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Soil Fertility Depletion and Its Management Options under Crop Production Perspectives in Ethiopia: A Review

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ABSTRACT

Soil is a non-renewable or finite resource and is the bank of nutrients for plant growth. Most soils in the tropical region including Ethiopia are highly weathered and infertile due to lower organic matter content and open nutrient cycling systems. These led to soil fertility depletion and crop productivity reduction in the country by different soil degradation agents. Therefore, the objective of this paper is to review soil fertility depletions and its management options under crop production perspectives in Ethiopia. The major drivers of soil fertility depletion are population pressure, land use pattern, free grazing of animals, lack of energy sources, land ownership and poor government policy problems. The major causes of soil fertility depletion are inadequate fertilizer use, complete removal of crop residues, continuous cropping systems, climate and soil types, lack of proper cropping systems and soil erosion and continuous cultivation. The promising technologies for improving soil fertility are integrated nutrient management, crop residue management, green manuring and cropping sequences, management of farmyard manure, applications of chemical fertilizers and soil amendments, agroforestry practices, applying conservation agriculture and application of soil-water conservation practices. Therefore, it needs a great attention by the community and the government to use innovative soil fertility management options to sustain soil fertility and crop productivity for the coming generations in the country forever enhancing nutrient input and recycling through following closed nutrient management systems in the cultivated lands.

Key words: Depletion, Nutrient cycling, Nutrient management, Organic matter content, Soil fertility.

Land degradation is reached to be 60% of the world's uncultivated arable land (total world uncultivated arable land) and an estimated 65% of arable land is degraded and loses of soil nutrients with worth of about US$ 4 billion each year in Africa alone (Tekalign and Tegbaru, 2015). Declining soil fertility decline is a major concern worldwide. Crop productivity in Ethiopia is very low and it is 1/3rd of the developing Asian countries and 1/10th of the developed United States. Of the 5.5 billion people living in developing countries a large proportion of them depend on agriculture for their livelihoods (Lal, 2015). Soil is the mantle or layer on the land surface that acts as a medium for plant growth (FiBL, 2012). Soil is a non-renewable, fragile resource and easily degraded when there is mismanagement (Lal, 2003).

The low soil fertility status has been aggravated by improper and inappropriate soil conservation and management practices. This is because of continuous cultivation and cereal-cereal cropping system has led to the depletion of soil fertility and deterioration of soil structure (Dalal, 1991). Past and current soil management practices have tended to enhance the physical, chemical and biological degradation of the soils, resulting into reduced soil productivity (Zingore *et al*., 2015). 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.

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The decline in soil fertility, therefore, has been caused by the increased withdrawal of plant nutrients from the soil without replenishment consequent to increase plant growth. To raise and sustain soil fertility and productivity in such areas, appropriate and holistic soil fertility management practices have to be developed and adopted by farmers (Muragea *et al*., 2000). Dramatic increases in crop yields during the 20th century are attributed to genetic improve--ments in crops, fertilizer use and improved cropping systems and these led to soil fertility depletion (Lal, 2003). The poor and declining performance of agriculture can be attributed to many interrelated factors including high population pressure (Drechsel, 2001), soil erosion and land degradation, unreliable rainfall, low water storage capacity of the soils, soil acidity, water logging, shortage of farm land, lack of improved technologies such as improved varieties, soil fertility management and water management.

Extremely soil fertility depletion status of agricultural land of smallholders is mentioned as one of the main constraints of crop yields in Ethiopia. Many empirical studies (Getachew *et al*., 2012; Bogale, 2014) have documented the problem of low soil nutrient reserves and negative nutrient balances in croplands with few or no external nutrient inputs compared to the nutrient status of forest areas, grazing or well managed lands. In Ethiopia, century-long, low input agricultural production, poor agronomic management practices, limited awareness of communities, absence of proper land use planning have aggravated soil fertility depletion (Gete *et al*., 2010).

The problem of soil fertility depletion is more serious in the highlands where most of the human and livestock population is found (Mitiku *et al*., 2006). This is mainly due to the complete removal of crop residues from farm lands for household energy and livestock feed, use of manure as a source of fuel instead of using it for soil fertility maintenance, low levels of inorganic fertilizer application and lack of appropriate and in-situ SWC practices (Akililu, 2006). Soil fertility management is a crucial component of any cropping system designed to enhance and sustain crop productivity forever. Thus, the mitigation of soil fertility depletion is currently a pressing issue and major national concern. Almost all crop residues were removed from the cultivated land and nothing is returned to the cultivated land so that depletion of soil fertility and lower crop yield productivity are the major problems created especially in developing countries. Therefore, the main objective of this paper is to review soil fertility depletions and its management options under crop production perspectives in Ethiopia.

Literature Review

Over view of soil fertility depletion in Ethiopia

According to Genizeb (2015) and Lindsay (1998) soil fertility is the status of a soil with respect to its ability to supply elements which are essential for plant growth without a toxic concentration. Soil productivity encompasses soil fertility plus all the other factors affecting plant growth, including soil management. Soil productivity is a measure of the soil's ability to produce a particular crop or sequence of crops under a specified management system (Genizeb, 2015). All productive soils are fertile for the crops being grown, but many fertile soils are unproductive because they are subjected to drought or other unsatisfactory growth factors or management practices (Genizeb, 2015). Therefore, soil fertility is a subset of soil productivity.

Soil fertility depletion is recognized as a constraint to increase food production and farm incomes in many parts of Sub-Saharan African (Shepherd and Soule, 1998). Ethiopia is one of the Sub-Saharan countries with the highest rates of nutrient depletion due to lack of adequate synthetic-fertilizer input, limited return of organic residues and manure, high biomass removal from farm lands, high soil erosion rate and leaching loss of nutrient elements (Endrias *et al*., 2013). Similarly, size of farm, access to credit, availability of extension services and training pertaining to soil fertility management are also the major constraints. The annual nutrient deficit in the country is estimated at 41 kg N, 6 kg P and 26 kg K ha^{-1} yr^{-1} (Genizeb, 2015; Zingore *et al*., 2015; Gicheru, 2012; Bayu *et al*., 2005) as shown in Fig 1. In the East African Highlands (Ethiopia, Kenya, Malawi and Rwanda), the annual net losses of N and P were estimated to be 42 and 3 kg ha^{-1} yr^{-1}, respectively. Because of low inputs, average nutrient balances for the arable land for some sub-Saharan African countries are negative (Table 1).

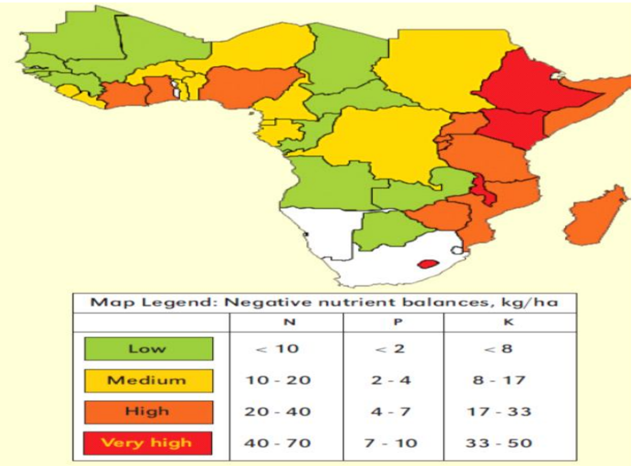
Major causes of soil fertility depletion in Ethiopia

According to Lal (2015); Tekalign and Tegbaru (2015) and Lindsay (1998), the major reasons for decline in soil fertility were: (1) loss of top soil by erosion; (2) nutrient mining; (3) physical degradation of soil (poor structure, compaction, crusting and waterlogging due to rugged topography etc.; (4) decrease in organic matter content (3 tones/ha/year) and

Table 1: Average nutrient balances of nitrogen, phosphorus and potassium for the arable land of some sub-Saharan African countries.

