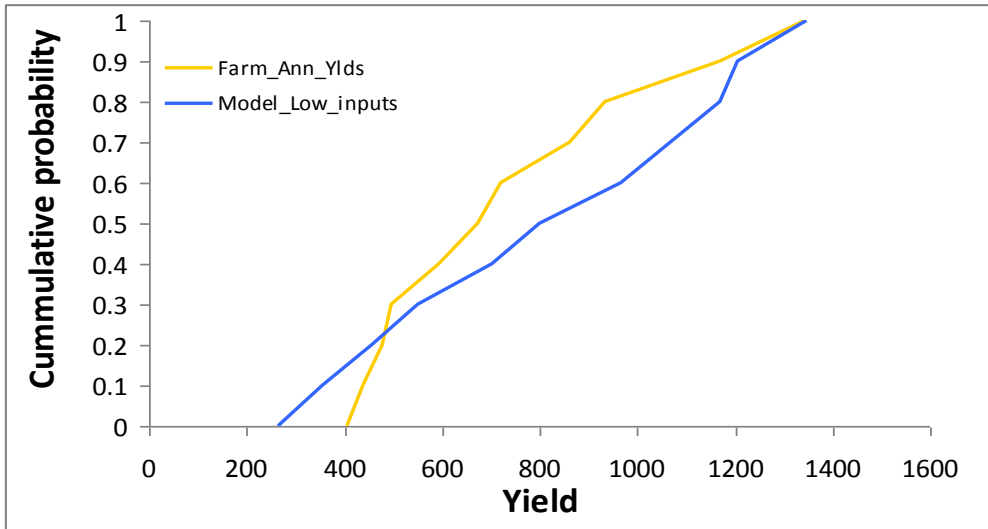


Figure 35: Maize yield distributions (kg/ha) derived from farmer survey data and simulated yields using APSIM for the period 1999 to 2011 at Mandela village, Eastern Tanzania.

