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Review

Soil fertility restoration techniques in sub-Saharan Africa using organic resources

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Food security concerns are currently escalating in sub-Saharan Africa (SSA) due to poor soil management practices on the fragile soils. This review describes the role of organic resources acting both as amendments and fertilizers in improving soil nutrient status and productivity potentials in SSA. The use of organic resources has achieved significant strides in improving soil fertility in many agro-ecological zones in SSA. Balanced fertilization of soils through synchronized supply of adequate nutrients to growing crops as well as increasing soil organic matter content over the long term are major gains realized through application of organic resources. Constraints that limit utilization of organic based soil nutrient management systems were also highlighted; with the conclusion that more committed research activity and better adoption of developed technologies would lead to promotion and establishment of the gains of procuring and utilizing organic resources for soil fertility improvement in SSA.

Key words: Organic resources, soil fertility, soil organic matter, food security, soil management.

INTRODUCTION

The need to meet ever increasing nutrition demands of the expanding human populations makes sustainable agriculture and agro-based sectors a front burner environmental and social development issue in sub-Saharan Africa. Soils are an integral component of agriculture and serve as medium for numerous eco-biological, chemical and physical processes. Over burdening of the soil as a natural resource capital has always been an issue due to its widely varied applications in the maintenance of human life activities. The need thus to effectively manage soil resources in order to achieve optimum productivity of soils is obvious. The goal of sound soil management is to create a healthy soil environment which may retain balanced nutrient status such that its fertility is maintained over time.

Soils in Africa are typically highly variable in fertility and in how they respond to inputs (Hossner and Juo, 1999; AGRA, 2007). Most soil resources in Africa exhibit low nutrient levels with a high propensity towards nutrient loss due to their fragile nature (van Wambeke, 1991; Lal, 1993; Juo and Wilding, 1996). Cultivated highly weathered soils in the tropics have also been observed to commonly suffer from multiple nutrient deficiencies and nutrient balances are generally negative (Tandon, 1993; Mokwunye et al., 1996). Soil nutrient depletion and likely degradation have been considered serious threats to agricultural productivity and have been identified as major causes of decreased crop yields and per capita food production in SSA (Henao and Baanante, 2006). A World Bank report estimated the rate of cereal yield increase in Africa over the years at a very low rate of 0.7% compared to growth rates in other developing regions of the world of 1.2 - 2.3% (AGRA, 2007). This trend of poor crop performances may be responsible for the dwindling confidence of the general citizenry of many countries in SSA in their governments' ability to ensure adequate food security. Neglect of local agricultural production has led to steady and unprecedented increase in food prices, resulting in a situation wherein essential food commodities are not readily available to the citizenry. Improving local agricultural production and ensuring adequate supply to the general populace is a vital step in preventing a total col- lapse of the food production and supply sector of the economies of developing countries of SSA.

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This review highlights recent advances in soil fertility improvement in countries of SSA through the employment of organic residues/resources. There is need to better understand the dynamics of employing various nutrient sources for the purposes of soil fertility improvement in order for agricultural production to be sustained on local soil resources in SSA.

Soil fertility decline trends in sub-Saharan Africa (SSA)