Country	Nitrogen (N) (kg ha^{-1} yr^{-1})		Phosphorus (P) (kg ha^{-1}yr^{-1})		Potassium (K) (kg ha^{-1} yr^{-1})	
	1982-1984	2000	1982-1984	2000	1982-1984	2000
Benin	–14	–16	–1	–2	–9	–11
Botswana	0	–2	1	0	0	–2
Cameroon	–20	–21	–2	–2	–12	–13
Ethiopia	–41	–47	–6	–7	–26	–32
Ghana	–30	–35	–3	–4	–17	–20
Kenya	–42	–46	–3	–1	–29	–36
Malawi	–68	–67	–10	–10	–44	–48
Mali	–8	–11	–1	–2	–7	–10
Nigeria	–34	–37	–4	–4	–24	–31
Rwanda	–54	–60	–9	–11	–47	–61
Senegal	–12	–16	–2	–2	–10	–14
Tanzania	–27	–32	–4	–5	–18	–21
Zimbabwe	–31	–27	–2	2	–22	–26

Source: Gicheru, 2012.



Source: Zingore *et al*., 2015.

Fig 1: Country-level soil nutrient balances in sub-Saharan Africa.

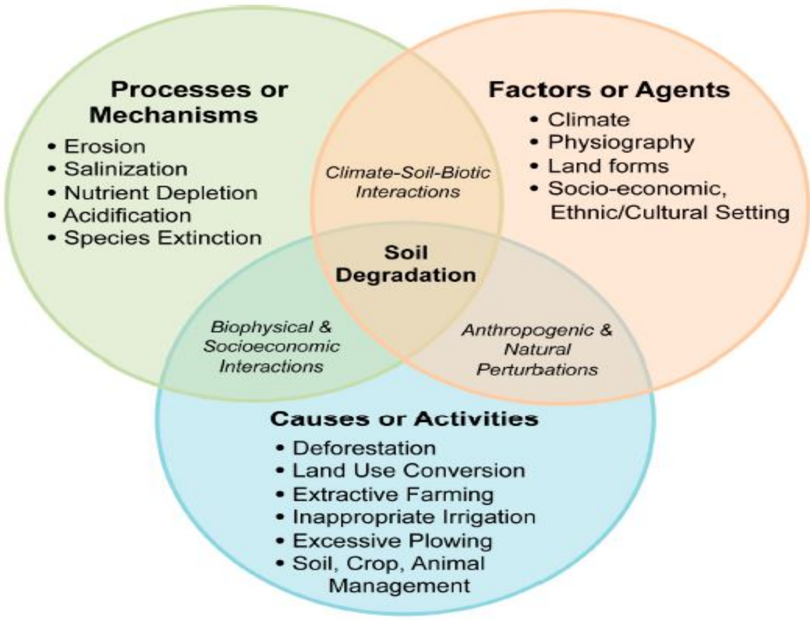
soil bioactivity due to continuous cultivation; (5) loss of nutrients through various routes; (6) soil acidification, salinization and alkalization; (7) inefficient soil management; and (8) soil pollution. Soil degradation is a 21st century global problem that is especially severe in the tropics and sub-tropics. Accelerated soil degradation has reportedly affected as much as 500 million hectare (Mha) in the tropics and globally 33% of earth's land surface is affected by some type of soil degradation (Lal, 2015). The process-factor-cause nexus as a driver of soil degradation are illustrated in Fig 2.

The major problems of soil productivity in SSA were a burgeoning population growth, extreme pressure on land, low food production, land degradation and soil fertility decline, droughts and insecurity of land rights (Genizeb, 2015). The major causes of soil fertility declining and major soil constraints are depicted in Fig 3 and 4, respectively. Population growth is increasing faster than the crop production.

Effects of inadequate fertilizer use on soil fertility

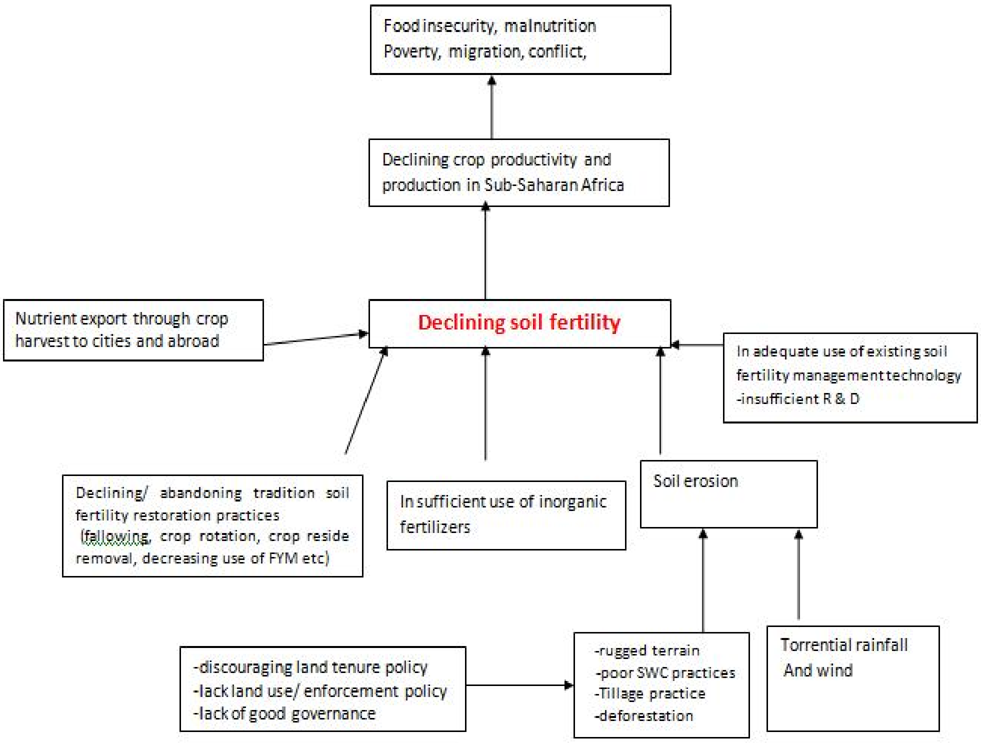
Because of scarcity and high cost, most smallholders' farmers in developing countries applying inadequate organic and inorganic fertilizers to the crops led to depletion of soil fertility (Muragea *et al*., 2000). To maintain a positive nutrient balance, nutrient inputs from chemical fertilizers are needed to replace nutrients which are exported and lost during cropping seasons. Otherwise, there would be negative nutrient balances due to the output nutrient is higher than the input nutrients (Gebremedhin *et al*., 2014) and it is depicted in Fig 5. Based on the full nutrient balances, N and K showed negative nutrient balances except P.

Moreover, continuous use of mineral fertilizer can have detrimental effects on soil properties. In temperate regions, continuous monocropping of cereals with optimum fertilizer use can sustain crop yields. But, on the strongly weathered, poorly buffered soils of the tropics (e.g. kaolinitic Alfisols, Ultisols and Oxisols) continuous monoculture of cereals, using chemical fertilizers as the main source of nutrients, can lead to a significant decline in yields after only a few years of cropping because of soil acidification and compaction (Hossner and Juo, 1999). Continuous use of imbalanced inorganic fertilizers resulted in decreased crop yields (Upinder *et al*., 2014). Therefore, integrated nutrient management is one of the viable options for sustaining soil health and crop productivity under such circumstances. Increasing fertilizer requirement of croplands and decreasing yield per unit of land were the main indicators of soil fertility decline in annual and perennial cropland, respectively (Dereje and Assefa, 2016).



