ORGANIC CARBON AND NUTRIENT DYNAMICS UNDER CROP-LIVESTOCK FARMING SYSTEM IN HARAMAYA AND KERSA DISTRICTS, EASTERN ETHIOPIA

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EXTENDED ABSTRACT

Crop-livestock farming system is a traditional and main agricultural practice in the eastern part of Ethiopia, where crop grains are produced for food security and residues are for animal feed and domestic fuel consumption. As a result, farmers practice crop residues removal management throughout the cropping seasons. However, there is no adequate information on the impacts of crop residues removal management on soil properties and crop yields under such farming system. These studies analyze the status of soil properties under crop-livestock farming system, phosphorus adsorption capacity of the soils, organic carbon and nutrient distribution, and transport under crop residues removal management practices, and effects of crop residue incorporation on soil properties and crop grain yield at two farms, Adele in Haramaya and Bala Langey in Kersa districts in Eastern Ethiopia. Soil samples were collected from the crop fields and homesteads at both farms and analyzed following standard methods for soil physical and chemical analyses as well as for P adsorption capacities. Haricot bean was intercropped with maize for two cropping seasons for residue incorporation at both sites. Results reveal that soils of both farms have same textural class, sand clay loam but are different in other properties. The pH of the soils at both farms was in the range of 6.50 to 7.50 which is a suitable range for most crops grown at both sites. Soil organic carbon (<1.5%), nitrogen (<0.2%), extractable P (< 10 $mgkg^{-1}$) and sulfur (<5 $mgkg^{-1}$) were low and are the soil productivity limiting factors associated with soil fertility at both farms. Soils of Adele farm had higher P adsorption capacity from KH_2PO_4 and DAP than soils of Bala Langey farm. Thus, soils of the two farms demand different P fertility management strategies. Distribution of organic carbon and nutrients in the farming system at both farms was highly affected by poor management of manure, household wastes and crop residues. About 2.95 and 2.15% OC was accumulated near homes of the households, respectively, at Adele and at Bala Langey farms. The quantity was less than 2% in the crop fields at both farms. About 100 and 41 mg Pkg^{-1} was accumulated near home at Adele and Bala Langey farms, respectively. But extractable P was low (< 15 mgkg^{-1}) in the crop fields at both farms. Other nutrients follow similar trends. Through incorporation of haricot bean residue under maize haricot bean intercropping system, soil bulk density values decreased from 1.38 to 1.21 gcm^{-3} at Adele site and from 1.34 to 1.20 gcm^{-3} at Bala Langey site. Soil organic carbon increased from 1.21 to 1.99% at Adele site and from 1.19 to 2.14% at Bala Langey site. CEC increased from 56.50 to 66.58 cmol(+)kg^{-1} at Adele site and from 56.77 to 59.13 cmol(+)kg^{-1} at Bala Langey site. Haricot bean residue incorporation significantly ($P<0.05$) affected maize grain yield. Moreover, maize grain yield was increased by 47 and 23% over the controls at Adele and Bala Langey farms, respectively. Growing two rows of haricot bean between maize plants was found to be effective in improving soil properties and maize grain yield at both farms.

DECLARATION

I, Lemma Wogi, do hereby declare to the Senate of Sokoine University of Agriculture that this dissertation is my original work and that it has not been submitted and will not be submitted to any other university for similar or other degree award.

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LIST OF ABBREVIATIONS AND SYMBOLS

AAS	Atomic Absorption Spectrophotometer
AGRA	Alliance for Green Revolution in Africa
CEC	Cation Exchange Capacity
cm	Centimeter
cmol(+)	Centimole Charge
DAP	Diammonium Phosphate
EC	Electrical Conductivity
%EC	Percent Equilibrium Concentration
EDTA	Ethylene Diamine Tetra-acetic Acid
EPC	Equilibrium Phosphorus Concentration
ESP	Exchangeable Sodium Percent
FAO	Food and Agricultural Organization
g	Gram
ha	Hectare
IFPRI	International Food Policy Research Institute
kg	Kilogram
m a s l	Meter Above Sea Level
mg	Milligram
mm	Millimeter
nm	Nanometer
OC	Organic Carbon
%Pa	Percent Phosphorus Adsorbed
PBS	Percent Base Saturation

RCBD	Randomized Complete Block Design
SCL	Sandy Clay Loam
SOC	Soil Organic Carbon
SOM	Soil Organic Matter
SUA	Sokoine University of Agriculture
TN	Total Nitrogen
UV	Ultra Violet

CHAPTER ONE

GENERAL INTRODUCTION

Background and Rationale

Agriculture is the major economic sector for the Sub-Saharan African countries on which two-thirds of the population depends on (Ephraim *et al*., 2008). However, agricultural productivity of the region is considerably lower than that of other developing regions and far below its potential (Wanzala and Groot, 2013). The agricultural productivity of countries in the region has been stagnant or declining because of low inherent soil fertility, land degradation, limited and erratic rainfall pattern (Obalum *et al*., 2012). Land degradation accounts to the largest extent for lower agricultural productivity of the region (UNEP, 2008). Approximately 23% of agricultural land is already degraded and the remaining arable lands are under continuous degradation because of inappropriate land use systems and the associated management practices (UNEP, 2008; FAO, 2005).

The densely populated areas in the highlands of eastern and central Africa are some of the areas that are under continuous and rapid land degradation processes (Henao and Baanante, 2006). In East African countries, land and natural resources degradation is a serious problem threatening agricultural productivity of the region and the livelihood of the rural community (UNEP, 2008). Land degradation, especially in the form of soil erosion, nutrient depletion and soil moisture stress, is particularly severe in the highlands of Ethiopia, Kenya, Tanzania and Uganda (Gebremedhin, 2004).

Ethiopia is an agrarian country and agriculture is the major economic sector. Agriculture employs about 80–85% of the labor forces of which the farming sector shares the highest.

The sector contributes about 40% of the total GDP; livestock and their products account for about 20% of agricultural GDP (Alemayehu, 2006).

Nevertheless, agricultural productivity of the country is low and declining because of land degradation and erratic rainfall pattern. Soil erosion and nutrient depletion are among the main root causes of land degradation and constraints to increasing agricultural productivity of the country (Amare *et al*., 2005). Land degradation also continue at a rapid rate in some regions of the country because of deforestation, overgrazing, expansion of cultivated land and unsustainable use of natural resources (Descheemaeker *et al*., 2011).

As a result, land degradation is mainly caused by high-intensity rain storms on mountainous land features, steep slopes, and barren land surfaces, which are highly susceptible to soil erosion. On the other hand, use of animal dung and crop residues for fuel (Gebraegizebher, 2007), deforestation for cultivation, poor farming practices in sub-humid and semi-arid areas are also among the main causes for increasing susceptibility of the land resources to degradation. Thus, land degradation in Ethiopia is a combined effect of natural factors such as land configuration (topography and aspect) and rainfall pattern, anthropogenic factors; over population, inappropriate soil and water management, nutrient mining and unsustainable natural resources uses.

Inappropriate soil and water management, especially nutrient mining, leaving surface soils without cover that exposes surface soils to water and wind erosion, are the main contributors to the poor performance of land productivity of the country. Nutrient mining and surface cover removal such as crop residues for animal feed and for domestic fuel are among the main root causes of soil fertility depletion.

Soil fertility depletion has restricted crop production and productivity of smallholder farms to the minimum (Girmay *et al*., 2008). Continuous mono-cropping and unbalanced nutrient applications have also been contributing to soil fertility depletion and subsequently decline in crop productivity. As a result, the economic status of a large number of farming communities has been adversely affected by severe poverty. The process of soil fertility depletion and nutrient losses are aggravated by many factors. Nutrient mining without replenishment and crop residue removal for domestic uses, as residential fuel, animal feed or for construction purposes contributes the most among others (Abera and Belachew, 2011; Girmay *et al*., 2008; Gebraegizebher, 2007).

