Soil Degradation in sub-Saharan Africa and Crop Production Options for Soil Rehabilitation

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Soil degradation associated with poor soil fertility management practices is a major factor underlying poor agricultural productivity in sub-Saharan Africa. About 65% of the agricultural land is degraded, mainly due to low nutrient application, soil erosion and soil acidification. Increased fertilizer use and balanced nutrient management in combination with various organic matter inputs offer the best prospects to reverse soil degradation.

The Status and Implications of Soil Degradation

Soil degradation is a major challenge that threatens the sustainability of crop and livestock productivity systems worldwide. Soil degradation in cropping systems is driven by suboptimal management practices that induce declines in soil biological, chemical and physical quality, reducing the capacity of the soil to support production and environmental functions. The impact of soil degradation is most severe in sub-Saharan Africa (SSA), where about 65% of the land area is classified as degraded (Vlek et al., 2008). The occurrence of severely degraded soils is very high. It accounts for about 350 million (M) ha or 20 to 25% of the total land area, of which about 100 M ha is estimated to be severely degraded mainly due to agricultural activities. Soil degradation costs SSA approximately US$68bn per year and reduces the regional annual agricultural GDP by 3%. Soil degradation is recognized as a major factor underlying the low crop productivity and high prevalence of malnutrition in SSA (Sanchez, 2002), and affects the livelihoods of the majority of the population that depends directly on agriculture for food and income. Over the past five decades, yields of cereal crops in SSA have stagnated at less than 1.5 t/ha although the yield potential of most crop varieties exceeds 5 t/ha (FAO, 2010). For legumes, yields have stagnated at less than 1 t/ha, although the potential averages more than 2 t/ha. Therefore, as opposed to other regions of the world, the per-capita food production in SSA is decreasing, increasing the levels of food and nutrition insecurity and poverty. Some of the areas experiencing the most rapid degradation are very densely populated areas with favorable climate and relatively fertile soils in much of the highlands of eastern and central Africa (Smaling et al., 1997).

Types and Causes of Soil Degradation

The major soil constraints in SSA include soil acidity and Al toxicity, nutrient depletion, soil erosion, and shallow soils (**Figure 1**). The main factors driving soil degradation in SSA include water erosion, wind erosion, and deterioration of physical, chemical and biological properties (Muchena et al., 2005). Many of the processes of degradation occur concurrently with detrimental effects on biological productivity and the environment under smallholder farmer management practices. Physical degradation covers deforestation and exposure of the

Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; Ca = calcium; Mg = magnesium; Al = aluminum; C = carbon; SOC = soil organic carbon; GDP = gross domestic product.

Land degradation associated with nutrient depletion and poor agronomic practices is widespread in sub-Saharan Africa.

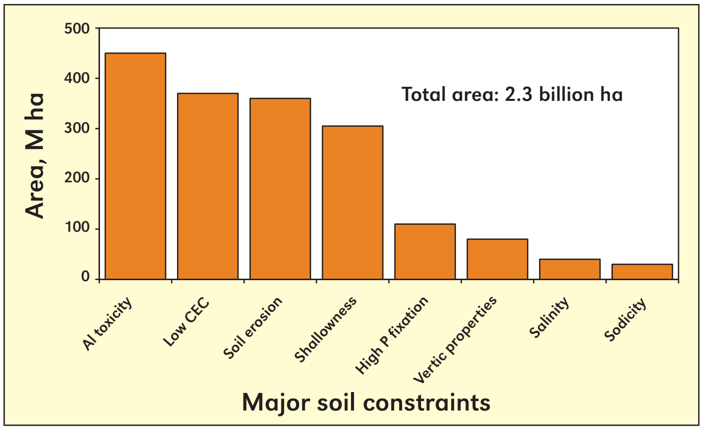

Figure 1. Major soil quality problems in sub-Saharan Africa and their distribution.