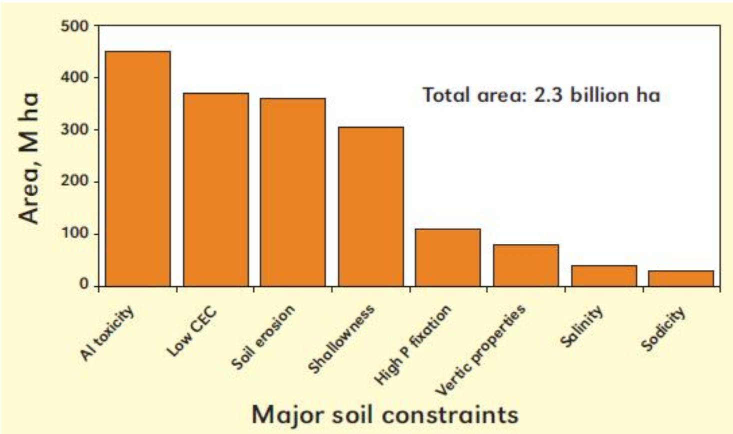
Source: Lal, 2015.

Fig 2: The process-factor-cause nexus as a driver of soil degradation.



Source: Muragea *et al*., 2000.

Fig 3: Causes of soil fertility decline and their interrelationship in sub-Saharan Africa.



Source: Zingore *et al*., 2015.

Fig 4: Major soil fertility problems in sub-Saharan Africa and their distribution.

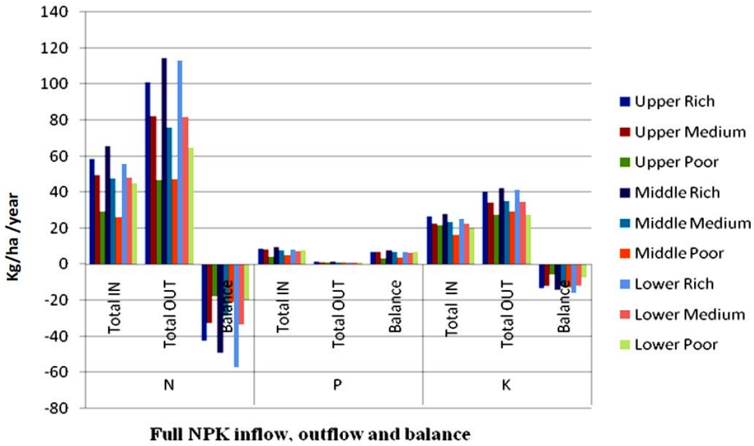
Effects of complete removal of crop residues for soil fertility depletion

Published results by Humberto and Lal (2009) showed that residue removal adversely affect the soil physical, chemical and biological properties. Unmulched soils are prone to particle detachment, surface sealing, crusting and compaction. Residue removal reduces input of organic binding agents essential to formation and stability of aggregates. It also closes open-ended biochannels by raindrop impacts and reduces water infiltration, saturated or unsaturated hydraulic conductivity (Table 2) and air permeability and thereby increases runoff or soil erosion (Fig 6) and transport of non-point source pollutants. Residue removal accelerates evaporation, increases diurnal fluctuations in soil temperature and reduces input of organic matter needed to improve the soils' ability to retain water. It reduces macro- (e.g., K, P, N, Ca and Mg) and micronutrient (e.g., Fe, Mn, B, Zn and S) pools in the soil by removing nutrient-rich residue materials and by inducing losses of soil organic matter (SOM)-enriched sediments in runoff (Fig 7). Crop residue removal reduces soil chemical properties of

Table 2: Crop residue removal affects soil structural, compaction and on soil hydraulic parameters.

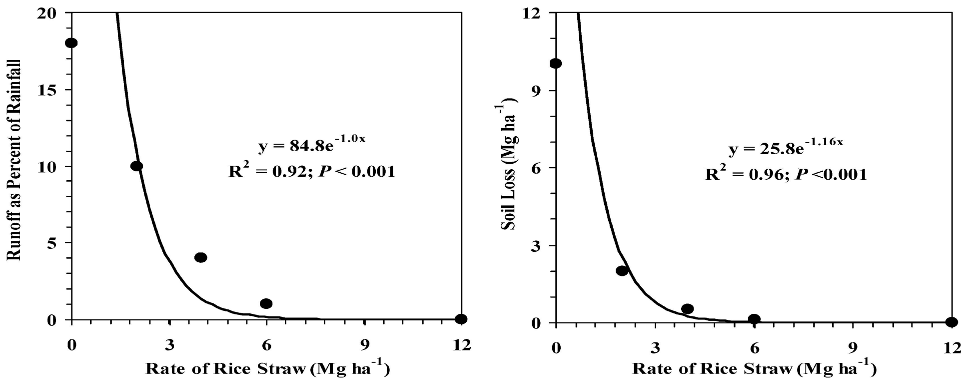
Residue cover (%)	Soil structural and compaction			Soil hydraulic parameters		
	Bulk Density (mg m^{-3})	Aggregate Stability (mm)	Saturated Hydraulic Conductivity (mm h^{-1})	Cumulative Water Infiltration (cm)	Water Retention (mm^3)	Plant Available Water (mm^3)
0	1.23a	1.92c	0.43b	18.2b	0.28c	0.114b
25	1.22a	3.25b	0.43b	19.9b	0.35bc	0.17b
50	1.23a	3.2b	1.01ab	33.7b	0.40b	0.22ab
75	1.20b	3.32b	2.20ab	52.5ab	0.42ab	0.23ab
100	1.10b	3.70b	2.40a	70.2a	0.43ab	0.23ab

Source: Humberto and Lal, 2009.



Source: Gebremedhin *et al*., 2014.

Fig 5: Full nutrient balance (kg/ha/year) for different resources inflow and outflow across the socio-economic groups in the landscape positions in the catchment, northern Ethiopia.



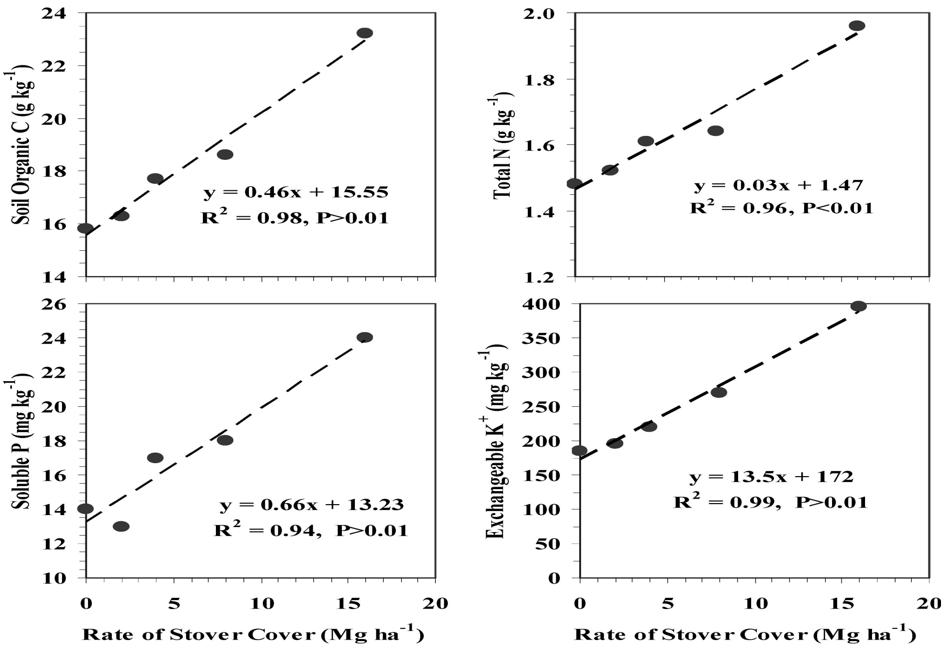
Source: Humberto and Lal, 2009.