Stroorvogel and Smaling (1990) estimated that in Ethiopia, soil nutrient loss was more than 80 kg ha^{-1} y^{-1}. Hawando (2000) indicated organic matter loss associated with the removal of surface soil ranges from 0.015–1.00 ton $ha^{-1}year^{-1}$ and nitrogen ranged from 0.39–5.07 million ton $year^{-1}$ and that of phosphorus ranged from 1.17–11.7 million ton $year^{-1}$. These authors indicated loss of nutrients at the national level; however, amounts of nutrients lost from the soil through crop residue removal or leached to the deeper layer and not accessible to plant roots at a farm level are not indicated in the reports. Quantification of nutrients lost from cultivated fields and identification of nutrients flow direction is important in the designing of the intervention mechanisms to mitigate nutrient loss from crop field under a particular farming system.

All the cited reports indicate causes of soil fertility depletion and the consequence on crop production and the environment. However, some of them lack indicating intervention directives for the managements to alleviate the soil fertility depletion. Girmay *et al*. (2008) indicated that management and restoration efforts made to reduce soil fertility depletion are minimal compared with the level required in Ethiopian crop production systems. Crop production is therefore, facing nutrient deficiencies induced by continues mining with minimal or without restoration of nutrients removed through natural or anthropogenic processes.

Fertilizers based green revolution attempted to improve soil productivity at the beginning of the 1990`s in some African countries including Ethiopia. Studies (Dercon and HilI, 2009; IFPRI, 2010) show that use of chemical fertilizers in Ethiopia has made a contribution to crop yield increase to a certain extent.

It is also suggested (IFPRI, 2010) that there is a potential for further improvement. Nevertheless, the experience of farmers mineral fertilizer use is less than 45 percent. Fertilizer is applied only to about 40 percent of areas under crop up to date. Fertilizer application rates are mostly below the blanket recommendations (100kg DAP and 100kg urea/ha) and applied to selected crops. Bationo *et al.* (2007) indicated that these application rates are relatively higher than the average for other Africa countries. Although, there is also suggestion that fertilizers applied to Ethiopian farming system is not as effective as expected to break the poverty cycle and be food self-sufficient for the smallholder farmers (IFPRI, 2010).

Mesfin and Tekalign (2010) commented that the current fertilizer application rates recommended for N and P are largely standardized for the country irrespective of agro-ecological variation and are at least more than 35 years back. Moreover, the N and P fertilizes are applied to specific crop such as maize, wheat, barley and teff without taking into account the differences in N and P requirements of the crops.

Chemical fertilizers uses also need detail information addressing whether the use of higher rates of chemical fertilizers than the recommended blanket rate is appropriate for the enhancement of soil productivity in Ethiopian crop production. *In fact, as it has been reported by IFPRI (2010), the impact of other soil properties that restrain fertilizer effectiveness needs to be examined in detail at a farm level.*

As reported by IFPRI (2010), data on soil properties in Ethiopia are largely out-of-date at the national level and are fragmented, and difficult to access at the local level. The last major surveys of macronutrient status across the country were conducted in the 1950s–60s. The national study of macronutrient levels conducted by Stoorvogel and Smaling (1990) indicates balances of -41kg N/ha, -6kg P/ha, and -26kg K/ha in cultivated highlands.

Therefore, the major soil fertility issues are only understood at a high level not at the farm level. IFPRI (2010) suggests more research needs to be carried out at farm or village level. *The suggested key soil parameters required for the assessment of soil fertility status include; soil physical characteristics, pH, organic matter content, topsoil thickness, macro and micro-nutrient levels, and salinity status of the soil under a particular farming system.*

Some authors (Dercon and HilI, 2009; IFPRI, 2010) also argued that at the beginning of the first five years, the fertilizers based green revolution seemed successful at its inception in Ethiopia. However, crop yield started to decline because of neglecting other soil fertility aspects such as *nutrients retention and release potential of the soils, suitability of particular fertilizer to soil conditions*, *which could have resulted in mismatch among soil conditions and fertilizer types, crop nutrient requirements and management practices*.

Zerpa and Fox (2010) suggests, knowing soil conditions before fertilizer application can help to make decisions as to where, when, and which fertilizer formulations might be used more effectively. Therefore, understanding of soil conditions and crop nutrient requirements and fertilizer formulation accordingly is imperative to increase soil productivity without causing negative impacts on soils and the environment.

Moreover, the decline in the Ethiopian soil productivity may be aggravated due to the mismanagement of soil organic matter (SOM). SOM plays an important role in nutrient cycling; maintaining soil fertility, improving soil physical, chemical and biological properties, and reducing the rate of inorganic fertilizers loss through increases in nutrient use efficiency (Karlen *et al*., 2011). SOM moderates atmospheric carbon dioxide (CO_2) concentration and minimizes the greenhouse gas effect. SOM is also an important indicator of soil quality and potential of soil as carbon sink. In relation to this, few studies have been undertaken in Ethiopia (Girmay *et al*., 2008). Thus, understanding organic carbon dynamics in relation to the farming system and the associated management is vital for identifying appropriate actions to mitigate the problems.

As a conclusion, data on soil fertility, organic carbon and nutrient dynamics in Ethiopia are scarce and fragmented in general and of the eastern parts in particular. Furthermore, the available data on the fertility status of Ethiopian soils are out of date as reported by IFPRI (2010), to lay the interventions framework to lessen the impacts of soil fertility depletion and the consequences on crop production and the environment.

Soil fertility depletion is also common to the eastern parts of the country where it is more aggravated as a result of mismanagement of SOM and crop residues. Maize and sorghum are the major food crops produced by the farmers of the regions under subsistent farming systems. The potential yields of these crops are limited because of low soil fertility and poor soil management practices, and poor soil chemical and physical properties induced by soil fertility depletion.

Soil fertility depletion is mostly aggravated as a result of crop residues removal and low soil organic carbon inputs to the cultivated fields. Crops residues are the ultimate source of soil organic carbon. However, crop residues have been used for various purposes instead of incorporating them into soils for the improvement of soil fertility status. Farmers remove all the above ground biomass and collect root residues for domestic fuel. On fields used for cultivation of maize or sorghum, almost no crop residues remain on the fields.

Farmers` experience is also minimal in taking other household wastes to the cultivated fields and in compost making from different organic waste sources. Only a few farmers take farm manure to the cultivated fields for selected crops. In some parts, farmers are not showing interests in applying mineral fertilizers for the improvements of soil productivity.

From the farmers` experience, crop responses to fertilizers are not promising. Low crop responses to fertilizers may be attributed to many factors. Absence of fertilizer recommendation rate specific for the region, lack of information on the potential suitability of the commonly used fertilizers DAP and urea to the soil conditions and lack of detail information on the fertility status of the soils. Volatilization losses of nitrogen from DAP or urea could also be suspected in some parts of the regions because of relatively high soil pH.

Regardless of other constraints to the accessibility of fertilizer to farmers, currently it is only phosphorus and nitrogen in the form of DAP and urea that are available in Ethiopian fertilizers market. Thus, farmers have only a chance of supplementing two nutrients of the 17 essential nutrients required for optimum crop production and normal plant growth and development. The extent of problems and constrains to crop production is wider in the farming systems of the region. Therefore, searching for alternative intervention mechanisms is crucial to mitigate soil fertility depletion and the consequences on crop production and the environment.

Over View of Soil Organic Carbon and Nutrient Dynamics

Soil Organic Carbon

Soil organic carbon (SOC) is an important index of soil quality, soil productivity and soil functions in an ecosystem (Karlen *et al*., 2011)**.** Soil organic carbon also represents an important carbon pool of the biosphere and plays a predominant role in the global biogeochemical cycle of the major plant nutrients (Tchienkoua and Zech, 2004).

Thus, SOC has a direct influence on crop productivity and agricultural sustainability. For instance, Lal (2006) noted that decline in SOC levels directly related to decrease in crop productivity. Zhang *et al*. (2009) suggested that maintaining SOC level is essential for long term sustainable agricultural production for food security and environment protection.