Health of African soils has become a constant challenge for farmers and agriculturists in the continent. Conflicting interests in the exploitation of soil resources by various stakeholders has led to mismanagement; and in some cases degradation of soils. In recent decades, unsustainable land cultivation practices (e.g. inadequate replacement of soil nutrients taken up by crops) have led to accelerated depletion of the natural soil base available for food production (Hossner and Juo, 1999). Soil productivity maintenance remains a major environmental issue in countries of SSA (Oyetunji et al., 2001). Low soil fertility inevitably leads to low agricultural productivity, since agricultural development is fundamentally affected by productivity status of land resources. Poor soil management and the fragile nature of tropical soils generally account for heavy nutrient losses through soil erosion and nutrient leaching in soils (Hossner and Juo, 1999). In countries of SSA, unsuitable soil management activities including deforestation, indiscriminate vegetation removal, overgrazing and use of marginal lands for agricultural purposes often precedes eventual degradation of soil resources and environmental damage (Henao and Baanante, 2006). Poor cultivation practices have resulted in decrease of soil fertility, reduction of soil organic matter (SOM), and increase in occurrence of acidified soils (Aihou et al., 1998). Decline in soil fertility as a result of land degradation decreases farmland productivity (Amede, 2003). Escalating rates of soil nutrient mining makes nutrient losses highly variable in agricultural areas of sub- humid and humid savannas of West Africa, where they range from moderate to severe loss of nutrients (Henao and Baanante, 2006). Smaling (1993) estimated that annual net nutrient depletion rates per hectare exceeded 30 kg N and 20 kg K in arable soils of several countries in SSA. In many parts of SSA where poor soil conservation methods prevail, long term productivity of soil is projected to decline considerably unless soil management practices improve.

Proper soil conservation becomes imperative when considering issues regarding soil fertility improvement in SSA. This becomes evident in the light that the lives of a greater percentage of the populace in the region are directly connected to agriculture and agricultural based Industries. Sustainable agricultural production incorporates the notion that natural resources be used to increase agricultural output and income without depleting the natural resource base (Gruhn et al., 2000). Effective soil management ensures nutrient conservation in soils and can lead to steady reclamation of degraded lands in sub-Saharan Africa over long term.

Major soil degrading factors in sub-Saharan Africa (SSA)

Human based and physico-climatic factors are among principal factors affecting soil productivity potential of soil resources in SSA. Indiscriminate activities often carried out in direct relation to the soil include continuous crop-ping, haphazard logging, vegetation removal, and uncontrolled bush burning practices. For instance, continuous cropping practices in Alfisols, Oxisols and Ultisols found in the tropics of SSA have resulted in rapid nutrient decline in soil organic matter (SOM) of surface soils during first few years following land clearing (Juo et al., 1995). Continuous cropping has also been observed to cause significant decline in soil pH and exchangeable Ca and Mg levels in soils (Hossner and Juo, 1999). Decline of crop yields under continuous cultivation has been attributed to factors such as acidification, soil compaction and loss of SOM (Juo et al., 1995). Woomer et al. (1992) also reported that continuous cropping with its associated till- age practices provokes an initial rapid decline in SOM which then stabilizes at low levels. Uncontrolled and repeated burning activities have negative impacts on soil microenvironment including acceleration of erosion and destruction of beneficial microorganisms such as earth-worms and termites. The phenomenon of bush burning which commonly occurs as a soil management system in SSA may thus contribute significantly to the soil fertility depletion (Hossner and Juo, 1999). According to Ayoola and Adeniyan (2006), the bush fallow system has been in use as a soil fertility management practice in the tropics; but this has also become unsustainable due to high population pressure on cropland resources for other human activities. Intensified cropping activities on available cropland resources have resulted in alteration of their natural physical and chemical properties, changes in biotic components of their microenvironment and an overall reduction in fertility status. Uncontrolled removal and cutting down of natural vegetation also have pronounced negative impact on soil systems in SSA. These comprise deterioration of soil physical structure and conditions through crusting and surface sealing, compaction and formation of restrictive layer in the soil profile. Such soils become more vulnerable to natural disasters such as wind and water erosion; which if left unchecked can lead to large-scale degradation of soils.

The natural physical and chemical features of soils in relation with the weather/climatic patterns also contribute significantly to the observed trend of soil fertility decline of countries in SSA. The main factors contributing to soil nutrient depletion through physico-climatic processes in tropical Africa and particularly SSA, are generally loss of nitrogen (N) and phosphorus (P) through wind and water erosion; as well as leaching away of N and potassium (Amede, 2003; Henao and Baanante, 2006). High intensity, short duration and large year to year variations in annual precipitation can also contribute to soil fertility decline in semi-arid countries of SSA (Sivakumar, 1987). Moreover, sunshine intensity is high in these areas with occurrence of high velocity winds as regular environmental phenomena. Sandy Entisols and Alfisols, the major soil types in this region, are weakly structured with low soil organic matter content and low water holding capacity. These especially are prone to wind and water erosion (Sivakumar et al., 1992; Deckers, 1993).