Fig 6: Application of rice straw reduced runoff and soil erosion in a tropical sandy loam in Nigeria.

except EC and soil pH (Table 3). Residue removal drastically reduces earthworm population and microbial carbon (C) and nitrogen (N) biomass (Fig 8). It eventually decreases crop production by altering the dynamics of soil water and temperature regimes especially in tropical areas. Generally, harvested crops and crop residues removal are the major causes of nutrient depletion (Gebremedhin *et al*., 2014).

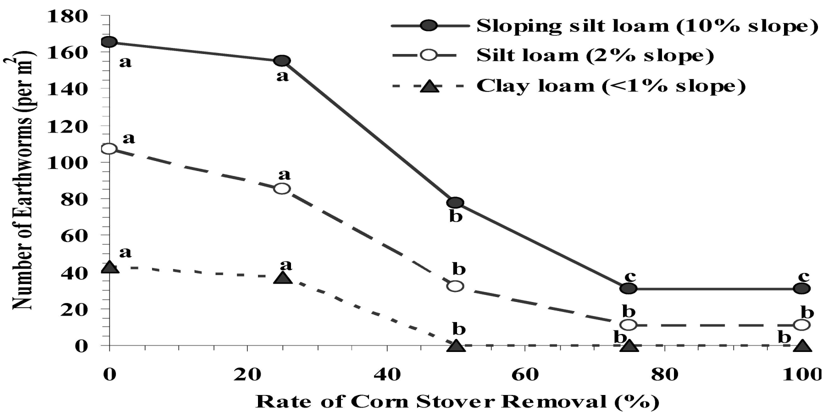
Effects of continuous or monoculture cropping systems on soil fertility

Continuous cropping or monoculture and intensive cultivation of crops can significantly decrease the nutrient level of the soil and its total fertility for a particular crop under cultivation; which, finally leads to a decrease in yield of the crops (Tewodros and Belay, 2015) and reduction in soil organic carbon and microbial biomass size (Gicheru, 2012). The main reason for the decline in yield of continuous or monoculture cropping systems is due to nutrient depletion of a soil as a result of continuous absorption of similar nutrients from the same root zones by the same crop. Similarly, the lower the clay content of the soil, the greater



Source: Humberto and Lal, 2009

Fig 7: Stover removal reduced soil nutrient pools on a silt clay loam soil.



Source: Humberto and Lal, 2009

Fig 8: Earthworm density decreases with stover removal regardless of soil type in the surface 0 to 15-cm depth.

Table 3: Influence of crop residue removal on soil chemical properties.

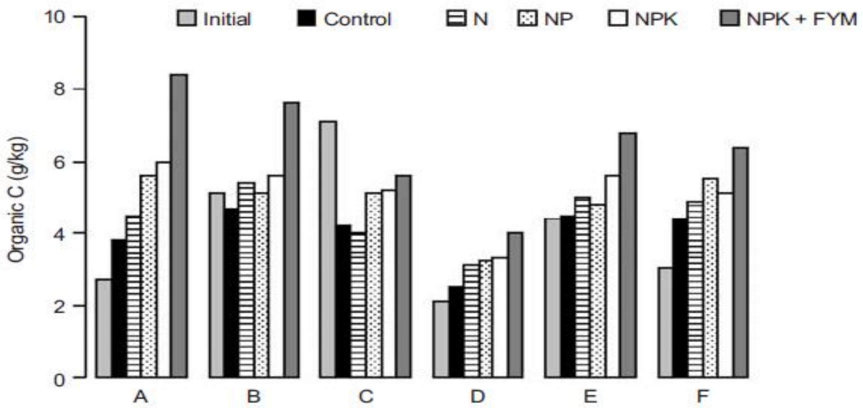
Residue cover (%)	pH	Organic C (g kg^{-1})	Total N (g kg^{-1})	Available P(mg kg^{-1})	Exchangeable K (mg kg^{-1})	Exchangeable Ca (mg kg^{-1})	Exchangeable Mg (mg kg^{-1})	CEC	EC
0	7.15a	18.9b	1.9b	32	331	1513	457	12	0.36a
25	7.12a	23.3ab	2.3ab	37	332	1648	502	13	0.34a
50	7.07a	23.0ab	2.3ab	38	351	1573	482	13	0.35a
75	7.04a	24.9a	2.4a	46	383	1541	475	13	0.25b
100	7.06a	27.1a	2.5a	52	389	1663	525	14	0.25b
200	7.05a	28.3a	2.6a	55	395	1650	530	14	0.24b

Source: Humberto and Lal, 2009.

was the rate of loss of organic matter under cultivation and larger the addition of more organic materials to maintain at a steady-state (Dalal, 1991) as depicted in Table 4. Under intensive cropping and imbalanced fertilizer use brings depletion of soil organic carbon (Manna *et al*., 2003) as indicated in Fig 9.

Effects of climate and soil types on soil fertility

Because of the cooler climate and the more fertile volcanic



Note: A = rice-rice; B = rice-rice; C = rice-wheat-jute; D = maize-wheat-cowpea fodder; E = maize-wheat-cowpea fodder; F = finger millet-maize-cowpea fodder.

Source: Manna *et al.*, 2003.

Fig 9: Effect of continuous cropping and fertilizer use on organic C content of a soil in India.

Table 4: Rates of addition of organic materials required to maintain organic matter levels at equilibrium or steady state.

Great soil group	Clay content	Soil texture	Rate of addition (t/ha/yr)
Black earth	72	clayey	1.4
Grey, brown and red clays	59	clayey	0.8
Grey, brown and red clays	49	clayey	1.6
Grey, brown and red clays	40	clayey	4.6
Grey, brown and red clays	34	loamy clay	5.4
Red earth	18	sandy loam	29.2

Source: Dalal, 1991.

soils, tropical highlands are generally densely populated and intensively cultivated. The growing season in rainfed farms in the tropical regions is determined by short rainy season and long dry-spells and bare lands. Rainfall is characterized by high intensity and these led to huge top soil erosion because of bare land due to frequent mixing of the soil without crops during the beginning of the rainy season. Upland soil types in tropical regions are dominated by acidic in nature with low effective cation exchange capacity. Therefore, climatic conditions and soil types have a great impact on soil fertility depletion. Soil types which are nearer to the homesteads are relatively fertile than soil types far away from the homesteads (Belay, 2015). Soil types which are far away from the homesteads have very low organic matter content, lower water holding capacity and low nutrient contents because of leaching of major cations due to water erosion and compaction. Therefore, in these areas soils are strongly weathered or old soils (acidic soils) due to low organic matter accumulation and low levels of mineral nutrients (i.e. Ca, Mg, K and P).

Effects of lack of proper cropping systems for soil fertility depletion

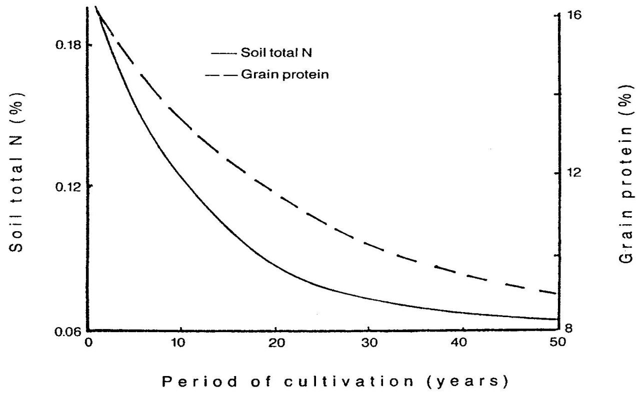
Cropping systems play an important role in improving soil quality. Therefore, the term lack of proper cropping system refers to lack of proper crop rotation systems and it implies a temporal sequence in which different crops are grown on the same land (Lal, 2003).