SOC management for sustainable agriculture is also recognized as one of the mitigation options for climate change (Choi and Sohngen, 2009), because of the potential of agro-ecosystem to absorb large amount of carbon dioxide through carbon sequestration in the form of SOC. However, world soils have been among the major sources of atmospheric CO_2, especially from those managed by distractive farming practices such as conventional tillage and crop residues removal (Lal, 2009). Thus, adaptation to an appropriate land use systems and SOC management can make world soils an important sink of atmospheric CO_2.

Several studies (Zhang *et al*., 2009; Hernandez-Ramirez *et al.* 2010) indicate that SOC levels are influenced by agricultural practices, soil conditions, climate and vegetation cover. Studies by Dalal *et al*. (2011) revealed that increases in SOC level under practices of balanced fertilization, organic amendments, conservative tillage and fallow periods. Mishra *et al*. (2010) have found that more SOC accumulated under no-till compared with conventional tillage and sequestered more carbon which is beneficial to soil conditions. Hernandez-Ramirez *et al.* (2010), Zhang *et al.* (2009) and Bationo *et al*., (2007) have indicated climate and vegetation cover effects on the amount and quality of organic matter inputs, decomposition rates, and stabilization of SOC. According to these authors, the levels and quality of SOC are the function of land use types, agricultural practices, soil conditions, climate and vegetation cover.

Literatures demonstrate that the roles of SOC in crop production and environment protection are dip and broad. Therefore, understanding the status of soil organic carbon and adaption of appropriate management is exceptionally important for sustainable crop production and environment protection.

Nutrient Dynamics

The cycling of nutrients in biogeochemical processes has been dramatically altered by human activities (Agoumé and Birang, 2009) such as land use systems and the associated management practices. Nutrient dynamics have also been found differed across seasons, soil types and conditions (Eaton *et al*., 2011). Moreover, nutrient dynamics is often highly susceptible to land use systems and associated management practices (Castillo and Wright, 2008).

Under crop production systems, soil productivity and nutrient dynamics could be estimated through quantity of dry matter produced, yield and nutrient cycling, nutrients release or transport processes. However, agricultural land use systems are the main cause of imbalanced nutrient dynamics in an ecosystem. Fallahzade and Hajabbasi, (2011) have described that cultivation of native natural vegetation for crop production is the most important factor that accelerates nutrient losses, which consequently affect the nutrient dynamics in the biogeochemical system.

Castillo and Wright (2008) reported that cultivation has significantly influenced soil physical and chemical properties and nutrient distributions. They also have noticed decreases in soil water holding capacity as a result of cultivation that likely from destruction of soil structure by tillage. Among crop production practices, cropping systems and nutrient management are the most that influence nutrient dynamics. Therefore, information on nutrient dynamics under land use system and the associate management practices are important to mitigate nutrient loss and soil fertility depletion.

Over View of Crop-Livestock Farming System

Crop-livestock farming is an agricultural system that integrates livestock and crop production components under one unit. It is a diversification system for smallholder farmers to increase farm productivity and improve food production in terms of quality and quantity (Gupta *et al*., 2012).

Livestock provide manure and service as part of the on-farm nutrient cycle. Animals recycle nutrients contained in forage and feed and make them available in their excreta

(Hilimire, 2011). Animals also provide partially digested and transformed plant materials that contribute to soil organic matter maintenance and accumulation (Russelle *et al*., 2007). Furthermore, Livestock is considered as form of wealth, power and security.

Therefore, integrating animals into cropping system provide cost-effective on-farm sources for soil fertility enhancement and crop productivity improvement. Animals also serve as an assurance asset in case of crop failure. Hilimire (2011) suggested that integrating animals into crop production can improve soil quality, decrease reliance on external inputs, contribute to pest management, strengthen farm economies and grant food security benefits to communities.

The cropping component provides valuable low cost residues for animal feed that result from the cultivation of cereals, pulses, roots and tubers (Gupta *et al*., 2012). Crop residues are the byproducts of the cropping system and the major source of nutrient for livestock production in developing countries.

Crop-livestock farming system is the common and main agricultural production in Ethiopia. The cropping and livestock systems are strongly interconnected in the farming systems of the country. Animals are being used as draught power for cultivation of land and for transportation. The cropping system provides crop residues that are being used for animal feed and as bio-fuel. As a result, farmers practice crop residues removal management for animal feeds and domestic fuel consumption.

Crop residues are the sources of organic carbon for soil microorganisms and nutrients for plants (Lal, 2009). Studies by Mbah and Nneji (2011) have shown that incorporation of crop residues significantly improved soil pH, organic matter, CEC, available phosphorus, exchangeable bases and grain yields per unit area. This again indicates crop residue incorporation is significantly important for the improvements of soil chemical properties. Therefore, appropriate crop residue management is vital for the enhancement of soil biological and chemical fertility. On the other hand, Bahrani *et al.* (2007) observed that burning and continuous removal of crop residues is one of the main causes for soil fertility depletion.

Crop residues retention or incorporation is also important for soil and water conservation. Wilson *et al.* (2008) and Lal, (2009) have observed retaining crop residues as surface cover is an important conservation technique for erosion control. Retention and/or incorporation of crop residue into soil can improve soil structure and subsequently soil permeability and hydraulic conductivity which are important soil physical properties. Therefore, appropriate crop residue management i.e. either retention on soil surface or incorporation into soil is a mandatory scenario for the improvement of soil biological, chemical and physical properties. However, in the study areas, crop residues are being removed for animal feed and domestic fuel consumption.

Justification

Several authors (Abera and Belachew, 2011; Girmay *et al*., 2008; Gebraegizebher, 2007) have made attempts to reveal the extents of soil fertility depletion in Ethiopia and the consequences on crop production and the environment. However, there is lack of recent information on the fundamental intervention methods or technologies that could be implemented at the farm level to mitigate soil fertility depletion and enhance soil productivity.

To come up with such fundamental intervention mechanisms, identification of the main root causes is very important. As recommended by IFPRI (2010), assessment of soil fertility status is the first step to jump into the ocean of problems. Quantification of nutrients removed from the field with harvest and other processes such as soil erosion, leaching and fixation helps to formulate fertilizer application that is in harmony with crop nutrient requirements.

There is also expectation that some of the nutrients removed from the field, most probably be accumulated at the homestead. This may provide a clue for the direction of nutrient flows, but quantification and characterization of the nutrients accumulated at the homestead and then matching with what has been lost from field is important to draw a conclusive remark. Thus, assessment of soil fertility status and nutrient dynamics are imperative to come up with fundamental intervention methods to alleviate soil fertility depletion and the consequences on crop production and the environment.

Overall Objective

To enhance soil organic carbon and nutrients through crop residues management for sustainable crop productivity.

Specific Objectives

i. To determine status of selected soil properties under crop-livestock farming system of the study areas
ii. To evaluate phosphorus adsorption capacity of soils of the study areas.
iii. To determine the distribution, flow and cycling of organic carbon and nutrients under crop residue removal management practices.
iv. To determine effects of haricot bean residue incorporation on selected soil properties and maize grain yields under maize haricot bean intercropping system.

