CAPACITY OF AFRICA'S SOILS TO SUSTAIN OR EXTEND CURRENT CROP AND ANIMAL PRODUCTION

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1. Introduction

As populations increase, available land for agricultural production and grazing decreases. All land on the African continent that is classified as very suitable for cultivation is already under cultivation. Such pressures are forcing farmers to utilize marginal lands or to intensify their agricultural production. Cultivation of marginal lands increases the risks of land degradation through deforestation, water and wind erosion, leaching and physical and biological degradation.

Avoiding the continued cultivation of more and more marginal land to meet the ever-increasing demand for food and livestock production will only be possible through intensification of existing farming systems. Changes associated with intensification of farming will affect the options open to farmers to maintain soil fertility; fallow periods are reduced or removed altogether from the production system and continuous crop production results. Therefore, the maintenance of soil fertility through additions of organic and/or inorganic fertilizers to the soil becomes a critical issue within the farming system. However, the confinement of livestock to smaller grazing areas during the cropping season and grazing of crop residues on exposed soils increases the risk of overgrazing and environmental degradation, and results in changes to the spatial and temporal arrangements within livestock production systems.

One of the factors driving agricultural development and policy interventions in Africa is the recognition that soil fertility depletion is a major biophysical limitation to crop production. Many scientific and popular publications have portrayed Africa as having vast areas of degraded agricultural land whose soils are infertile, and often incapable of sustained agricultural production. It has been hypothesized that traditional agricultural production systems and technologies promote soil fertility depletion and subsequent land degradation, and cannot sustain high crop yields on smallholder farms.

These concepts are based on (i) average levels of crop productivity; (ii) broad soil genesis-based soil fertility descriptors, (iii) available soil and plant tissue analytical data sets, and (iv) extrapolated nutrient budget and balance data. These arguments are true in aggregate, but not universally, because of the vast diversity of soils in Africa. On those soils with superior fertility there are sustainable soil management and cropping systems. Nevertheless, these are not sufficient to overcome Africa's food needs. Therefore, sustainable crop and livestock production in Africa is not an option but a goal necessitating development and adoption of technologies that serve to modify production capacities of the poorer soils. There already are some good examples of potential soil management systems that could be deployed in many agro-ecosystems in sub-Saharan Africa to sustain or extend crop and animal production.

2. Current agricultural production in sub-Saharan Africa

Africa is characterized by diverse agricultural systems that are typically low input and based on subsistence farming. The traditional shifting cultivation and rotational systems have increasingly been disbanded as population and pressures for land use increase. To meet the ever increasing demand for food, more land has been brought into production, often at the expense of dwindling forest reserves and marginal lands (e.g. between 1948 and 1981, the proportion of land area cropped increased in Machakos, Kenya from 35 to 81%). Such practices increase the risk of degradation through erosion, leaching and physical and biological degradation if the reclaimed land is put to an inappropriate use. For example soil loss during the peak of a rainy season from a cultivated maize field (20% slope) in the Ethiopian highlands has been estimated to be 19.5 t ha^{-1} compared to 0.02 t ha^{-1} from a pasture (25% slope) and a four year old Juniper forest (65% slope). Where there is no more land to bring into production, there has been a notable increase in the frequency with which land is cultivated, loosely defined as permanent intensive cultivation, an ultimate post-traditional agriculture practice. Sometimes this is combined with livestock production.

Presently, grain yields per unit of land in African countries are low, averaging hardly 25% of the potential production levels, or those commonly obtained in countries with developed agricultural systems such as the USA, as illustrated in Table 1. The Food and Agriculture Organization (FAO) of the United Nations has attributed the low productivity to instability and conflict, as has been raging in Mozambique, poor governance, erratic weather, poverty, agricultural failure, population pressure and fragile ecosystems (including soils). The trends of crop production in the African countries depicted in Table 1 do not give any indication of change from traditional shifting and rotation farming systems (considered environmental friendly and soil rejuvenating) to agricultural intensification. In addition to global limitations to production, Table 2 illustrates the type of constraints that obtain at the farm level. Farmers appear to practice sensible land management, and the continued low yields must be attributed to the limited capacity of their economic and environmental resource base. We consider that soils are but one of several elements that interact at a particular time and location to ensure sustainable agricultural systems. There is need for knowledge and understanding of these elements, because removing one constraint will not result in increased productivity unless the others are also addressed.

	1950 - 52	**1983 - 85**	**1989 - 91**	**1997**
Nigeria	760	714	1076	1185
Mozambique	620	545	375	861
Tanzania	1271	1091	1316	1053
Sudan	780	479	440	569
South Africa	ND	ND	2209	1883
USA	ND	ND	6038	6983

Calculated from FAO production statistics

Table 1. Grain yields per hectare in some African countries and in the USA, showing yield trends between 1950-1997

Farm statistics	
Average farm size	2.3 ha
Household members	4 adults, 6 children
Principal crops	maize, beans, potatoes, vegetables, coffee
Farm animals	5 cattle, 3 goat, 2 swine, 15 poultry
Reported crop yields (kg ha^{-1})	maize 1420; beans 675; 3800 potatoes
Farm management practices	
Apply animal manures	96%
Feed crop residues to livestock	92%
Apply inorganic fertilizers	82%
Combine organic and inorganic fertilizers	72%
Produce domestic compost	32%
Production constraints	
Availability of labor	98%
Pests, diseases, wildlife	82%
Market access and input costs	64%
Poor soil conditions	32%

Table 2. A soil-fertility management biased profile of smallholder farming in the Central Kenyan Highlands. Results of interviews of 50 farming households in Kiambu District.