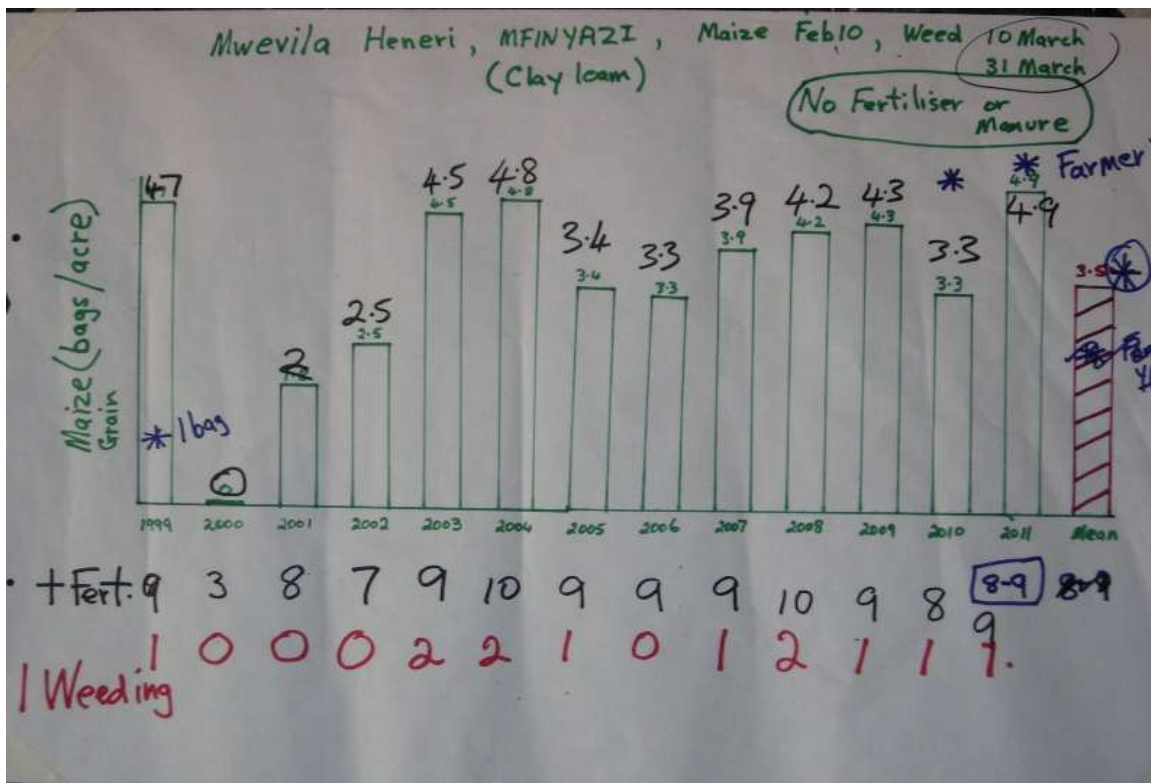


Figure 36: Simulated maize grain yield (bags x 100kg /acre) for farmer's field and management (described at top of sheet) at Mandela (bar chart). Yield outcomes for alternative management (50 kg urea/ha, 1 weeding in crop) are shown at bottom of sheet (bags/acre)

However, simulated yields were not close in all seasons discussed with the farmer, in particular his

drought-affected yield in 1999. The discrepancies between model and farmer yields provided points for discussion on reasons for the differences. The model results for alternative management practices were then shared with the farmers. With fertiliser (50 kg urea /ha), maize yield across seasons was 140% higher than farmer practice and highly reliable. With one weeding, simulated maize yield was zero in 4 seasons and 75% lower than farmer practice across seasons.

6.4.4. Advantages/disadvantages of participatory modelling approach

The main benefit of the participatory modelling approach is that it provides yield responses for farmer's own soil and management conditions interacting with local rainfall patterns. Such context relevant information on climate related risk and returns can give farmers more confidence to experiment with new technologies and improve their crop management. The rapid feedback of information to the farmers only 2 days after the initial interaction is also much appreciated by farmers and extension officers.

A further benefit is that based on the results of the modelling outputs, farmer can be canvassed on possible treatments for on-farm experimentation. In the case of Mandela, an on-farm fertiliser trial was established on 2 soils where farmers were shown how to apply urea to maize crops and yield responses tested (4 levels of urea applied). A small quantity of fertiliser (2 kg urea) was also distributed to farmers and its use (amount applied, which crop) monitored. The main reason for not using fertiliser in the village seemed to be concerns about the longer term effects on soil health (others included high cost and no experience in using fertiliser). As a consequence, a special feature of the trial design was that residual effects would be tested in the 3rd season, using a test crop nominated by the farmers.

While a 3-day interaction with farmers to develop an experimental programme is expensive (and no evaluation of the cost-benefits have been undertaken), the quality of the interaction and relevance of the on-farm trial design to be implemented would seem to justify the high costs of the exercise. The other drawbacks of the approach are the data input requirements, especially local climate data, and the need for high level modelling skills.

6.4.5. Comparison of rainfall risk across sites

APSIM was used to explore the maize grain response to N fertilizer inputs under the same management, soil and seasonal conditions at Mandela and at the more water limited environment of south western Zimbabwe (Matopos, near Bulawayo).

At Mandela, the yield distribution for ON is very steep, covering the range 300 to 1400 kg/ha, and is indicative of a very 'resilient', low productivity and low risk cropping system (Figure 37.a). With increasing N inputs, there is an almost parallel shift to the right in the yield distributions, except for the least favourable 10 % of growing seasons. This result indicates that fertilizer use in this environment would be a low risk intensification strategy.