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CHAPTER TWO

Status of Selected Properties of Soils under Crop-Livestock Farming System in Eastern Ethiopia

Abstract

Information on soil properties and the fertility status of soils at farm levels under particular farming system is essential for boosting farm productivity and for sufficient food production. This study was conducted to investigate status and properties of soils under crop-livestock farming system, where crop grains are produced for food security and residues for animal feed and domestic fuel consumption. Two farms under similar farming system were selected from two districts in Eastern part of Ethiopia, Adele farm from Haramaya and Bala Langey farm from Kersa districts. Soil samples were collected from crop fields of each farm and analyzed following standard methods for soil physical and chemical analyses. The results indicated that soil textural class is sandy clay loam at both farms. The mean bulk density values were 1.43 and 1.39 g cm^{-3} for Adele and Bala Langey farms, respectively. The soil reaction for Adele farm was neutral (pH = 7.23) whereas soils of Bala Langey farm had slightly acidic reaction (pH = 6.57). Organic carbon contents of soils of both farms were low, less than 1.5%. Nitrogen was low for Adele farm soils (< 0.15%) and in the moderate range for Bala Langey farm soils (0.15-0.25%). Available soil P was very low at both farms (< 10 $mgkg^{-1}$). Extractable soil sulfur was also low for both farms (< 5 $mgkg^{-1}$). CEC of the soils of Adele farm was very high (> 50 $cmol(+)kg^{-1}$) and it was high (> 40 $cmol(+)kg^{-1}$) for Bala Langey farm soils. Exchangeable base contents and EDTA extractable micronutrients were in the sufficiency ranges for soils of both farms. This study indicated that very low phosphorus, low organic carbon and nitrogen followed by sulfur are the most productivity limiting factors associated with soil fertility that constraint productivity of the farms as a result of crop residues removal for animal feed and domestic fuel consumption. Intervention management should focus on the enhancement of organic carbon, phosphorus, nitrogen and sulfur.

Key words: Crop residue; farm; farm productivity; soil fertility; soil properties

Introduction

Crop-livestock farming system is a traditional and the main agricultural practice in the Eastern part of Ethiopia, where crop grains are produced for food security and residues for animal feed and domestic fuel. Sorghum stover is also used for construction by farmers who do not have adequate trees. Stover is mixed with wood for constructing houses and fences. Thus the contribution of crop residues in supporting the livelihood of small-scale farmers is significantly high in the farming system of the region. However, productivity of such farming system is being challenged by several constraints. Land degradation due to soil erosion, decline in soil organic carbon and nutrient depletion are among the main challenges contributing to low farm productivity [1; 2; 3]. Low farm productivity is common to the country in general and to the eastern part in particular.

Continuous mono-cropping with unbalanced nutrient application and nutrient mining have been reported as the causes for soil fertility depletion [4; 5] in the farming system of Ethiopia. As a result, farm productivity is limited to the minimum capacity and has failed to satisfy the demand for food in terms of quality and quantity [6; 7]. Maize and sorghum are the dominant food crops grown by farmers in the eastern part of the country for subsistence consumption. However, productivity of these crops remains generally low due mainly to soil fertility depletion.

The extent of soil fertility degradation and nutrients which are highly depleted and require immediate attention is not adequately addressed under the crop- livestock farming system of the region. The generalized soil fertility depletion context might not be applicable to all nutrients and farming systems. For instance, soil fertility depletion under agro-pastoral, agro-forestry and crop-livestock farming systems could not be the same. In view of this, assessment of the status of the nutrients is deemed necessary for designing interventions for alleviating soil fertility depletion problems under specific farming system.

Soil fertility depletion may also be aggravated due to mismanagement of crop residues and soil organic carbon (SOC). Since, crops residues have been used for animal feed and domestic fuel instead of being incorporated into soils for enhancement of soil fertility. Crop residues are important constituent in nutrient cycling in biogeochemical systems [8] if not removed from the crop fields where they have been produced.

The significant impacts of crop residues return on soil organic carbon and nutrients have been reported by several investigators [9; 10; 11; 12]. Nonetheless, the impact of crop residues removal on soil fertility and farm productivity has not been adequately addressed for the crop-livestock farming system of the eastern part of Ethiopia, where farmers practice the overall crop residue removal management for animal feed and domestic fuel consumption.

Information on fertility status is essential for boosting farm productivity and food production. However, detailed information on the fertility status of soils at farm levels under particular farming system is scarce in general and in the eastern part of the country in particular. Furthermore, as reported by [2], the recently available data on the fertility status of Ethiopian soils are mostly from on-station research and experimental plots.

Because of these, detailed studies of major soil properties and fertility status in relation to organic carbon and nutrient contents at farm level are the top priority issues of soil fertility management programs of Ethiopian agriculture. Ethiopia is launching a soil test based fertilizer recommendations management under the package of soil health and fertility management program (Ethiopian Agricultural Transformation Agency), with the target of site specific soil fertility management.

Comprehensive studies of soil properties and on the fertility status of the soils under specific farming system are thus vital so as to understand farm productivity limiting factors from the soil fertility perspective. The objectives of this study were to investigate selected soil properties under crop-livestock farming system and to identify farm productivity limiting factors associated with soil fertility status.

Materials and Methods

Description of the Study Farms

The study farms are in eastern part of Ethiopia at Haramaya and Kersa districts in Oromia Regional State. The two districts were selected based on the farming system of the region. One farm was selected from each district. Adele farmers' village from Haramaya and Bala Langey from Kersa district were selected. The farms were selected from a group of interested farmers who permitted the study to be conducted in their farms.

The geographical location of Adele farm at Haramaya district is between 09^{o}24`26``N, 041$^{o}$58`00``E and 09^{o}24`34`` N, 041$^{o}$58`04``E with an average altitude of 2075 m.a.s.l. Bala Langey farm at Kersa lies between 09^{o}25`41``N, 041$^{o}$47` 48``E and 09^{o}25`46``N, 041$^{o}$47`56``E with an average altitude of 2005 m.a.s.l. Information obtained from Haramaya University Meteorological station indicates that the mean annual rainfall and mean maximum and minimum temperatures of Haramaya district are 784 mm and, 24.36

and 9.61°C, respectively for the last 7 years (2007-13) as presented in Fig. 1. Data on rainfall and temperature were not available for Kersa district.

The components of the farming systems at the selected farms are crop-livestock production. The cropping systems are maize and sorghum intercropped with legumes. Haricot bean is the dominant legume intercropped with main crops in the cropping system of the region. Khat (*Cath edulis*) is the main cash crop for the whole farming systems of the region. Vegetables are grown during rainy seasons but, more so in the dry seasons where underground water is available for irrigating the crops.

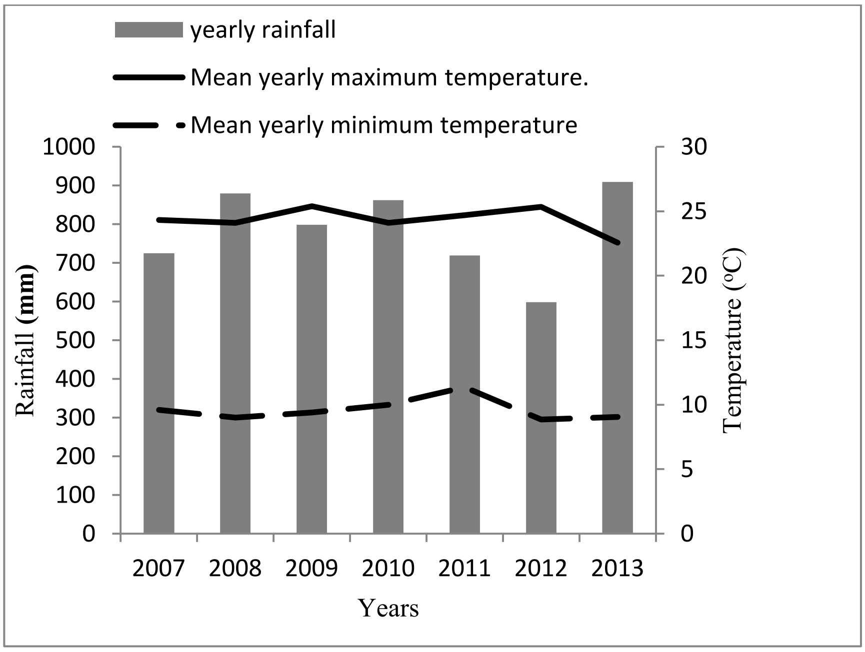

Figure 1: Yearly rainfall and mean maximum and minimum temperature of Haramaya district (2007 - 13)

The components of the livestock system are cattle, donkey, sheep, goats and poultry at both farms. There are no goats in Bala Langey farm. Livestock are used as sources of food (meat, milk and milk products) and as saving asset while manure is used for soil fertility management to some extent.