Organic resources utilization for soil fertility improvement in SSA

The use of organic resources for soil fertility improvement in SSA has been in practice since earliest times; though the strategies by which these materials were applied may differ from recent conventional methods through technology development and adaptive strategies to meet peculiar modern needs. Following widespread popularity of inorganic fertilizer sources used in agriculture since the 1940's, the use of inorganic fertilizer became the natural complementary option that received the attention of agriculturists in an effort to boost soil productivity. This has achieved a considerable level of success over the years by increasing crop production at accelerated and balanced rates. However, application of inorganic fertilizers has also faced important limitations due to high costs, highly variable nature of soils and inherent low nutrient conversion efficiency (AGRA, 2007). Average fertilizer use rates for countries in SSA are considered too low and ineffective for sustaining crop and soil fertility maintenance (Gruhn et al., 2000). Alternative sources of nutrients are already being sought in several areas in Africa where soil fertility needs to be rebuilt and high cost and supply quantities limit inorganic fertilizer application. There is growing need to develop techniques for improving soil fertility without causing damage to the environment (Topliantz et al., 2005). Organic resources have been identified as reliable alternatives to reduce continued large scale use of inorganic fertilizers and have found great application in agricultural development of SSA due to relatively easy access and easy procurement from the local environments. Common organic nutrient sources in tropical SSA include plant (crop) residues, leguminous cover crops, green manures, animal manure, mulches and household wastes (Hossner and Juo, 1999). These organic materials contribute directly to the building of soil organic matter (SOM), which itself performs diver- se functionary roles in improving the physical, chemical and biological composition of the soil. The maintenance and management of SOM are central to sustaining soil fertility on smallholder farms in SSA (Woomer and Swift, 1994). In low input agricultural systems, SOM helps to retain mineral nutrients in the soil; making them available to plants over many years in small amounts as it is mineralized (Kumwenda et al., 1996). In addition, SOM in soils include improves soil structure, increases water holding capacity of soils, increases cation retention capacity (CEC) of soils and increases capacity of low activity clay soils to buffer changes in pH (Woomer et al., 1994; Hossner and Juo, 1999).

The application of organic materials to soils have been shown to enhance crop yields, whereby yield increases varied with agro-ecological setting and rates of amendments applied (Schlecht et al., 2006). The success of applying organic materials in the tropics is due to higher decomposition rates (3 - 5 times) of plant residues and soil organic matter in humid tropical environments than under temperate conditions (Mueller-Harvey et al., 1985). Organic materials have also been observed to increase microbial biomass and activity in soils (Fraser et al.,1988; Vinten et al., 2002); which suggests a more responsive microbial community in such soils. The application of organic residues has also been shown to decrease incidence and abundance of Striga weed aside from improving soil fertility status (Esilaba et al., 2000). The use of organic manures generally ensures effective and efficient management of soil by providing nutrients in correct quantity and proportion in environmentally beneficial forms (Gruhn et al., 2000). Farmyard manure can also improve nutrient and water use efficiency as well as yields of common crops in the humid/ sub humid transition zones of SSA (Juo and Kang, 1989).

Figures 1 and 2 show the results of experimental studies in western Kenya where plant residues of Tithonia diversifolia (Hemsl.) A. Gray was observed to increase mineral N content of soils and increase maize yields comparably to inorganic fertilizer (Ayuke et al., 2004). Conway and Barbier (1990) identified that improved soil management techniques and green manures application improved the yield of potato crops as against over application of chemical fertilizers which gave reduced yields. Timely applications of organic materials with low C:N ratios such as green manures and compost can synchronize nutrient release with plant demand and minimize the amount of inorganic fertilizer needed to sustain high crop yields for short cycle cropssuch as maize, rice and soy- bean; all of which have a high nutrient demand (Lathwell, 1990; Burle, 1992). Organic residues with high C:N ratios often have soil fauna