Effects of soil erosion and continuous cultivation on soil fertility depletion

Soil erosion is described as the process of loss of nutrient rich clay (fine particles) and organic matter in rain drop splash, impoverishing the upper top soil while continuous cultivation is repeated tillage practices of the farm land and it aggravates to soil erosion. Therefore, soil erosion and continuous cultivation are the major causes of soil fertility declines especially in Ethiopia (Tewodros and Belay, 2015). In Ethiopia, due to torrential nature of rainfall, seasonality of rain fall and rugged topography led to higher losses of top soil and reached about 137 ton/ha/year. Out of the different types of soil erosion, water erosion is the major causes of soil fertility decline in Ethiopia. The national soil removal by soil erosion is estimated to be 1.5 million tons per annum in Ethiopia. The major driver of soil erosion for the formation of soil fertility decline in Ethiopia is pattern and this brings to depletion of soil organic matter and finally results in reduction of crop yields (Tewodros and Belay, 2015).

Constraints of soil fertility management

Higher fertilizer applications on cultivated land resulted in declining soil fertility due to lower retaining biomass on cultivated lands (Eyasu, 2009). Nitrogen and phosphorus are the most serious limiting factors for cereals and food legumes, respectively. There are different nutrient deficiencies in acidic soils due to continuous cultivation and Al toxicity for different crops. Continuous cultivation also causes a significant decline in soil pH and exchangeable Ca and Mg levels. This is even more pronounced when acidifying fertilizers are used (Teferi, 2008). Soil organic N declines as the cultivation period increases and the same is true for grain protein content of crops (Dalal, 1991) as depicted in Fig 10. Reduction of desired quality level of malt barley and its yield under soil fertility depletion and absence of legume crop rotation (break crops or legume cropping



Source: Dalal, 1991

Fig 10: Decline in soil nitrogen and grain protein with increasing period of cultivation.

sequence) or continuous barley cropping systems were observed in the highlands of Ethiopia (Getachew *et al*., 2014). Therefore, soil fertility depletion can reduce the quality of crops due to unavailable of sufficient nutrients for the crops to optimize its acceptable standard quality.

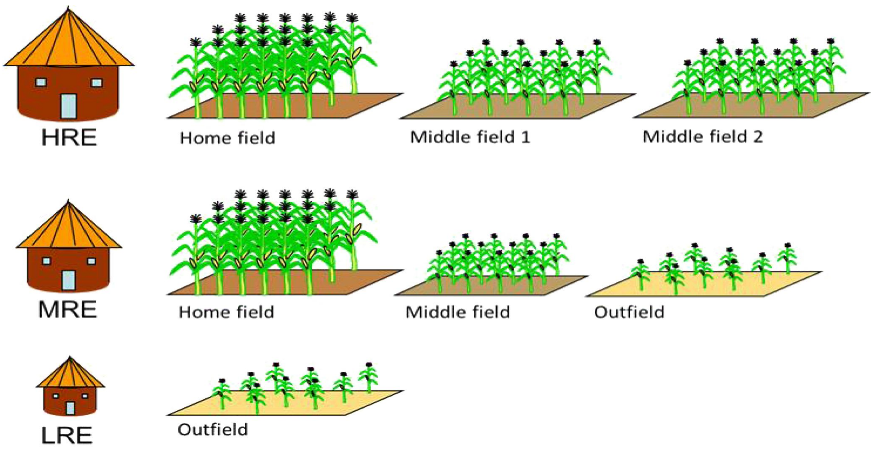
Cultivated highly-weathered soils commonly suffer from multiple nutrient deficiencies and nutrient balances are generally negative. Similarly, nutrient balances are more negative for outfields which are subject to erosion and leaching (Reddy, 2013). The decline of crop yields under continuous cultivation has been attributed to factors such as acidification, soil compaction and loss of soil organic matter (Hossner and Juo, 1999). Thus, application of organic materials is needed, not only to replenish soil nutrients but also to improve the physical, chemical and biological properties of soil.

High-resource-endowed farms (HRE) tend to have more cattle and manure and can maintain good soil fertility and crop yields across all of their fields. Low-resource-endowed farms (LRE) have no livestock and manure and their fields are often uniformly poor in soil fertility and crop yields. Farmers of intermediate resource endowment (MRE) have limited resources that they apply preferentially to the home fields, creating strong gradients of soil fertility. This allows the classification of fields across the different farms into three types: fertile home fields, moderately fertile middle fields and poorly fertile outfields for three farmer typologies (HRE, MRE and LRE) (Zingore *et al*., 2007a) as shown in Fig 11. The major constraint of soil fertility management is strongly correlated to the wealth status of the population which is either rich, middle and poorness conditions. Therefore, better soil fertility condition is existed in richness wealth status of the population because of the presence of more number of cattle, manure, even usage of external inputs and timely coverage of the farm fields (Zingore *et al*., 2011). This is generally related to the presence of more incomes to do every farm activities timely.

Soil fertility management options for better crop production

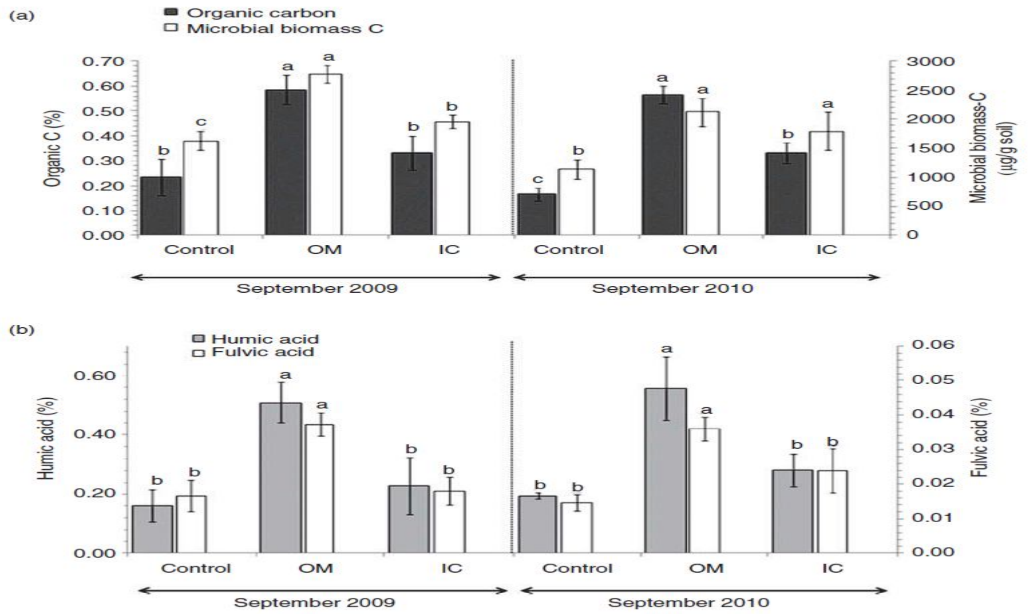
Integrated nutrient management

Sustainable soil nutrient management enhances strategies to involve the wise use and management of inorganic and organic nutrient sources for sound production systems (Endrias *et al*., 2013). Integrated nutrient management optimizes all aspects of nutrient cycling. It attempts to achieve fitted nutrient cycling with synchrony between nutrient demand by the crop and nutrient release in the soil, while minimizing losses through leaching, runoff, volatilization and immobilization. Long-term integrated use of inorganic fertilizers and organic manure (FYM) found superior in comparison to alone application of inorganic fertilizers to sustain crop productivity and soil fertility and enhancing the soil quality in a rice-wheat cropping system (Shri *et al*., 2016). Perhaps, application of integrated soil fertility management can give better yields than non-integrated ones (Tewodros and Belay, 2015). On the same way, integrated use of inorganic fertilizers and organic



Source: Zingore *et al*., 2007a.