Site Selection, Soil Sampling and Analysis

Soil sampling sites were selected from the crop fields of 2.5 ha at Adele and 2 ha at Bala Langey farms along diagonal lines from one end to the other opposite end. Disturbed soil samples were collected with an auger from 16 representative sites, 8 along one diagonal line and 8 along the other diagonal line at a depth of 0-30 cm. Four composite subsamples were made from the 16 samples, 2 from samples collected along each diagonal line. The samples were air-dried and crashed to pass through 2 mm sieve. Subsamples were crushed to pass through 0.25 mm sieve for nitrogen and organic carbon analysis. Four undisturbed soil samples were also collected, 2 along each diagonal line using a core sampler of 2.50 cm radius and 5.50 cm height for the determination of dry soil bulk density to the depth of 0 – 30 cm.

Soil particle size distribution was determined by the Bouyoucos hydrometer method as described in [13]. Soil dry bulk density was determined following the procedure described by Blake [14]. Soil pH was measured in 1:2.5 soil-water suspensions. Organic carbon and nitrogen were determined following the method described by [15] and Kjeldahl method, as described by [16], respectively.

Exchangeable bases were extracted using ammonium acetate solution buffered at pH 7 [17]. Calcium and Mg were measured using Buck Scientific (AAS) model 210VGP atomic absorption spectrophotometer, in acetylene-air flame. Na and K were analyzed on Corning flame photometer. Cation exchange capacity (CEC) of the soils was estimated following the ammonium acetate procedure. The NH_4^+ ions were determined by ammonia (NH_3) distillation into sulfuric acid solution and then by back titration with dilute sulfuric acid.

Available phosphorus was determined by the Olsen method [18]. Extractable sulfur was extracted with calcium tetrahydrogen phosphate [17]. Sulfur ($S-SO_4^{-2}$) content of the extract was measured by turbidmetric method [16] using UV/Vis spectrophotometer; model T80+, PG Instruments. The extractable micronutrients (zinc, iron, copper and manganese) were measured by atomic absorption spectrophotometer after extraction with EDTA [16]. Sub soil samples were digested with mixed acids, perchloric and nitric acids [19] to estimate total nutrient (P, K, Ca, Mg, S, Zn, Fe, Cu and Mn) contents of the soils. Percent exchangeable or extractable nutrients were calculated as: $P = a/b \times 100$

Where: P = Percent exchangeable or extractable nutrient

a = Content of each exchangeable or extractable nutrient

b = Total content of each exchangeable or extractable nutrient

Results and Discussion

Soil Physical Properties

Soil texture and bulk density are the soil physical properties that were determined for the soils of the study farms**.** The results revealed that soil textural class was sandy clay loam at both farms with higher percentage of sand separates relative to clay and silt sized particles (Table 1). Soils textural class reveals that soils of both farms are expected to have good drainage and can possibly drain or leach ions. However, the values of percent base saturation (Table 4) depict that the soils are weakly leached. Furthermore, from the textural class perspective, soils of the two farms can be managed under similar management practices for crop production.

The mean bulk density values were 1.43 for Adele farms soils and 1.39 $gcm^{-3}$for Bala Langey farm soils (Table 1). As reported by [20], sandy clay loam soils with bulk density values above1.6 gcm^{-3} showed evidence of compaction which restricts root penetration and affects hydraulic conductivity and subsequently soil available water holding capacity. According to this concept, soils of the two farms under the current study do not have problems associated with soil bulk density.

Table 1: Selected physical properties of soils of Adele and Bala Langey farms

	Particle size distribution (%)			Textural	Bulk density
Farms	Sand	Silt	Clay	class	(gcm^{-3})
Adele	57.50	16.00	26.50	SCL	1.43
Bala Langey	56.25	14.25	29.50	SCL	1.39

*SCL=Sandy clay loam

Soils of the study farms have same textural classes, sandy clay loam, but different bulk density values. From the soil properties point of views, soil texture and organic carbon are the soil constituents which can contribute to the variability in soil bulk density values. Differences in the bulk density values of soils of the two farms can be attributed to differences in the organic carbon contents of the soils. Data in Table 2 show that the two soils have different organic carbon contents. The data also indicate that soil with relatively higher organic carbon content has lower bulk density value. Therefore, increasing soil organic carbon content through organic matter amendment is a mandatory management option for reducing higher bulk density values of soil for optimum crop production.

Soil Chemical Properties

Soil pH_w: Soil pH_w is the pH of the soil solution that plant roots and soil microbial are exposed to in the soil [20]. The mean pH_w values of the soils under the current study were 7.23 and 6.57 for the Adele and Bala Langey farms, respectively (Table 2). As per the pH ratings of [21], soils of the two farms had neutral reaction. However, the pH value for the

Adele soil was very close to lower range of mildly alkaline reaction whereas value for soils of Bala Langey farm was also very close to upper range of slightly acidic reaction. In general, the pH values of the soils of both farms are in the range of pH values desirable for most crops grown in the region. Furthermore, the pH, electrical conductivity (EC) and exchangeable sodium percentage (ESP) data (Tables 2 and 4) depict that the soils have no salinity or sodicity problems [22].

Organic Carbon and Total Nitrogen: The soil organic carbon contents for both farms were less than 1.5%, which is the upper limit of low range for agricultural soils [23]. Nitrogen was in the range of low (0.05 - 0.15 %) for Adele farm soils and moderate (0.15 - 0.25%) but very close to lower limit for Bala Langey farm soils [20]. Thus, organic carbon and total nitrogen contents of the soils of the farms were low (Table 2).

These low organic carbon and total nitrogen content of the soils could be attributed to non-incorporation of the biomass into the soils. Since, all the above ground biomass and crop residues are removed for animal feed and domestic fuel consumption. Furthermore, application of animal manure is also minimum or non to the crop fields.

Farmers are aware of the benefits of manure for the enhancement of soil fertility. Nevertheless, the quantity of manure from their farmyard is not sufficient for the replenishment of organic carbon and nitrogen taken away with the crop residues. These all together resulted in low organic carbon and nitrogen contents of soils of the two farms.

Table 2: pH, electrical conductivity (EC), organic carbon (OC) and total nitrogen (TN) contents of soils of Adele and Bala Langey farms (mean ± Standard deviation)

Farms	pH	EC (dS/m)	OC (%)	TN (%)
Adele	7.23 ± 0.08	0.103± 0.01	1.16 ± 0.09	0.15 ± 0.01
Bala Langey	6.57 ± 0.09	0.02 ± 0.003	1.41 ± 0.20	0.16 ± 0.01

Extractable Phosphorus: Olsen`s extractable phosphorus content of soils of both farms (Table 3) was less and below the lower limit of low range (10 $mgkg^{-1}$) of the P content of cultivated soils [24] for crop production. Nevertheless, total P content of the soils was very high 27.25 g Pkg^{-1} soil (116.90 ton Pha^{-1} to 0-30 cm depth) for the Adele farm and 19.40 g Pkg^{-1} soil (80.90 ton Pha^{-1} to 0-30 cm depth) for the Bala Langey farm (Table 3). Percentage extractable P from the total P of the soils was 0.007 and 0.04 for Adele and Bala Langey farm soils, respectively. These results indicate that P is the least extractable nutrient for Adele farm soils and the second least extractable for Bala Langey farm soils (Table 3).

The data in Table 3 reveal that soils with low extractable P have high total P in unavailable form to the plant roots. This calls for characterization of the soils in terms of their phosphorus adsorption capacity and a particular management option for the conversion of the unavailable phosphorus to be accessible to the plant roots. Organic matter amendment could be the best, because soils of Bala Langey farm with relatively higher organic carbon content had higher available and lower total phosphorus compared with Adele farm soils.