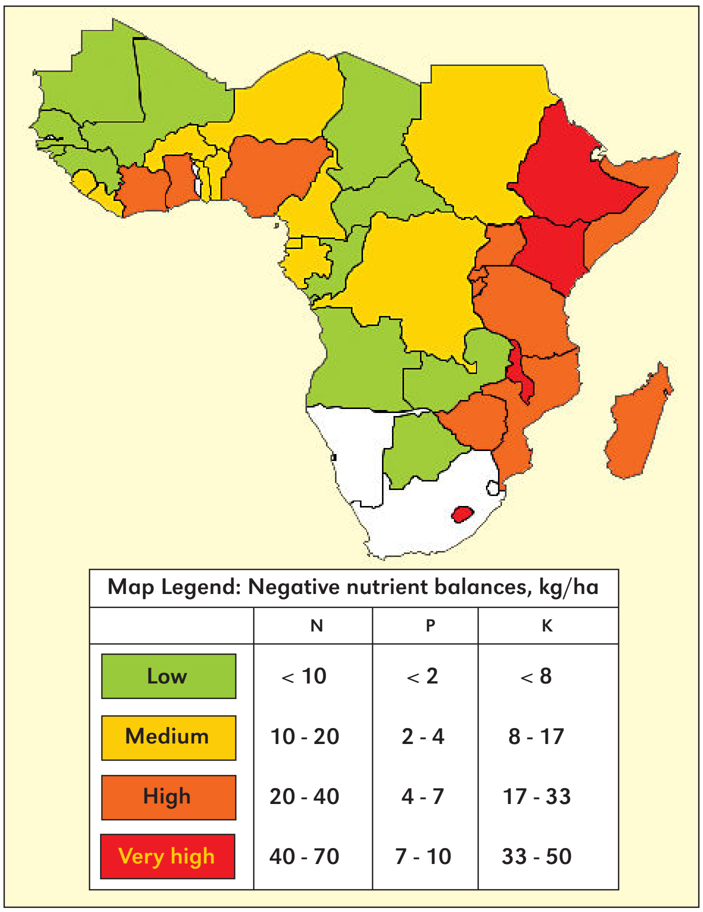

Figure 2. Country-level soil nutrient balances in sub-Saharan Africa.

soil surface to erosion, which leads to the loss of the fertile topsoil. Soil compaction, as a result of excessive soil tillage operations and animal grazing, results in poor crop rooting and water infiltration. Biological degradation is mainly connected to the decline of soil organic matter, which in turn impacts other soil biological, chemical, and physical processes and properties. Chemical degradation includes nutrient depletion and loss of organic matter, salinization, acidification, and chemical pollution.

Sub-Saharan Africa contains some of the oldest and most inherently infertile soils, with many areas characterized by low nutrient contents and soil organic matter, and are highly

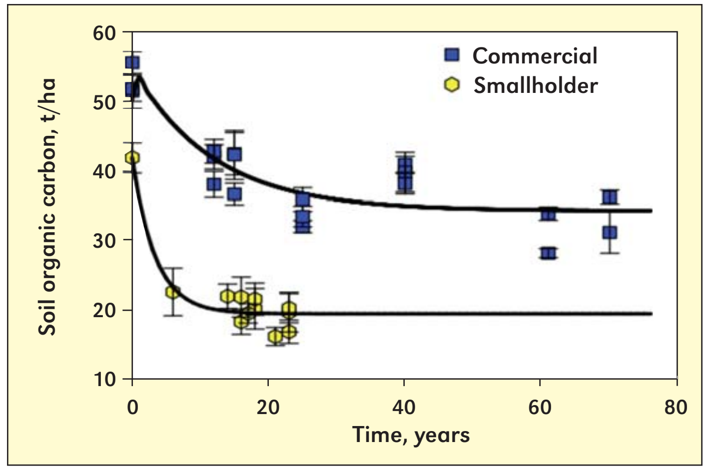

Figure 3. Long-term soil organic matter dynamics in smallholder and commercial farming systems in Zimbabwe (Adapted from Zingore et al., 2005).

susceptible to erosion. The fragile soils are exposed to soil degradation by limited use of both fertilizer (totaling less than 15 kg nutrients per ha) and organic nutrient inputs. Nutrient balances for SSA show overall large negative values, and losses of macronutrients at the country level estimated at 10 to 70 kg N/ha, 2 to 10 kg P/ha, and 8 to 50 kg K/ha annually (Stoorvogel and Smaling, 1998) (**Figure 2**). These large negative balances stem from over-exploitation of soil nutrient stocks as farmers use low levels of nutrients in both organic and inorganic form, coupled with removal of nutrients in harvested produce and losses mainly through erosion.

Long-term changes in soil organic matter and N stocks have been measured where native forestlands were cleared to pave way for food crop production. These soils have shown a rapid decline of >50% of soil organic matter in the initial 10 years of cultivation under low-input smallholder management due to small amount of fertilizer inputs, low crop productivity and removal of stover to feed livestock (**Figure 3**). However, commercial farming with intensive use of mineral fertilizers and incorporation of maize stover led to more gradual decline of soil organic matter. At equilibrium, contents of SOC in a clay soil were 15 t C/ha greater than the contents in similar soils on smallholder farms. Maize yields of 7 to 10 t/ha were sustained, highlighting the importance of good fertilizer management in maintaining yields and environmental sustainability. Low nutrient application and nutrient mining has direct consequences on poor crop growth and concomitant poor aboveground biomass to protect the soils from water and wind erosion, and declining soil organic matter because of limited crop residues available for recycling back to the soil. In studies carried out in central Kenya, soil losses by erosion were very high, up to 200 t/ha (Mutegi et al, 2008). A strong correlation between the rate of soil loss and maize productivity was observed, with maize productivity declining by up to 1.5 t/ha with increasing erosion (**Figure 4**), which represents a seasonal economic loss of more than US$300 per year.