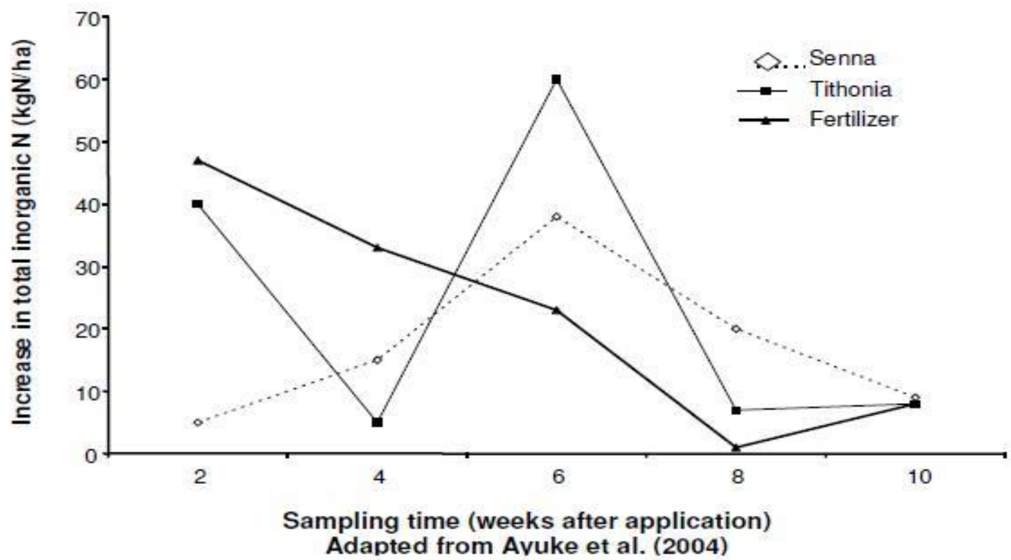

Figure 1. Increase in mineral nitrogen (total mineral nitrogen in the top 0 - 30 cm soil depth) above the control (no input) over 12 weeks under different inputs of organic and inorganic nutrient sources.

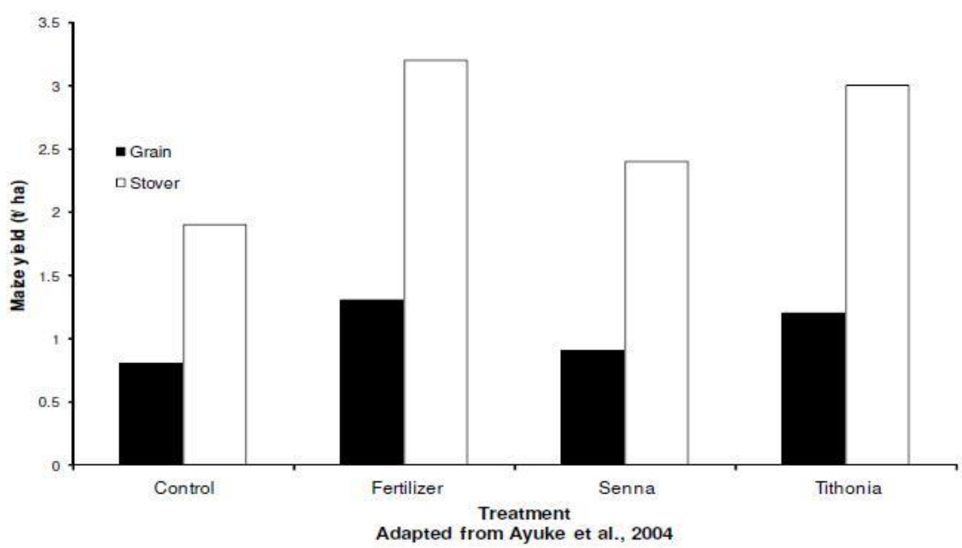

Figure 2. Maize yields affected by organic residues and fertilizer compared with no input during 1997 short rains in Western Kenya.