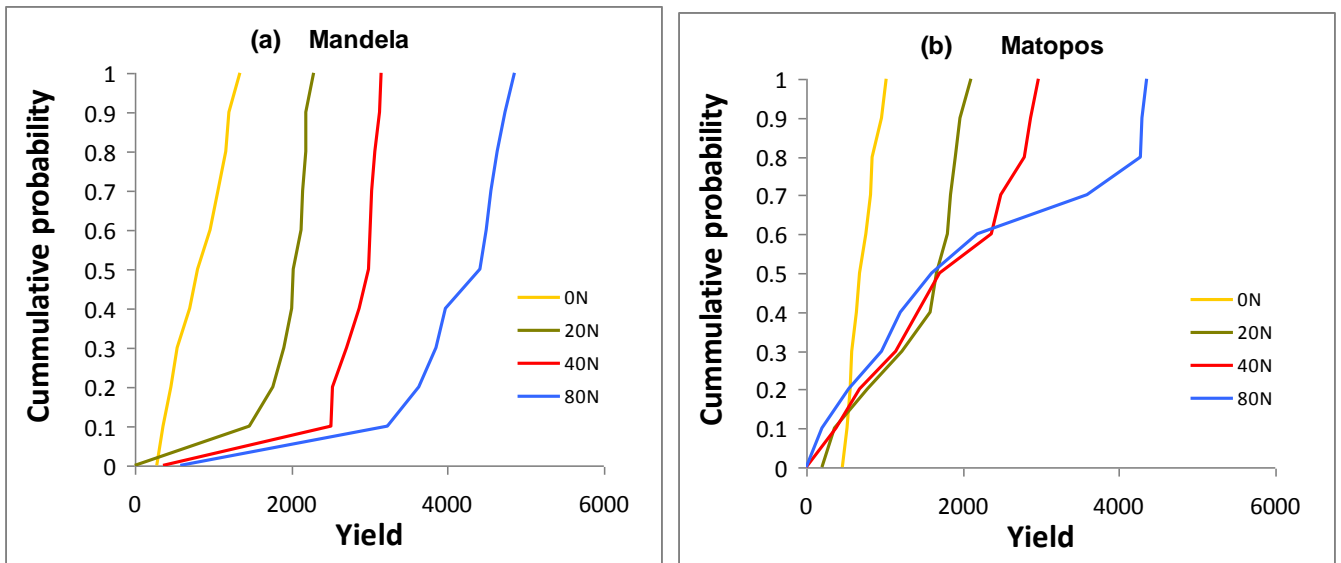


Figure 37: Simulated maize yield distributions (kg/ha) in response to fertilizer N inputs (kg N /ha) at (a) Mandela, Tanzania, and (b) Matopos, Zimbabwe.

At Matopos, the range of maize yields in the 0N distribution (i.e. default farmer practice) is even tighter than at Mandela (450 to 1000 kg/ha), but response to N inputs is much more uncertain, reflecting the strong interaction with the more variable rainfall patterns Figure 37b). Relative to the farmer baseline, high inputs of N (the local recommended level is 60 kg N/ha) can be expected to have negative effects on yield in about 20 % of seasons, whereas maize yields of over 4000 kg/ha are achievable in the most favourable 20 %. On the other hand, the simulated yield distribution for the 20N treatment suggests that there is an N constraint in the cropping system in more than 85% of seasons, rather than a water constraint. (Using the 50 % yield increase criteria of Foley *et al.*, the simulation results suggest that the nutrient constraint is prevalent in 65 % of seasons).

6.4.6. Conclusion

To reduce climate risk perception as a barrier to increasing investments, farmers (and other stakeholders in the agricultural development arena) need to be engaged directly on their subjective assessments of climate risk and comparisons made with more objective assessments (rainfall records, crop simulation outputs). This can lead to design of field experimentation that reinforce the opportunity for practice change and ultimately increase farmers' investments in crop management technologies.

6.5. New initiatives and global players

Despite the very limited successes of initiatives like the Africa Fertilizer Development Financing Mechanism set up in response to the 2006 Abuja Fertilizer Summit (see chapter 4.5), a range of new Africa-based initiatives and non-profit organization have emerged quite recently, and especially NGOs play an increasingly important role in promoting the increase of mineral fertilizer use, advocating the importance of sustainable nutrient management systems, or by investments in African agriculture in general. Goals and activities of a few of them are outlined in the following.

6.5.1. Alliance for a Green Revolution in Africa (AGRA)

AGRA was founded in 2006 by Rockefeller Foundation and the Bill and Melinda Gates Foundation (BMGF). These two founders contribute the majority of funding, but AGRA also receives financial support from other governments, agencies and international institutions. Obviously, the name of the organization implies that the Green Revolution – in a nutshell the introduction of high-yielding varieties and mineral fertilizer together with infrastructure development that enabled Asian countries like India and the Philippines to become food-self-sufficient in a few decades – could be replicated/kicked off successfully in Africa.