Sulfur: Sulfur is one of the macronutrient that plant demands in large quantity for optimum biomass production and for the synthesis of sulfur containing amino acids and proteins. Plant obtains sulfur from soils which exists in the available form (SO_4^{2-}). The mean values for extractable soil sulfur were less than 5 mg kg^{-1} for soils of both farms (Table 3), which is the upper range of very low phosphate extractable soil sulfur [25].

Table 3: Extractable, total, percent extractable phosphorus and extractable, total and percent extractable sulfur of soils of Adele and Bala Langey farms (mean ± Standard deviation)

Farms	Phosphorus			Sulfur		
	Extractable (mgkg^{-1})	Total (gkg^{-1})	Extractable (%)	Extractable (mgkg^{-1})	Total (gkg^{-1})	Extractable (%)
Adele	1.88 ± 0.86	27.25 ± 1.43	0.007 ± 0.003	2.36 ± 3.78	66.06 ± 8.90	0.004 ± 0.006
Bala Langey	8.21 ± 1.72	19.40 ± 2.11	0.04 ± 0.005	2.53 ± 3.35	39.11 ± 2.60	0.007 ± 0.009

Therefore, sulfur fertility management is not optional for these soils for sustainable crop production. On the other hand, total sulfur content of the soils was 66.06 g Skg^{-1} (28.34 ton Sha^{-1} to 0-30 cm depth) for the Adele farm and 38.89 g Skg^{-1} (16.22 ton Sha^{-1} to 0-30 cm depth) for the Bala Langey farm. Similar to total phosphorus, soil with low extractable sulfur had high total sulfur content. Higher total sulfur content which is not extractable may be from the sulfide minerals in soils which are hardly soluble in water. These minerals can be solublised through chemical or biological oxidation which is governed by the soil conditions.

Biological oxidation is carried out by microorganisms in the soil system. Presence of microorganisms in soil again depends on quantity and quality of soil organic carbon. However, organic carbon contents of soils of the two farms were low (Table 2) to support the biological oxidation of hardly soluble sulfur. This suggests that bioavailability of sulfur is affected by low soil organic carbon. Therefore, increasing soil organic carbon in terms of quantity and quality is essential for increasing bioavailability of sulfur.

Cation Exchange Capacity and Exchangeable Bases: Cation exchange capacity and exchangeable bases are soil quality indicators related to soil fertility status. The cation exchange capacity (CEC) of the soils of Adele farm was very high (Table 4), greater than 50 cmol (+) kg^{-1}. The very high CEC value is due to pH of the soil which is > 7.00 where presence of $CaCO_3$ is expected. For soils of Bala Langey farm CEC was high greater than 40 cmol (+) kg^{-1} according to the rating by [26].

The exchangeable Ca was very high for soils of Adele farm and high for soils of Bala Langey farm (Table 4). Exchangeable Mg was very high for soils of both farms. Exchangeable K was in the range of [0.7 - 2.0 (cmol(+)kg^{-1}] which is high range for potassium [20]. Thus, the exchangeable bases are sufficient for crop production.

The Ca to CEC ratio was in the range of (0.65 - 0.80) for soils of Adele farm, which is a normal range for many plants [21] but below the range for soils of Bala Langey farm (Table 4). The Mg to CEC ratio for soils of both farms was above the range suggested by [21]. Ratios for K to CEC were in the normal range (0.01- 0.05) for soils of the two farms. These ratios reveal that there are no soil fertility problems associated with CEC and exchangeable bases.

Magnesium is the dominant exchangeable base of the total basic cation analyzed for the soils of the two farms, followed by calcium then potassium. Sixty and 42% of Mg is exchangeable from the total Mg content of soils of Bala Langey and Adele farms, respectively, (Table 4). At both farms, the order of percentage exchangeable bases of the total is Mg > Ca > K, but the order of exchangeable bases from the soil exchange sites is Ca > Mg > K > Na (Table 4).

Percent base saturation (PBS) was very high for soils of Adele farm (> 80%) and high for soils of Bala Langey farm (> 60%) as per the rating by [21]. This suggests that the exchange sites of the soils are mostly occupied by basic cations and are weakly leached.
Exchangeable base contents of the soils of both farms are in the ranges of high and very high which indicate sufficiency of these nutrient for crop production. But organic carbon, phosphorus, nitrogen and sulfur are in lower or close to lower ranges for agricultural soils. This indicates productivity of the farms is definitely affected by soil fertility associated with organic carbon, phosphorus, nitrogen and sulfur.

Table 4: Cation exchange capacity, Exchangeable, total, percent exchangeable bases and percent base saturation of soils of Adele and Bala Langey farms (mean ± Standard deviation)

Exchangeable properties	Adele farm	Bala Langey farm
CEC (cmol(+)kg^{-1}	50.72 ± 1.64	46.87 ± 2.57
Exchangeable bases (cmol(+)kg^{-1}		
Ca	35.89 ± 2.19	20.05 ± 3.84
Mg	9.07 ± 0.12	13.03 ± 0.39
K	0.79 ± 0.02	0.76 ± 0.03
Na	0.32 ± 0.02	0.28 ± 0.02
Total bases (cmol(+)kg^{-1}		
Ca	176.08 ± 6.25	115.11 ± 5.37
Mg	21.25 ± 1.93	21.43 ± 0.86
K	14.81 ± 0.13	14.50 ± 0.50
PBS	92.81 ± 3.23	72.65 ± 4.82
ESP	0.63 ± 0.001	0.60 ± 0.001
Percent exchangeable bases		
Ca	20.38 ± 0.57	17.42 ± 3.33
Mg	42.68 ± 4.06	60.80 ± 2.92
K	5.33 ± 0.14	5.24 ± 0.09
Ratios		
Ca/CEC	0.71 ± 0.03	0.43 ± 0.07
Mg/CEC	0.18 ± 0.13	0.28 ± 0.04
K/CEC	0.02 ± 0.001	0.02 ± 0.003
Ca/Mg	3.96 ± 0.25	1.54 ± 0.34

Therefore, enhancement of soil organic carbon through crop residue incorporation or manure application is important for the intervention of soil organic carbon depletion. Phosphorus, nitrogen and sulfur fertilizers application rates should be studied at the field and in glass house. Fertilizers should be applied based on the study results.

Micronutrients: Micronutrients are essential elements for plant growth but required at the micro level by the plants. The concentrations of EDTA extractable micronutrients were much lower than the total contents in the soils of both farms under the current study (Table 5).

Single EDTA extractable micronutrients for soils of both farms follow the order Mn > Fe > Cu > Zn. [27] reported similar order for EDTA extractable micronutrients for some Ethiopian soils. On the other hand, the total soil micronutrient content follows the order Fe > Mn > Cu > Zn for the Adele farm. For the Bala Langey farm the order is Fe > Mn >Zn > Cu, which is the order for the abundance of these elements in the earth crust. This is also similar with the [28] report for total acid digested micronutrient concentration for Argentina soils. Difference in order of total Zn and Cu content of the soils may be because of the difference in chemical properties of the soils.

Percentage extractable follows the order of Cu > Mn > Zn >Fe indicating that more Cu but less Fe was extracted by single EDTA extraction compared with the total content in the soils. EDTA extractable micronutrient contents of Bala Langey farm soils were slightly greater than that of Adele farm soils. This can be attributed to the relatively lower soils pH value and higher organic carbon content. Similar to phosphorus and sulfur, total micronutrient contents of Adele farm soils were higher than that of Bala Langey farm soils. Therefore, soil properties and conditions are playing significant role in restraining the bioavailability of the nutrients. The extractable micronutrients concentration of soils of the two farms are above the critical values established by [29] and used by [30] and [31] for the assessment of micronutrient status of some Ethiopian soils.