Restoration of Degraded Soils

Lessons from the Green Revolution in other regions globally point to increased fertilizer use, improved crop varieties and irrigation infrastructure as key investments to increased

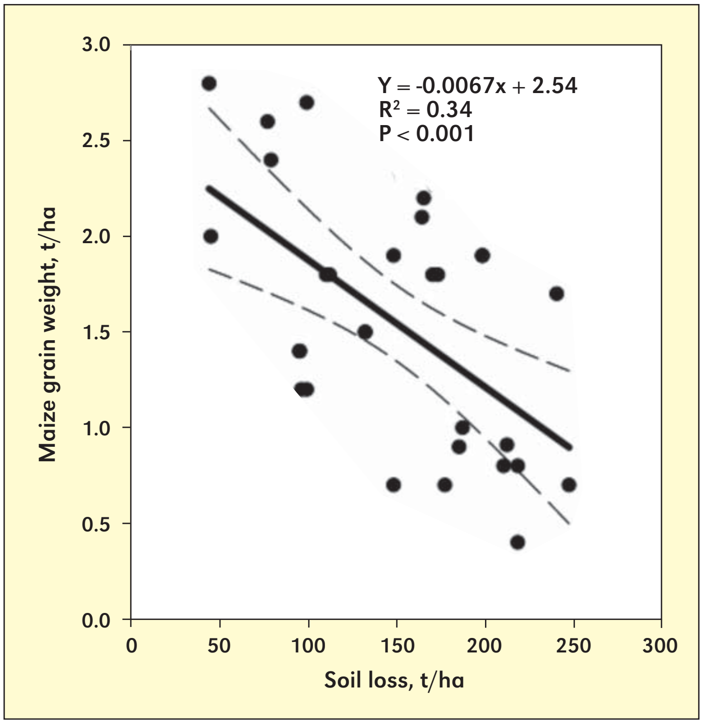

Figure 4. Relationship between soil losses and maize productivity in central highlands of Kenya (adapted from Mutegi et al., 2008).

crop productivity. In the SSA context, efforts to intensify crop production will first require rehabilitation of large areas of degraded soils. Although N and P are considered as the main yield-limiting nutrients in SSA, optimal productivity with N and P fertilizer is only possible in small areas with non-degraded soils. Increasing severity of soil degradation results in the progression of constraints to crop production, in turn increasing the complexity of soil fertility management options required to increase land productivity.

In moderately degraded soils, where multiple nutrient deficiencies are the overriding constraint, yields can be readily increased by balanced application of base cations (K, Mg and Ca) and micronutrients. Integrated soil fertility management (ISFM) provides a framework where both organic and inorganic fertilizers can be provided to the soils to improve soil fertility and boost soil organic C (Vanlauwe et al., 2010). Among the common ISFM practices in SSA are intercropping and rotation of cereals with legumes, manure application, and application of both organic and inorganic materials either simultaneously or sequentially to the same crops. The inclusion of legumes in cereal systems allows cereals to benefit from the N that is fixed by legumes. This enables better crop production, enhancement of soil fertility, and availability of more above and belowground biomass for transfer to the croplands. Furthermore, deep-rooting cover crops capture nutrients that leach and accumulate below the top soil, enabling recycling of nutrients when such cover crops are incorporated into the soil. With increased biomass production, crop residues become available to increase soil organic matter. The main limitations with use of compost and animal manures are low availability and poor quality. Application of the right quality and quantity of lime is also required in soils affected by soil acidity and Al toxicity.

A major challenge exists in restoring productivity of severely degraded soils that respond poorly to nutrient application due to multiple chemical, physical, and/or biological constraints interacting with each other. Under such conditions, multi-purpose options addressing several constraints have been shown to be able to rehabilitate non-responsiveness, but most of the time only after a number of years of increasing soil organic matter to increase retention of soil nutrients and water, improve soil structure, and improvement of soil health through increased soil biodiversity. Zingore et al. (2007) showed that on degraded sandy soils in Zimbabwe, annual application of fertilizer in combination with at least 10 t/ha of animal manure for three years was required to significantly increase crop productivity. Research on the use of biochar is still young, but there is potential to reverse degradation with its use, although this requires large amounts of organic resources that is still a challenge in SSA except in some localized zones (e.g., rice-growing areas).

Other legume-based technologies to restore severely degraded soils include deep-rooting hedgerow trees, green manures and legume crops adapted to marginal soil conditions; although these have also been shown to require multiple seasons to increase yields substantially. The dilemma for restoration of degraded soils in SSA is that the problem mostly affects poor farms with very limited access to fertilizer and manure. These farms have very limited land to spare for rehabilitation using technologies that do not contribute directly to food production. The potential to produce crops under degraded conditions is therefore a challenge. Although breeding of efficient genotypes may also be feasible, its potential to address food security under severe soil degradation where multiple limitations are at play, is not yet clear. BC

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