3. Soils

Soil characteristics are the key element in determining the productivity of the land, and these differ widely as a result of different parent materials and pedogenesis. Africa has a high proportion of its land in predominantly old soils (see Table 3).

The major soils have largely lost their weatherable minerals over aeons of exposure to the elements, resulting in acidic or poorly buffered soils that are difficult to manage under long-term cultivation because their fertility is largely stored in the fragile organic matter fraction.

So, why are poor soil conditions ranked as the least constraint in Table 2? Soil fertility depletion is a less obvious but pervasive background constraint, and farmers often give it low priority relative to problems that may occur sporadically but with dramatic effects.

Soil order		**Coverage %**	**Brief description**
USDA Taxonomy	**FAO/UNESCO equivalent(s)**		
Aridisols	Yermosols, Xerosols	34	Semi-desert or desert soils with weak ochric A horizons. Soil organic matter less than 1%
Oxisols	Ferralsols	22	Strongly weathered, deep, red/yellowish red/yellow soils of the humid tropics with sesquioxides and kaolinitic clays. CEC<16me/100 g clay and oxic B horizons.
Alfisols	Nitisols, some Luvisols	22	Deep clayey, often reddish brown soils with argillic B horizons. Still have some weatherable minerals. Base saturation of B horizon >50%
Entisols	Fluvisols, Regosols, some Gleysols	12	Recent alluvial soils; weakly developed, lack diagnostic horizons.
Ultisols	Acrisols	4	Acid, low base status soils of warm temperature regimes. Base saturation of the B horizon <50
Inceptisols	Andosols, Cambisols	3	Mainly soils derived from recent volcanic deposits
Vertisols	Vertisols	2	Dark montmorillonite-rich clays to >30 cm. Deep and wide cracks in dry season, have gilgai relief and slickensides in subsoil

Table 3. Major soil orders in Africa: their coverage and characteristics.

Characteristic	**Oxisol (Ferralsol)**		**Alfisol (Luvisols, some Nitisols)**	
	Ustic/Xeric	**Udic**	**Ustic/Xeric**	**Udic**
Constraints – soil qualities				
Water holding capacity	xxxxx	xxxxx	xxxxx	xxxxx
Nutrient retention capacity	xxxxx	xxxxx	xxxxx	xxxxx
Nutrient availability	xxxxx	xxxxx	xxxxx	xxxxx
Phosphorus fixation	xxxx	xxxx	x	x
Chemical constraint	xxx	xx	x	x
Physical constraints	xxxx	xx	x	x
Effective soil volume	x	x	xxxxx	xxxxx
Tilth	x	x	xxxxx	xxxxx
Erodibility	xxx	x	xxxx	xxx

Water logging	x	x	x	x
Management options				
Shifting cultivation	xxxxx	xxxxx	xxx	xxxx
Annuals	x	x	xxxxx	xxxx
Perennials	xx	xxxxx	xxx	xxxxx
Agrofroestry	xxxxx	x	xxxxx	xxxx
Forestry	xxxxx	xxxx	xx	xxx
Nutrients	xxxxx	xxxxx	x	xx

* x indicates relative importance to sustainability: x very low to xxxxx very high.

Table 4. The importance of soil qualities and management options of two dominant African soils on agricultural sustainability (adapted from Eswaran et al, 1993).

The characteristics of two soil types on which most of the farming is done show that several soil qualities are limiting to agricultural sustainability but their relative importance varies with soil order and moisture regime (Table 4). The Alfisols have fewer limitations and thus have higher probability of attaining sustainability even under low-input systems.

The dominant constraints are nutrient availability and retention capacity, and water holding capacity. Consequently, the management options that are of importance to sustainability directly or indirectly promote these soil qualities, and are key to sustaining or extending crop and livestock production in Africa.

Within each broad soil order, there can be vast fertility diversity that needs to be captured at the level of detailed soil maps in order to design appropriate soil management systems. On a 220 ha farm at Kabanyolo, Uganda, for example, three major soils, Oxisols, Alfisols and Inceptisols, have been mapped.

Their distribution and properties are related to relief, one of the soil formation factors. For smallholder faming, the different soils would likely require different management techniques for sustainable agricultural production.

It has been proposed that inventorying of such diversities in form of Major Land Resource Area (MLRA) maps at national level is necessary:

- As a basis for making decisions about agricultural issues;
- As a framework for organizing and conducting resource intervention programs;
- For geographic organization of research and conservation needs and of the data from these activities;
- For coordinating technical guides among states and districts of a nation, and between countries;
- For organizing, displaying, and using data in physical resource inventories; and
- For aggregation of natural resource data.

Such databases will be increasingly necessary as site-specific management demands grow for crop and livestock production on Africa's soils. Once response patterns have been established and understood, they can serve to develop models for sustainable management of the land resources.

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Biographical Sketches

Mateete Bekunda is Dean, Faculty of Agriculture and Associate Professor of Soil Science at Makerere University, Uganda. Dr Bekunda's teaching responsibilities have been in tropical soil fertility as well as soil and plant analysis. His research interests have been in the integrated management of soil fertility for optimal productivity in low-input smallholder agriculture, supervising research of more than 20 graduate students in the process and collaborating with institutions like the Tropical Soil Biology and Fertility Programme, IAEA, and the African Highlands Initiative.

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