AGRA works to achieve food security in Africa through the promotion of rapid, sustainable agricultural growth based on smallholder farmers. AGRA's programs focus on four basic areas: soil, seeds, policies and markets. In other words, AGRA aims to ensure that smallholders have access to modern varieties, healthy soils, markets, information, financing, storage and transport, as well as policies that provide them with comprehensive support. By 2020 AGRA strives to reduce food insecurity by 50 % in at least 20 countries, double the incomes of 20 million smallholder families and put 15 countries on track to attain and sustain a Green Revolution. The entry point of AGRA is the high-potential breadbasket areas of Africa with tremendous potential to increase farmer productivity as well as implement ideas and solutions that could be scaled up in other countries. AGRA works to transform smallholder agriculture into a highly productive, efficient, sustainable and competitive system, while also protecting the environment. In 2011, AGRA had total assets worth approximately US\$ 170 million at their disposal (AGRA 2011). As of June 2009 AGRA had approved 116 grants in 14 countries valued at US\$83 million.

6.5.2. Grow Africa

Grow Africa is a partnership platform established in 2011 by the African Union Commission, the New Partnership for Africa's Development (NEPAD) and the World Economic Forum. Operative in 2012, seven member states joined the partnership, namely Burkina Faso, Ethiopia, Ghana, Kenya, Mozambique, Rwanda and Tanzania. *Grow Africa* seeks to accelerate investments and transformative change in African agriculture based on national agricultural priorities and in support of the Comprehensive African Agricultural Development Programme (CAADP) that was established in 2003 by NEPAD. It plays a catalytic role to increase private-sector investments, enable multi-stakeholder partnerships, and expand knowledge and awareness of best practices and existing initiatives. So far, *Grow Africa* countries attracted 97 commitments from 62 companies, including 39 based in Africa. By April 2013, companies reported progress against 79 of these commitments (81%). The private-sector engagement, according to *Grow Africa*, amounted to over \$3.5 billion of planned investment across *Grow Africa* countries in 2012 alone (*Grow Africa* 2013).

6.5.3. The African Fertilizer and Agribusiness Partnership (AFAP)

AFAP is an independent non-profit organization founded only in September 2012 by a partnership of African development organizations, among others, NEPAD, AGRA, the International Fertilizer Development Center (IFDC), the African Development Bank, and the Agricultural Market Development Trust. Major financial contribution (~\$25 million) to sustain AFAP comes from AGRA, which itself receives considerable financial support from BMBF (see above).

AFAP, as does *Grow Africa*, builds on the work of the CAADP. It works with the public and private sectors to invest in fertilizer markets, to establish more competitive and sustainable fertilizer markets. It wants to make fertilizer accessible and affordable for African smallholder farmers, bolster capacity and incentive for fertilizer use and foster responsible fertilizer use to increase crop yields and decrease food insecurity. The very concrete goal is to increase the number of fertilizer users by 15 % and at least double total fertilizer use in the countries where AFAP works. To achieve these goals, AFAP catalyses initiatives, such as introducing new fertilizer suppliers to new markets, adding new or improved blending or granulating plants, and developing new and improved retail and cooperative storage facilities that increasing fertilizer storage available. Using so-called Agribusiness Partnership Contracts (APCs), AFAP tries to combine industry and development interests. The APC is available to eligible agribusinesses that want financial, technical and logistical assistance as they invest in emerging African markets. AFAP also connects entrepreneurs and business leaders with development organizations that have proven track records in providing African smallholder farmers with the incentive, initiative and capability to source and use fertilizer.

6.5.4. Root Capital

On the 2013 top-100 list of most successful NGOs *Root Capital* ranks number 12 (Global Journal 2013). *Root Capital* is a non-profit social investment fund that emphasizes on building sustainable livelihoods by lending capital, delivering financial training, and strengthening market connections for small and growing agricultural businesses in Africa and Latin America. *Root Capital* began working in Africa in 2005. Nowadays, *Root Capital* runs projects in Ethiopia, Kenya, Uganda, Rwanda, Tanzania, Malawi, Zambia and Mozambique supporting farmers growing coffee, cocoa, nuts, honey, fresh vegetables, and spices. By the fourth quarter of 2012, the NGO had disbursed \$467 million in loans to enterprises in Africa and Latin America, reaching 218,000 farmers or artisans in poor, environmentally vulnerable rural communities (Root Capital 2013).