Fig 11: High-resource-endowed farms (HRE), intermediate resource endowed farms (MRE) and low-resource-endowed farms (LRE) in a crop field.



Note: OM – Organic manures amended soil; IC – Inorganic chemical fertilizer amended soil.

Fig 12: Impact of long-term addition of organic manures and inorganic fertilizers on changes in SOC and microbial biomass-C (a) and humic and fulvic acid fractions of SOC (b).

sources of plant nutrients has shown potential yield of maize crop on acidic Nitosols of Southern Ethiopia (Detchinli and Sogbedji, 2015; Solomon and Jafer, 2015) and on wheat and tef in the highland Nitosol area of Ethiopia (Agegnehu *et al*., 2014). Long-term nutrient experiment was conducted in Alfisol of India and the result revealed that organic amendments induced higher microbial population (Fig 12) and enzyme activity (Fig 13) compared to inorganic and control soils (Chinnadurai *et al*., 2014).

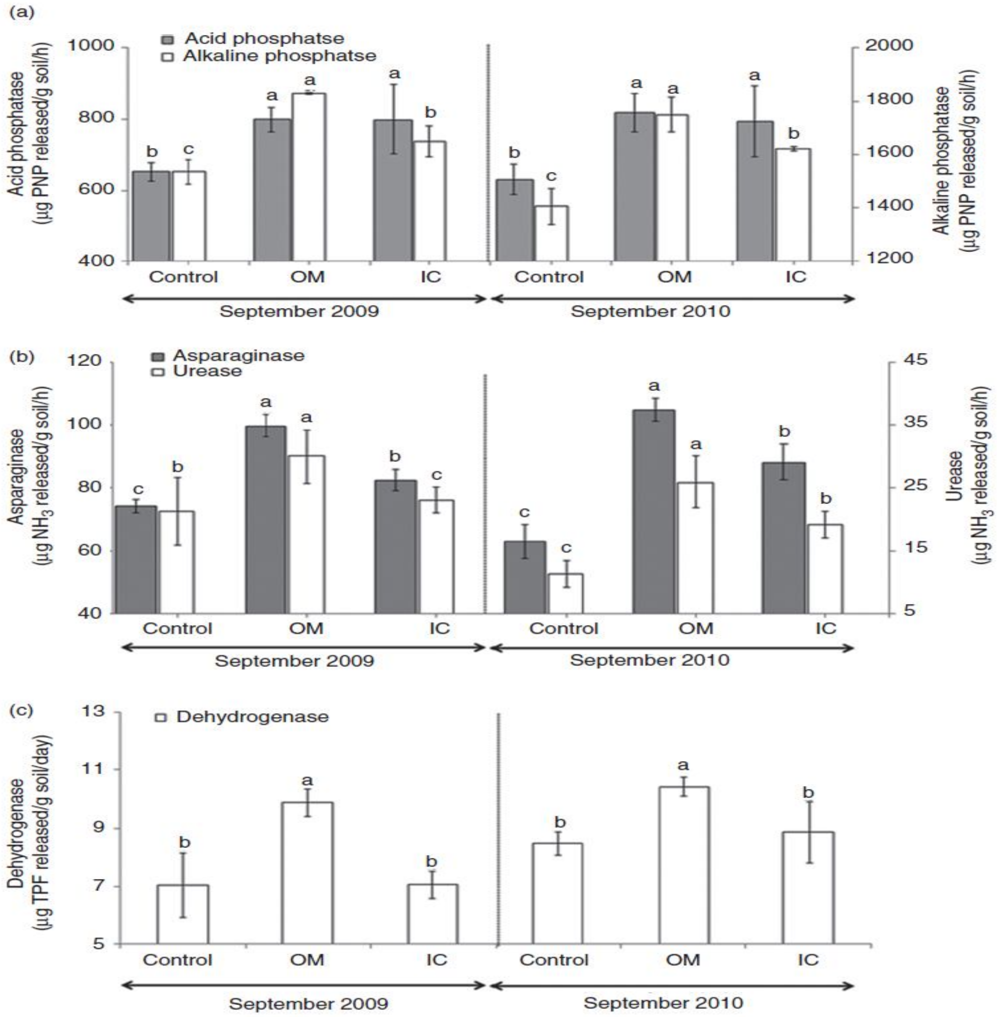
Integrated nutrient management involving nitrogen fixing herbaceous legumes such as groundnuts, mucuna, clotalaria and lablab or tree legumes such as *Sesbania,* Pigeon peas, Tephrosia, Gliricidia and Tithonia, with and without compost and livestock manures have proved to be the best options for soil fertility management in Malawi (Kanyama-Phiri, 2005).

Benefits of leaving crop residues

According to the report of (Humberto and Lal, 2009), crop residues are 40-46% C and provide innumerable ecosystem services including reduction in soil erosion and water pollution, improvement in soil physical, chemical and biological properties, increase in agronomic production and sequestration of soil organic carbon (SOC) with the attendant mitigation of the global climate change (Blanchet *et al*., 2016). Among numerous benefits of leaving crop residue are the following: (1) maintaining agronomic productivity by replenishing nutrients (both macro- and micro-nutrients) in the soil, increasing the soil organic matter (SOM) concentration, conserving soil water, reducing excessive evaporation, promoting biological activity (Blanchet *et al*., 2016), enhancing soil aggregation, strengthening nutrient cycling, reducing abrupt fluctuations in soil temperature and improving soil tilth; (2) improving water and air quality by reducing soil erosion and non-point source pollution, absorbing agricultural chemicals, filtering runoff and buffering against the impact of air pollutants; and (3) mitigating global climate change by sequestering SOC and off-setting emissions of CO_2 and other greenhouse gases. Besides to those factors, complete removal of crop residue increased the kinetic energy of the rain drop impacts on the soil particles to accelerate runoff and soil erosion easily. Similarly, maintaining crop residue cover also significantly reduces losses of NO_3-N, NH_4-N and PO_4-P in runoff.

Organic nutrient sources include plant residues, leguminous cover crops, mulches, green manure, animal manure and household wastes were used as source of soil nutrients. Under continuous cropping, recycling and reusing nutrients from organic sources may not be sufficient to sustain crop yields. Nutrients exported from the soil through harvested biomass or lost from soil by gaseous loss, leaching, or erosion must be replaced with nutrients from external sources. Crop residue management increased the grain yield of wheat in Ethiopia (Taa *et al*., 2004). On the other hand, integrated application of crop residues with inorganic fertilizers had a significantly higher grain yield of wheat than crop residues or inorganic fertilizer alone (Rezig *et al*., 2013).

According to Hossner and Juo (1999) rates of decomposition of both fresh plant residues and humidified soil organic matter are three to five times greater in the humid tropical environment than under temperate conditions. Therefore, in cultivated fields in the humid tropics, frequent application and larger quantities of organic materials are



Note: OM–Organic manures amended soil; IC–Inorganic chemical fertilizer amended soil.