playing a greater role in their decomposition compared to those with lower C:N ratio and high water content in their tissues (Ayuke et al., 2004). Organic residues have also been found to reduce P sorption capacity of soils and increase crop yields in P limiting soils (Nziguheba et al., 1998). Chukwuka and Omotayo (2008) showed in their study (Table 1) that the application of green manures as soil amendments improved the physical properties and chemical nutrients in nutrient depleted soil. Soil microbial communities have also been shown to benefit from specific farming techniques, including application of green manures to the agricultural soil system (Bossio et al., 1998). This agrees with observations of Stark et al. (2005) that addition of green manures to soil improved soil and increased microbial biomass and activity in them.

Crop residues have also been found very successful in improving soil fertility in SSA. Crop residues utilization and application is similar to that of green manures and

Table 1. Top and subsoil Nutrient Analyses before amendment.

Soil Type	Clay (%)	Silt (%)	Sand (%)	pH in water	Org. C (%)	Ca C mol kg^{-1}	Mg C mol kg^{-1}	K C mol kg^{-1}	Na C mol kg^{-1}
Top Soil	21.0	12.01	68.03	7.4	3.29	30.81	3.02	1.08	0.59
Subsoil	33.1	10.04	56.90	5.5	2.09	5.14	1.51	0.78	0.73
Soil Type	Exchangeable acidity	ECEC ppm	P ppm	Zn ppm	Cu ppm	Mn ppm	Fe ppm	NO_3^-N ppm	NH_4^- N ppm
Top Soil	0.17	33.80	55.62	2.66	3.02	230.78	115.92	10.68	28.90
Sub Soil	0.17	8.33	23.83	1.61	2.38	79.18	77.52	6.16	11.72

ECEC- Effective Cation Exchange Capacity. Source: Chukwuka and Omotayo (2008).

Table 2. Top soil nutrient analyses after amendment with Tithonia green manure and water hyacinth compost.

Treatments	Ca Cmol kg^{-1}	Mg Cmol kg^{-1}	K Cmol kg^{-1}	Na Cmol kg^{-1}	Exch. Acidity	ECEC	Mn ppm	Fe ppm	Zn ppm	Cu ppm	P ppm
A [Tith.1kg]	53.62	7.54	3.11	1.06	0.43	65.76	266.15	103.28	2.84	3.29	97.43
B [W.H.1kg]	49.71	6.86	2.94	1.01	0.39	60.51	271.54	115.69	3.01	3.27	98.56
C [Tith+W.H.0.5kg:0.5kg]	51.93	7.36	3.09	1.28	0.41	65.07	256.81	107.82	2.79	3.36	89.35
D [Tith+W.H.0.25kg:0.75kg]	56.49	7.28	3.17	1.33	0.41	68.07	263.1	105.66	2.83	3.29	91.86
E [Tith+W.H. 0.75kg:0.25kg]	48.33	6.91	2.78	0.98	0.38	59.38	269.32	104.33	2.79	3.18	95.57

ECEC- Effective Cation Exchange Capacity, Tith.- Tithonia green manure, W.H.- Water hyacinth compost. Source: Chukwuka and Omotayo (2008).

cover crops use in soil fertility management; except that crop residues usually contain far less residual nutrients (e.g. N) relative to green manure crops or legume cover crop species. Thus, their main action in building soil fertility is adding organic matter to the soil which eventually helps to improve the overall nutrient status of such soils. Studies in south-eastern Nigeria by Oguike et al. (2006) showed rice mill waste utilized as soil amendment displaying relatively higher potentials in improving physico-chemical properties of nutrient depleted Haplic Acrisols compared to NPK fertilizer (Tables 2 and 3). Earlier findings by Mbagwu and Piccolo (1989) also clearly demonstrated that repeated application of organic residues to soil improves physico-chemical properties of tropical agricultural soils in SSA.