6.5.5. One Acre Fund

Also *One Acre Fund* has been ranked high (number 18) in the 2013 top-100 list of most successful NGOs (Global Journal 2013). *One Acre Fund* sees itself as a provider of basic farm services to subsistence farmers – intentionally called *clients* – that plant one acre or smaller farms in sub-Saharan Africa. It uses a market bundle of seed, fertilizer, finance, and training to help subsistence farmers to "grow themselves out of poverty". *One Acre Fund* facilitates activities and transactions at each level of the farming value chain, from organizing farmer groups to negotiating with export markets. In 2013 *One Acre Fund* has established operations in Kenya, Rwanda and Burundi with pilot programs in Ghana, Tanzania, and Ethiopia. Starting their operations only in 2007, by the end of 2013, *One Acre Fund* will serve almost 150,000 smallholder families, most of them in Rwanda and Kenya, and will have disbursed about \$15 million in the form of credits, with a repayment rate of 98 % (Jenya Shandina, personal communications).

6.5.6. Conclusions

The aforementioned examples of relatively new entrepreneurs with sizeable financial means, a clear goal-driven agenda and an impressive short-term track record, provide reason for optimism that after some decades of relatively fruitless attempts to intensify farming systems in a sustainable manner, there is now the time to achieve notable impact in sub-Saharan Africa. Yet, most of these new players will require, and indeed explicitly ask for, scientific backup to make sure that their chosen intensification pathways are not only profitable in the short run, but also sustainable in the long run.

7. Information & knowledge gaps and bottlenecks

Addressing the issue of food insecurity in response low agricultural productivity from a natural resources point of view, it should have become obvious at this point that the solution lies in a sustainable, profitable and eco-efficient way of managing resources, and that the entry point is increasing the use of fertilizer by smallholders.

Profitability requires maximizing agronomic efficiency (AE) of fertilizer and reducing the impact of climate constraints, such as droughts or access amounts of rainwater (storm events) on AE. Integrated Soil Fertility management (ISFM) or Conservation Agriculture (CA), or the combination of the two, which we call ISFM+, provides for such increased AE by enhanced organic matter management and recycling.

One of the primary bottlenecks of adaptation of profitable and sustainable nutrient management systems is the lack of knowledge of site-/region-specific soil fertility constraints. The quantitative analysis of major soil health constraints (chapter 2) provided strong evidence that not only N and P are constraining production in many of the production systems across sub-Saharan Africa. Other macronutrients, but also micronutrient and low organic matter content of the soils might limit crop growth and yield. There is thus an urgent need to be able to identify such constraints and to find the optimal mix of inorganic and organic fertilizer and residue retention/recycling in a rapid fashion. We believe that, for instance, mid-infrared spectroscopy is a promising tool to deliver such rapid assessment, but the required comprehensive spectral libraries for many of the concerned nutrients or soil fertility as a whole are yet to be developed.

Only if farmers are able to invest in the right mix of soil quality improving measures, will they be able to reach a productivity level for staple crops like maize that generates enough income to make and investment in inputs like chemical fertilizer viable – unless either the input prices drop considerable (e.g. by provision of subsidies) or the output prices increase substantially. Alternatively, increasing the productivity of (low-value) staple crops for securing food self-sufficiency, even if not profitable per se, could allow farmers to set aside land for the production of high(er) value cash/market crops; as such self-subsidizing own food-security by generating cash income through market access and participation.

All of this, however, only applies to production environments where nutrients rather than water are the major production constraint and where soils are responsive to fertilizer application. In semi-arid to arid agro-ecosystems or in regions where soils are so inherently poor or degraded that the chemical fertilizer application alone does not stimulate sufficient biomass production and crop yield, intensification pathways are very much limited. Here, an increased fertilizer application cannot be recommended as an entry-point for increasing production, and other flanking measures, such as for instance the ZAI technology, are required.

Sound knowledge of the nutrient budget of the cropping systems is a pre-condition for monitoring and subsequently increasing the agricultural eco-efficiency, so as to maximize AE and to minimize damage to the environment, e.g. by nitrate losses in to aquatic systems, emission of greenhouse gases, or the loss of crucial ecosystem services.