Table 5: EDTA extractable, total and percent extractable micronutrients of soils of Adele and Bala Langey farms (mean ± Standard deviation)

Micronutrients	Farms	
	Adele	Bala Langey
Extractable ($mgkg^{-1}$)		
Cu	8.40 ± 0.49	8.54 ± 0.44
Fe	70.66 ± 5.42	91.39 ± 4.74
Mn	20356 ± 3.80	21078 ± 6.76
Zn	2.26 ± 0.62	2.51 ± 0.62
Total ($mgkg^{-1}$)		
Cu	13884 ± 4.62	64.35 ± 0.64
Fe	67780 ± 540	64350 ± 359
Mn	3620 ± 160	3.52 ± 0.38
Zn	68.85 ± 7.08	66.07 ± 3.12
Percent Extractable		
Cu	6.05 ± 0.49	12.49 ± 0.81
Fe	0.12 ±0.013	0.14 ± 0.02
Mn	5.62 ± 0.36	5.98 ± 0.58
Zn	3.28 ± 1.01	3.80 ± 0.88

In general, the micronutrient contents of soils of both farms are in the sufficiency range [26] except Zn which is in the medium range. Therefore, even though EDTA extracts more micronutrients, fertility enhancement of these nutrients is not as serious as organic carbon, phosphorus, nitrogen and sulfur for soils of both farms. Thus, management should focus on sustainable utilization and monitoring of the micronutrients in relation to the crops grown seasonally on the soils.

Conclusions

The textural class of soils of both farms is sandy clay loam. At both forms the soils do not have problems associate with bulk densities. The pH of the soils is in the range for most crops grown in the region. There are no salinity or sodicity problems at both farms.

Organic carbon, nitrogen, extractable phosphorus and sulfur are low at both farms. Except nitrogen which was moderate for soils of Bala Langey farm. Cation exchange capacity and exchangeable bases are very high for Adele farm soils and high for Bala Langey soils and are sufficient for crop production. Micronutrient contents of the soils are also sufficient.

In general, soils of the studied farms do not have fertility problems associated with pH, CEC, exchangeable bases and micronutrients. However, extractable phosphorus, organic carbon and nitrogen followed by sulfur are the most limiting soil fertility factors contributing to the lowest productivity of the farms. Therefore, intervention management should focus toward the enhancement of soil organic carbon, phosphorus, nitrogen and sulfur.

Soil organic carbon can be enhanced through crop residue incorporation or animal manure application. Phosphorus, nitrogen and sulfur fertilizers application rates should be studied at field and in glasshouse and applied based on the study results.

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CHAPTER TREE

Phosphorus Adsorption Isotherm: A Key Aspect for Soil Phosphorus Fertility Management

Abstract

Characterization of soils in terms of phosphorus adsorption capacity is fundamental for effective soil phosphorus fertility management and for efficient utilization of phosphorus fertilizers. This study was conducted to investigate the phosphorus adsorption characteristics of soils of two farms and to elucidate the implications of soil phosphorus adsorption isotherm studies for soil phosphorus fertility management. The two farms, representing the major farming systems of the respective districts were selected from Adele village in Haramaya and Bala Langey village in Kersa disricts in eastern Ethiopia. Soil samples were collected from the crop fields at Adele and Bala Langey farms. Two different P-bearing sources, potassium dihydrogen phosphate (KH_2PO_4) and diammonium phosphate (DAP-$(NH_4)_2HPO_4$) were used for the adsorption isotherm studies. The P-adsorption data were fitted to the linear and Freundlich adsorption isotherm models. Both models revealed that soils of both farms had different P adsorption capacity from the two P sources. Amounts of P adsorbed from DAP solution was higher than amount of P adsorbed from KH_2PO_4 solution by soils of both farms. Phosphorus adsorption capacity of Adele farm soils was higher than that of Bala Langey farm soils. Therefore, soils of the two farms should be managed differently for P fertility. Percentages of P adsorbed (%Pa) and P remained in the equilibrium solution (%EC) were also calculated. By plotting the two percentages i.e. % Pa and % EC against the initial concentration of P (IC), two regions were observed. The two regions were described as P intensity and quantity factor windows. Based on the intensity and quantity factor windows, at currently existing soil

condition, between 200 and 500 $kgha^{-1}$ P should be applied as fertilizer to soils of Adele farm at 0-30 cm depth for immediate benefits and soil P fertility maintenance.

Key words: Phosphorus sources; P-fertility; P- intensity-quantity factor window

Introduction

Phosphorus is one of the 17 essential elements for plant growth and development. Plants obtain phosphorus from the soil solution which is either from the weathering of the parent materials or from the applied fertilizers. However, accessibility of phosphorus applied with fertilizers to plant is governed by different factors such as phosphorus adsorption-desorption characteristics of soil, soil texture, soil organic matter content and management practices [1; 2]. Therefore, understanding interaction of phosphorus with those factors in soil is crucial for soil phosphorus fertility management and for sustaining phosphorus in pedobiochemical cycle.

In the soil system, phosphorus exits in two forms; the labile form which is weakly adsorbed on the surface of soil particles which is considered as not readily accessible to the plant. The other form is a portion of phosphorus in soil solution which is readily accessible to the plant [3]. The labile phosphorus is in equilibrium with phosphorus in soil solution and may be available to plant. But the rate of release is very slow and may not be available to the plant within the short period of crop reproductive cycle. The equilibrium between labile P and solution P will be disturbed when a phosphate fertilizer is applied to soil. This leads to rapid adsorption of P on the surface of soil particles and makes phosphorus to be more firmly held [4]. As a result, the amount of phosphorus adsorbed on the surface of soil particles increases while the quantity of phosphate ions in soil solution decreases.

The amount of phosphorus adsorbed on the surface of soil particles is termed as the quantity factor and the phosphate ions remaining in soil solution is the intensity factor [5].These factors are very important for soil phosphorus fertility management. Phosphorus adsorption isotherm describes the interdependence of these two factors i.e. the intensity and the quantity factors. In a simple term, phosphorus adsorption isotherm is a plot of quantity factor against intensity factor [6]. The ratio of the quantity factor (Q) to intensity factor (I) is the buffering capacity of the soil [5; 7]. This governs soil phosphors supply to plants.

Phosphorus adsorption isotherm is the most useful experimental procedure for studying interaction of phosphate ions with soil constituents [8; 4]. It is also a useful parameter to monitor availability of phosphorus to plants. Furthermore, phosphorus adsorption isotherm study can help to describe phosphorus dynamic in the soil system. Characterization of soils in terms of phosphorus adsorption capacity is crucial for effective and efficient utilization of phosphorus fertilizers with respect to quantity, type and placement [9]. Thus, phosphorus adsorption isotherm is a key aspect for soil phosphorus fertility management.

Many workers have investigated phosphorus adsorption characteristic of soils from the environmental sustainability point of views [10; 11; 12]. Others reported that phosphorus adsorption characteristic of soil is affected by soil clay and organic matter contents [13]. In fact, this is directly related to soil fertility. In almost all the studies cited above, KH_2PO_4 was used as phosphorus source for the laboratory studies of soil P adsorption isotherm, which is rarely applied to soil as fertilizer. DAP is commonly being applied as phosphorus fertilizer for soil fertility management in Ethiopia. However, phosphorus adsorption characteristics of soils and impacts of DAP on soil properties when applied as fertilizer have not been studied for soils of eastern Ethiopia.

In general, phosphorus adoption characteristic of soils of the eastern part of Ethiopia is not well investigated either from the environmental or soil fertility management perspectives. Therefore, the objectives of this study were to investigate the P-adsorption capacity of soils of the study areas using two different P-bearing sources; potassium dihydrogen phosphate (KH_2PO_4) and DAP, and to elucidate the implication of soil phosphorus adsorption isotherm for soil phosphorus fertility management.

Materials and Methods

Soil samples for the study were collected from two farms at Adele in Haramaya district and Bala Langey in Kersa district, Oromia Region, Eastern Ethiopia. Both farms were selected as representatives of the respective farming systems of the districts. From each crop field of the farms 16 sampling points were selected and soil samples collected from 0-30 cm depth. One composite sample was made from soils collected from the 16 representative sampling points of the crop fields of each farm. Some properties of the soils are presented in Table 1.