Fig 13: Impact of long-term addition of organic manures and inorganic fertilizers on changes in soil enzymes' activities. (a) Acid and alkaline phosphatase; (b) Asparaginase and urease; (c) Dehydrogenase.

required to maintain adequate soil organic matter levels than in temperate regions. This is due to in humid tropical region including Ethiopia there is high temperature so that rate of decomposition of organic materials is very high as compared to temperate regions and the organic matter level is very low for tropical areas. This is because of high torrential rain fall and high soil erosion and led to leaching of major cations.

Strategies and practices for soil organic matter management include: (1) Returning organic materials to the soil, to replenish soil organic carbon lost through decomposition (recycling of plant and animal residues, green manuring, cover crop rotation); (2) Ensuring minimum disturbance of the soil surface (residue mulch, conservation tillage) to reduce the rate of decomposition; (3) Reducing soil temperature and water evaporation by mulching the soil surface with plant residues; and (4) Integration of multipurpose trees and perennials into cropping systems to increase the production of organic materials (Hossner and Juo, 1999).

Green manuring and cropping sequences (intercropping and crop rotations)

Timely applications of organic materials with a low C/N ratio, such as green manure and compost, could synchronize nutrient release with plant demand and minimize the amount of inorganic fertilizer needed to sustain high crop yields. Leguminous green manures and cover crops are able to: (1) Enrich the soil with biologically fixed N; (2) Conserve and recycle soil mineral nutrients; (3) Provide ground cover to minimize soil erosion; and (4) Require little or no cash input (Lal, 2003). Cover crops are legumes, cereals or an appropriate mixture grown specifically to protect the soil against erosion, ameliorate soil structure and enhance soil fertility.

A Study in Poland showed that proper implementation of crop rotations can improve soil P resources, P use efficiency of crops and crop yield stability. Additionally, cropping sequence can reduce external P inputs such as farmyard manure and chemical fertilizers (Lukowiak *et al*., 2016). Designing cropping systems with legumes reduced nitrogen oxide emissions with comparable or slightly lower nitrate-N leaching and phytosanitary effects (Reckling *et al*., 2016). Similarly, use of appropriate cropping sequences after legume crops planting cereal crops results in good quality and acceptable range of protein content of malt barley quality besides to improving soil fertility (Getachew *et al*., 2014).This is because of the ability to change soil fertility (both physical and chemical soil properties) through legume crop residue decomposition and fixation of atmospheric N_2 by the legume crops.

A number of green manure species including legumes from the genus *Crotalaria*, *Mucuna*, *Macroptilium*, *Sesbania*, *Tephrosia* have been tested for the purpose of soil fertility improvement in different parts of Africa (Oluyede *et al*., 2007). Cowpea and lablab also have high potential as a green manure. When incorporated into the soil, they can provide the equivalent up to 80 kg N/ha to a subsequent crop. Many fast-growing leguminous crops such as *mucuna*, soybeans and phaseolus species are grown as green manures and cover crops for erosion control, weed suppression and for soil fertility restoration. These green manure legumes have huge biomass accumulation and tree root activities and can improve the soil physical conditions. Generally, organic amendments are very effective for soil fertility improvement and nitrogen mineralization dynamics in the soil. But, there is a great variation between organic amendments such as fresh cattle manure, fresh white clover, vegetable, fruit and compost from yard waste and popular tree. Therefore, the highest net N mineralization and microbial biomass carbon content was higher from clover-amended than with manures or composts (Masunga *et al*., 2016).

Management of farmyard manure and household wastes

Organic resources acting both as amendments and fertilizers in improving soil nutrient status and productivity potentials in SSA (Omotayo and Chukwuka, 2009). Farmyard manure and household waste are major sources of nutrients for food crops in many parts of the tropics. Cattle dung is also a potential source of plant nutrients, but only in areas where animals are tethered or penned, so that dung can be collected. Composting is a low-cost, efficient method of processing crop residues and household wastes through biological decomposition, although extra labor is required.

The use of animal manure and household wastes are limited to areas near the farm compound. Another system of manure utilization in West Africa is known as Kraaling. In this system, farmers invite nomadic Fulani herders to graze on their croplands during the dry season. Cattle are confined in a designated field during the night, to ensure a concentrated application of manure and urine on the cultivated field (Bayu *et al*., 2005). It should be covered by soil otherwise loss of nutrients through volatilization in the form of methane (CH_4) and ammonia (NH_3) gases at high temperature.

Applications of chemical fertilizers and soil amendments

Judicious uses (lower rates, split application and banding) of inorganic fertilizers are needed on problematic soils (acidic), to sustain high crop yields and maintain an optimum balance of nutrients. Therefore, using the inorganic fertilizer is the most reliable option (Kanyama-Phiri, 2005). But, fertilizer use in Africa is very low (<10 kg/ha) and it is below the recommended rates as compared to other parts of the world (Morris *et al*., 2007). The amount of fertilizer use can be reduced by: (i) improving efficiency through improved formulations, mode and time of application, etc., (ii) decreasing losses due to erosion, leaching and volatilization and (iii) strengthening nutrient recycling mechanisms (Lal, 2003).

Continuous use of relatively high rates of nitrogen fertilizers on problematic soils, especially under cereal monoculture, can reduce soil pH (acidification) and seriously reduce soil fertility. Over 50 years long study in Swiss, only farmyard manure application improved soil physicochemical properties besides to crop yield enhancement as compared to mineral fertilizers alone (Blanchet *et al*., 2016). On the other hand, application of organic manures with combination of chemical fertilizers resulted in higher levels of carbon and nitrogen accumulation in addition to improvement of soil physical properties (Rong *et al*., 2016). Similarly, corn yield was sustainably increased by application of only organic matter amendments together with inorganic sources as compared to inorganic fertilizers alone in China (Song *et al*., 2015).

Soil amendments such as lime, manure and inoculants are important for soil fertility management (Kihara *et al*., 2016; Tekalign and Tegbaru, 2015). Lime and manure are the basic resources for acid soil management to increase the soil pH and lowers the concentration of Al. On the other hand application of the investigated straw-based hydrogels in Egypt showed improvement of chemical properties of a soil. These effects are slightly decreasing soil pH, increasing cation exchange capacity, increasing organic matter, increasing organic carbon, total nitrogen, macro-nutrients and improving biological activity (bacteria number, fungi and actinomycetes) of the soil (El-Saied *et al*., 2016). Biochar and rice straw amendments have also great contribution for soil productivity, carbon sequestration and the possibility for mitigating greenhouse gas emissions (Thammasom *et al*., 2016) and reduction of heavy metal uptakes (Pb, Cu and Zn) (Gwenzi *et al*., 2016).

Phosphorus deficiency is widespread throughout the tropical regions. However, in oxidic soils, higher rates of P application are needed, because the Fe and Al oxides and allophanes in these soils have a high capacity for P immobilization or fixation. A long-term P placement trial with maize in Brazil showed that banding application is more effective than broadcasting on these high P-fixing soils. Soil amendments such as lime application is essential to treat acidic soils of annual crop lands and these also improve the efficiency of soil fertility management techniques of farmers (Dereje and Assefa, 2016).

Agroforestry practices

Agroforestry refers to all forms of land-use systems in which trees or woody perennials are in association with livestock and/or annual crops, with significant ecological interactions between the woody and non-woody components for the sake of reducing poverty, improving food security and fostering sustainability (Luedeling *et al*., 2016). The major categories of agroforestry practices are alley cropping, buffers, forest farming, windbreaks and silvopasture (Motavalli *et al*., 2013).