Probably more related to upstream information and policy advice, a quantification of the current yield gap and bio-physical and socio-economic reasons for such gap is required. This would lead to knowledge about the “exploitable” gap, and would allow also estimating the costs required to close

the gap, which then could guide policy makers to identify hotspots or regions with the highest benefit-cost ratio of governmental interventions.

There is some evidence – confirmed by feedback from many stakeholders participating in the industry-policy-science workshop on “Market-smart interventions to facilitate the availability, access and use of nutrients by smallholders in East and Southern Africa” (see chapter II) – that intensifying smallholder production requires a stepping stone approach, where the farmer can adopt improved technologies little by little. Our ISFM+ approach – outlined in more detail in chapter III – allows such stepwise adoption, and ultimately could/should lead to a full adoption of CA. Little knowledge so far has however been generated in terms of a wider-applicable blueprint for this adoption pathway, and more participatory action research is required to fill this knowledge gap.

Even though some research in the past highlighted the importance of crop residues as livestock feed, too little is known about the true value of residues. Only if the value is known and the importance of livestock understood – beyond the mere economic value, also taking into account the social value of “live stock” – can ISFM+ be successfully introduced or adjusted to the system, such as e.g. by putting emphasis on forage production to compensate for the residues required to make ISFM+ functioning.

Innovation Platforms (IPs) have received quite some attention in the past few years. Their usefulness has been proven in a number of examples. Yet, the concept of IPs has not yet been streamlined enough, to rest assured that it is self-promoting. It might also require an upfront buy-in from stakeholders others than farmers along the value chain of a product or management system. In the case of fertilizer, for instance, a fertilizer retailer may benefit little initially, as long as the IP is still in its infancies. Similar applies to other IP members. It is anyway an open question, if/how IPs could be established broad-scale involving millions of farmers in sub-Saharan Africa; whether market opportunities basically allow this (or whether competition is too large), and whether stakeholders, such as extension services, could handle the stampede in terms of number of staff available. If IP is the concept of choice, that would have to be looked into and most likely a range of policies would have to be changed or new ones created to make IPs successful.

II. Synthesis from an industry-policy-science workshop

A workshop on “*Market-smart interventions to facilitate the availability, access and use of nutrients by smallholders in East and Southern Africa*” was held on 16-17 April 2013 in Harare, Zimbabwe. It was attended by a broad range of participants from international research institutes, NGOs, the fertilizer industry / private sectors and one farmer.

The workshop was divided into four sections: 1) ‘**setting the scene**’, 2) ‘**status of fertilizer use**’, 3) ‘**available experience**’, and 4) ‘**options/possible interventions & implications and the way forward**’. Discussions and group work were facilitated by Edward Chuma from *PICOteam*.

Setting the scene started with the facilitator explaining workshop modalities, people introducing themselves, and the positioning of participants in terms of their gender and profession. Participants then were asked to explain their expectations for the workshop. These ranged from sharing ideas to identifying issues that farmers face, networking, strengthening multidisciplinary, developing communications to policymakers and developing a road map. These expectations were in line with the objectives of the workshop as were agreed upon by the organizers, namely to:

- share information on the status of availability and access of nutrients to smallholder farmers;
- identify information gaps and challenges regarding the availability, and access of nutrients to smallholder farmers;
- propose the design and implementation arrangements of market-smart interventions that improve the availability, and access of nutrients to smallholder farmers, and the incentives required for private investment in input markets;
- identify research questions that could be addressed by researchers regarding the availability, and access of nutrients to smallholder farmers.

The **status-of-fertilizer-use** section comprised two keynote lectures, the first (*Fertilizers and African Agriculture*) presented by Rob Groot (IFDC) and the second (*Fertilizer subsidies – boon or bane?*) by Ademola Braimoh (World Bank). Rob Groot pointed out that there is a huge potential in Africa to increase fertilizer use, as the current use is only approximately 8 kg/ha/yr. He then identified and discussed in detail some of the constraints along the fertilizer supply chain that are responsible for the poor use of fertilizers by farmers in Africa. Ademolah Braimoh highlighted that traditional fertilizer subsidies are costly, inefficient and unsustainable. The lately advocated, so-called, market-smart fertilizer subsidies may be justifiable, if they are part of a broader productivity enhancement strategy.