Constraints facing organic fertilizers use in sub- Saharan Africa

Decline in soil fertility in SSA is largely attributable to poor soil management practices as earlier stressed; but this is in turn made worse by other factors such as inappropriate land use policies in most developing SSA countries, insufficient commitment to investment in agricultural research, falling agricultural prices, land availability constraints and w ill defined property rights (Gruhn et al., 2000). These factors also generally affect the applicability of any soil nutrient management system practiced in the region, whether organic or inorganic resource based. Some of the most important constraints limiting development of organic based soil nutrient management systems in tropical SSA include utilization of large labor force required for both processing and transporting of organic materials in bulk quantities as well as large amounts of organic residues often needed to supply adequate nutrients to soils for successful crop production (Palm et al., 1997).

Table 3. Subsoil soil nutrient analyses after amendment with Tithonia green manure and water hyacinth compost.

Treatments	Ca Cmol kg^{-1}	Mg Cmol kg^{-1}	K Cmol kg^{-1}	Na Cmol kg^{-1}	Exch. Acidity	ECEC	Mn ppm	Fe ppm	Zn ppm	Cu ppm	P ppm
A [Tith.1kg]	26.41	3.67	1.43	0.76	0.29	32.58	153.89	89.36	2.04	2.81	61.50
B [W.H.1kg]	26.39	4.05	1.46	0.81	0.31	33.02	144.36	84.67	1.93	2.66	59.83
C [Tith+W.H.0.5kg:0.5kg]	25.58	3.29	1.27	0.83	0.28	31.25	98.97	91.35	1.89	2.74	63.34
D [Tith+W.H.0.25kg:0.75kg]	30.01	3.74	1.29	0.82	0.29	36.15	115.38	87.64	2.07	2.83	62.09
E [Tith+W.H. 0.75kg:0.25kg]	26.59	4.01	1.48	0.88	0.30	33.23	152.11	90.14	1.11	2.79	58.66

Exch. Acidity- Exchangeable Acidity, ECEC- Effective Cation Exchange Capacity, Tith.- Tithonia green manure, W.H.- Water hyacinth compost. Source: Chukwuka and Omotayo (2008).

Adequate management of low quality, slowly decomposing organic residues to adjust to growing crop requirements also poses a great challenge. Leaching of nutrients due to erosion also poses as an important problem especially when using high quality, fast decomposing organic resources such as Tithonia, Crotolaria and Sesbania spp. Acceptability and practical application of organic based systems on large-scale basis by local farmers are yet to be fully adopted as a result of farmers' reluctance to change from familiar methods of soil nutrient management to newer methods. Other constraints include prioritization of use of organic resources in local farmland systems other than soil fertility improvement, lack of supportive institutions, harsh climatic conditions in some agro-ecosystems of SSA (Lele, 1994; Bumb and Baanante, 1996; Meertens, 2003; Chianu and Tsujii, 2005). The future of organic nutrient resource management lies in using isotopic tracers (^{15}N and ^{32}P) in order to measure supply of major elements (N and P) from various organic sources in a wide variety of environments (IAEA, 2003). Better farmer's education, support of local governments and improved logistics are also top priority concerns for sustainable future efforts in proper soil management for countries in sub-Saharan Africa (SSA).

CONCLUSION

Fully exploiting the potentials of organic based systems in tropical sub-Saharan Africa for the purposes of soil fertility improvement in this region will go a long way in addressing the food security concerns on the African continent. This is due to the fact that this region is richly endowed with abundant agricultural potential (both human capital and soil resources). The following recommendations when implemented will help greatly in overcoming the challenge of soil fertility depletion in countries of SSA:

i.) Development of participatory policies wherein governments can effectively partner with local farmers to achieve sustainable soil management through appropriate technologies.
ii.) Greater and more efficient utilization of vast wealth of information from previously executed organic based projects to meet the needs of all stakeholders in agricultural development.
iii.) Establishment of more trial farms and researcher- managed organic based systems in various regions of the country.
iv.) Continued investment in agricultural research to propel development of yield enhancing technologies through organic based systems.

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