Agroforestry has the potential to improve soil fertility. This is based on the increase of organic matter and biological nitrogen fixation through leguminous trees. Agroforestry has a number of successful technologies following benefits of tree-annual crop association: (1) Retrieval of nutrients from below the rooting zone of annual crops; (2) Reduction of nutrient losses from leaching, runoff and erosion; and (3) Legume trees increase the supply of nutrients within the rooting zone of annual crops through N input by biological N_2 fixation (Mbow *et al*., 2014). Out of soil fertility management techniques, agroforestry was the top preference for perennial crop land by farmers (Dereje and Assefa, 2016). On the same way, alternate land use systems such as agroforestry is more effective for soil organic matter restoration than monocropping systems (Manna *et al*., 2003).

Alley cropping is an agroforestry system involves planting hedgerows of perennial shrubs along the contour lines of a slope. In this system, food crops are produced in the alleys between the hedgerows. The foliage of leguminous shrubs is used for nutrients for the soil. Next to reduction of runoff and soil erosion, leguminous hedge rows are used for soil fertility management (Garre *et al*., 2013).

Applying conservation agriculture

Conservation agricultural (CA) systems are being extensively tested around the world and show promise way of sustainable land management system. The three major principles of CA are minimum soil disturbance (conservation tillage and direct seeding), permanent soil cover (residues and soil cover) and crop rotation (Motavalli *et al*., 2013). An experiment was conducted using grass vegetation strip with minimum tillage, organic amendments and weed mulch in India and the result revealed that mean wheat yield is 47% higher in conservation agriculture than conventional agriculture. Similarly, mean runoff coefficients and soil loss were very low and soil moisture conservation i.e.108% higher under conservation agriculture than conventional agriculture (Ghosh *et al*., 2015).

A study in Iran showed that no-tillage technology is considered to be one of the environmental benefits from soil erosion, soil compaction, degradation of soil structure and high energy consumption (Samiee and Rezaei-Moghaddam, 2016). Another conservation agriculture study was conducted in Egypt and the results showed that CA led to reduction in electrical conductivity by 2.21% and increased organic matter by 391.5% and available N by 210.7%, P by 272.7% and K by 183.5% under the condition of half dose of NPK fertilizer recommendations as improvement of soil fertility (Harb *et al*., 2015). Conservation agriculture or conservation tillage can have the capacity to reduce the emission of soil carbons and greenhouse gases as compared to conventional or traditional tillage (Awada *et al*., 2014). No-tillage technology can reduce accelerated soil erosion through integrated application of conservation tillage, crop rotation with leguminous plants and residue management for soil surface cover (Golabi *et al*., 2014). But, for developing countries conservation agriculture is not yet very well practiced because of socioeconomic and political factors. To tap the benefits of conservation agriculture in the country, this soil conservation technique is a new technology and it should be practiced for each farmer's farm land.

Application of soil-water conservation measures

There are different soil and water conservation (SWC) technologies or measures to overcome the soil fertility depletions especially in developing countries. These are advanced throughout the developing world include structural methods, such as soil and stone bunds; agronomic practices, such as minimum tillage, grass strips and agro-forestry techniques; and water harvesting options, such as tied ridges and check dams. SWC techniques also reduce soil loss from farmers' plots, preserving critical nutrients and increasing crop yields and this is the chief selling point for farmers (Kassie *et al*., 2009). Farmers construct soil-water conservation measures on their farm land for the sake of long-term effects on the cultivated land to restore more nutrients (Yirga and Hassan, 2009).

Challenges of soil fertility management

According to the study of Tekalign and Tegbaru (2015), soil fertility depletion is an increasing challenge to Ethiopian farmers. Realizing that crop productivity is the lowest in SSA by world standards and this is the great challenge for the ever-increasing population. To transform the soil fertility management options for agricultural productivity in a sustainable way, there are major problems. These are lack of good policy, research, capacity buildings, networking, knowledge management, coordination, institutionalization and a sustainable system. Therefore, Ethiopia's historically poor management of its soil resource led to severe soil fertility depletion and which creates food insecurity in the country. Finally, Ethiopia loses a billion metric tonnes of soil annually to the neighboring countries through soil erosion.

The factors that contribute to soil fertility challenges include the removal of input subsidy, high cost of moving fertilizers from ports to the farm, untimely availability and low quality of fertilizers, poor cultural practices, inadequate supplies of organic and inorganic fertilizers, deteriorating soil science capacity and weak agricultural extension services, lack of soil fertility maintenance plans, nutrient mining and low nutrient use efficiency, inappropriate fertilizer recommendations, differences in crop response to fertilizers and nutrient deficiency and climate change (Jonas and Justina, 2012).

CONCLUSION AND RECOMMENDATION

Soil fertility depletion is the major bottle neck problem in the world including developing countries like Ethiopia. Declining of soil fertility is very severe in developing countries due to open nutrient cycling systems due to various challenges or drivers. These are population pressure, land use land cover changes, free grazing of animals, lack of energy sources, poor knowledge of agricultural chemistry, land tenure and poor government policy problems. All those challenges or drivers can cause severe soil fertility problems through degradation of the finite or non-renewable resource known as soil which is the bank of nutrients for plant growth. The major causative agents of soil fertility depletion are inadequate fertilizer use, complete removal of crop residues, continuous or monoculture cropping systems, climate and soil types, lack of proper cropping systems, soil erosion and over cultivation.

In developing countries like Ethiopia, soil fertility management must be implemented by closed nutrient management systems. Sustaining crop production is achieved by managing the soil fertility through different technological options. The promising technologies for improving soil fertility are integrated nutrient management, crop residue management, green manuring and cropping sequences, management of farmyard manure, applications of chemical fertilizers and soil amendments, agroforestry practices, applying conservation agriculture and application of soil-water conservation practices.

Due to the delay of controlling soil fertility depletion and a “business as usual” attitude, the world has started to see more soil degradation. The problem is more severe in developing countries, especially in Sub-Saharan Africa where more of food insecurity, poverty and burgeoning population pressures are more significant. Therefore, soil is the bases for more food production to feed the ever increasing population in these days because of soils contain the nutrient houses for plant growth. The public sector, policy-makers and heads of governments have been alerted to stop and think about the precarious soil resource and the need to give more emphasis to soil fertility depletion and care on a continuous basis. This is to say for soil fertility management for the coming generations without deteriorating its function by all actors should join their hands and sing the song together about soil fertility depletions and its management options to crop production perspectives in Ethiopia.

Therefore, the following recommendations should be practiced to sustain the soil fertility and crop productivity under soil fertility depletion situation:

- Conservation agriculture system should be practiced.
- Soil carbon sequestration because of soil is the second largest carbon sink.
- Setting an approach of agricultural chemistry knowledge to soil fertility management for the different actors.
- Ecological niche conservation e.g., “*Addey* Flower”, *Murie* grass in Ethiopia are reduced its coverage due to soil fertility depletion as the marginal land is converted into farm lands.
- Legume based cropping systems and residue retention as mulch should be practiced.
- Regular organic inputs to the farm lands should be practiced;
- Soil biological management.
- Minimizing nutrient losses through applying better land management technologies such as physical, agronomic and biological soil and water conservation measures.
- Stop free grazing in the farm land rather using cut and carry system of animal feeding.
- Set proper soil fertility management policy issues and soil-testing services is a pre-requisite to sustain soil fertility and enhancing crop yields for each farmer’s farm land.
- Proper selection of land use planning for each agro-ecology of the country.
- Establishment of profitable and sustainable nutrient management systems.
- More investment should be done on land management because of investing the land means replenishment of soil fertility after a while the return would be fivefold with in one dollar invested.
- Continuous monitoring of cultivation lands is necessary to enhance soil fertility and to take possible measures.
- There should be a coordinated strategy of collaboration between actors in nutrient management.

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