Subsequently, the group discussed causes for poor adoption of fertilizer, and grouped emerging issues into five domains, namely: Finances, Policy and Legislation, Partnerships and Institutional Arrangements, Appropriate Fertilizer Management Strategies, and Input and Output Markets.

Five keynote lectures addressed **experiences**, institutional arrangements and ongoing activities/projects with the aim to increase the use of fertilizers by smallholders for a sustainable intensification of crop production and alleviation of food insecurity. Cecilia Khupe from Africa Fertilizer Agribusiness Partnership (AFAP) laid out the goals of her organization, i.e. to increase the number of fertilizer users and double the usage in the AFAP countries. Nelson Mango (CIAT) explained the concept of an Innovation Platform (IP); a group of stakeholders that meet on a regular basis with the aim to facilitate the flow of information between producers and market players to collectively identify challenges and opportunities to improve production. John Dimes presented results and outcomes of

an ACIAR-funded project in the Limpopo Province of South Africa that focused on improved fertilizer recommendations and policies for farmers in Southern Africa. The inability of farmers to pay for larger quantities of fertilizer (the usual 50 kg bags) was identified as one major constraint to increased use of fertilizers by farmers. One of the outcomes of the project was that the local fertilizer company (Zimbabwe Fertilizer Company), adopted a new marketing strategy, where fertilizer was sold also in smaller packs (down to 2 kg) to make it affordable to farmers. Zwide Jere (Total LandCare) provided a lecture about the state of agriculture and inputs in Malawi with a focus on fertilizers. In view of the many challenges that the Malawian fertilizer market faces, he suggested possible steps forward, including, among others, the need for smart agriculture technologies, such as conservation agriculture, which increase fertilizer use efficiency. Jenya Shandina (One Acre Fund) presented insights into One Acre Fund, which operates following a simple business strategy, namely purchase inputs in bulk, provide farmers access to inputs (loan based system) and training, and establish distribution networks. OAF currently serves 130,000 farmers in Kenya, Rwanda and Burundi. The farmer loan repayment rate is 98 %. To improve its service OAF relies on partnership, such as with fertilizer companies, government agencies, seed companies and research institutions. In the subsequent group discussion, participants exchange experiences and distilled key lessons from these five presentations. A set of key principles/lessons were identified that are required to increase the use of fertilizer by smallholders: conducive policies, strategic partnerships, appropriate technologies and smart subsidies. It also became obvious that in some cases access and use of fertilizers by smallholders can be achieved by providing farmers with means (credits) to buy the fertilizer, and allowing them to strengthen their stake by the formation of farmers groups.

To develop **ways forward**, the participants then identify options available to address the challenges/ root causes of poor nutrients use. The solution were developed around three topics: **policies**, appropriate **technologies** and **markets**. The Policy group identified the following major stepping stones: smart subsidies, NGO activities, government investment and donor commitment. The Technology group emphasized that to increase fertilizer use, also the issue of fertilizer use efficiency would need to be addressed by developing specific fertilizer recommendations that address crop, soil and farm variability. A general soil map of Africa, soil testing at local level, and the development of a farm-level decision-support tool were the three stepping stones identified by this group. The Market group concluded that the current trading margins for fertilizer are low, and that there is a lack of market information on actual demand; all of which is discouraging fertilizer industries to commit themselves to larger investments. The group agreed that pathways for market-smart interventions could include organizing farmers into economically viable units, the advocacy for policy support, output market development as a driver for the demand side of inputs, and identifying a facilitator to drive the process of output market development. A range of research questions were identified by all three groups.

Farmers' perception was given by Alemayehu Makonnen, commercial farmer from Ethiopia, in the closing lecture on "Farming arrangements and fertilizer use in Ethiopia". He pointed out that the challenges of the fertilizer sector in Ethiopia are related to imports, distribution, lack of regulatory system and distribution mechanisms. The participants evaluated the workshop at the end. They were happy with the proceedings. The main take home message was that one should try to keep solutions as simple as possible (but not any simpler!) and that strategic partnerships are required to facilitate increased fertilizer use in smallholder agriculture.

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