Table 1: Some physical and chemical properties of soils from the crop fields of Adele and Bala Langey farms

Sampling sites	(%) Sand	(%) Silt	(%) Clay	Textural class	pH	(%) OC	Olsen P(mg/kg)	Total P (g/kg)
Adele farm	58	17	25	SCL	7.24	1.21	1.56	28.97
Bala Langey farm	58	13	29	SCL	6.53	1.45	8.74	17.13

*SCL = Sandy clay loam

Twenty four, 100 ml capacity plastic bottles were prepared and arranged in two rows, each row containing 12 bottles. One gram air dried soil (<2mm) from Adele farm was placed in every bottle in each row. The rows were labeled as 1st and 2nd. Every bottle within the row was labeled with the P sources, KH_2PO_4 used for P adsorption study in the laboratory and DAP commonly applied as P fertilizer for crop production in the region.

Twenty five ml of 1.0, 5.0, 10, 20, 30, 40, 50, 60, 70, 80, 90 and 100 mgL^{-1} P solution made from KH_2PO_4 and DAP were added to the respective labeled bottles containing the soil. A supporting electrolyte of 10 mM $CaCl_2$ solution was added to all bottles and the contents in the bottles were shaken continuously for 24 hours at 22 $\pm$ 2^{o}C on an orbital shaker at 300 rpm [14]. After the equilibrating time, the contents of each bottle were filtered through Whatman No. 42 filter paper. Three ml of the filtrates were taken for color development with ammonium molybdate solution containing potassium antimony tarterate and ascorbic acid [15]. The P contents of the filtrates were read on a spectrophotometer (model T80+) at 880 nm after the development of the blue color. Same experiment was repeated for the soil from Bala Langey farm.

Adsorbed P was calculated as the difference between initial and final concentration of P in the equilibrium solution. The adsorption data were fitted to the linear model and Freundlich adsorption isotherm model as described:

Linear Model: $x/m = a + bc$ Freundlich Model: $x/m = kfc^{1}/^{n}$

Linear form of Freudlich model: $\log x/m = \log kf + 1/n \log c$

Where:

c = Concentration of P in equilibrium solution (EPC) (mgL^{-1})

x/m = Amount of P adsorbed (mg kg^{-1})

kf = Proportionality constant for the Freundlich model ($mgkg^{-1}$)

1/n = Slope of the curve, when logx/m vs logc was plotted

a = Y-intercept, when x/m vs c was plotted ($mgkg^{-1}$)

b = Slope of line, when x/m vs c was plotted. Slope is the buffering capacity of soils with respect to P and clay contents [16]

Percentages of P adsorbed (Pa) and P in the equilibrium solution (EC) were calculated for the adsorption data of DAP solution as:

$\%Pa = [(IC – EC) \times 100]1/IC$ $\%EC = (EC/IC) \times 100$

Where:

Pa =Phosphorus adsorbed from initial solution (mgL^{-1}) = Quantity factor

IC = Initial phosphorus concentration (mgL^{-1})

EC = Equilibrium phosphorus concentration (mgL^{-1}) = Intensity factor

%Pa = Percentage of adsorbed phosphorus from initial solution

%EC = Percentage of phosphorus in equilibrium solution

Values for the two percentages (%Pa and %EC) were plotted against initial concentration (IC) of P to determine the intensity and quantity factors region or windows for soil of the two farms from DAP adsorption data.

After equilibrating time, pH of the soil suspension to which DAP was added for the adsorption isotherm study also measured with pH glass electrode. Similarly, pH of soil samples collected from experimental sites established within the crop fields at both farms, where DAP was applied at the rate of 100 $kgha^{-1}$ for two consecutive cropping seasons was measured. The soil sampling was done before planting in 2012 and 2013, and after harvesting in 2014. The pH was measured for 1:2.5 soil water suspensions with combined pH glass electrode.

Results and Discussion

Phosphorus Adsorption Characteristics of the Soils

The adsorption data were calculated and fitted to the adsorption isotherm models. It was found that the adsorption isotherm data best fit to the linear model and Fruendlich adsorption isotherm model than the other models. The linear model and Fruendlich adsorption model revealed that soils of the two farms have different P adsorption capacity from KH_2PO_4 and DAP solutions used as P sources for the study (Figures 1 a and b). The adsorption isotherm data showed that amount of P adsorbed by soils from both farms increased with the increased concentration of phosphorus in initial solution of the two P-sources.

As shown by Figures 1 a and b, at lower concentration amount of P adsorbed from DAP solution is greater than that of P adsorbed from KH_2PO_4 solution by the soils. This can be attributed to the differences in chemical properties of the two compounds used as P-sources. Upon dissolution in water the two compounds yield different phosphate ions as indicate below:

$$KH_2PO_4 + H_2O = K^+ + H_2PO_4^-$$

$$(NH_4)_2HPO_4 + H_2O = 2NH_4^+ + HPO_4^{2-}$$

Thus, one phosphate anion is released from 1 mole of KH_2PO_4 and two phosphate anions from 1 mole of $(NH_4)_2HPO_4$, which are readily absorbable on the soil anion exchange sites.

The P adsorption capacity of Bala Langey farm soils from DAP was not as high as that for Adele farm soils (Figures. 1 a and b). Even though, there were differences between the two soils from the two farms in P adsorption capacity, more P was adsorbed from DAP solution by the soils of the two farms compared with KH_2PO_4 solution (Figures. 1 a and b). This suggests that when phosphorus is applied as fertilizer, its accessibility to plant is threatened by the soil factors and the chemical and physical properties of the fertilizers applied. Therefore, studies of soil phosphorus adsorption characteristics as affected by P sources could be very effective for soil P fertility management and for efficient utilization of P fertilizers.

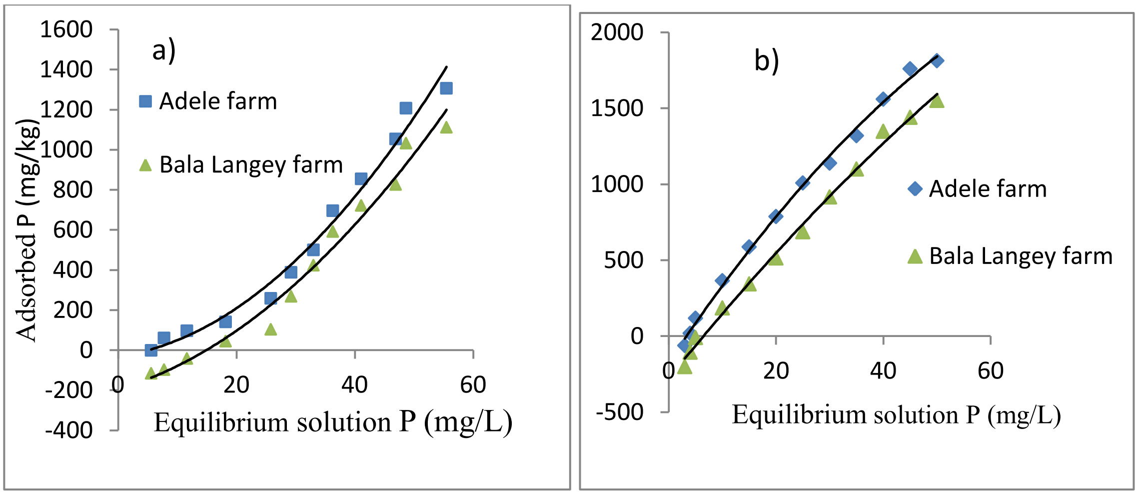

Figure 1: Phosphorus adsorption characteristics of soils of the two farms as was affected by different P sources KH_2PO_4 (a) and DAP (b) solutions

Soil organic carbon, clay mineralogy and content, calcium carbonate and soil pH are among the main soil constituents that are responsible for differences in phosphorus adsorption characteristics of soils. It has been reported by several investigators [17; 4; 1; 2; 3] that P adsorption is positively correlated with soil clay, calcium carbonate contents and pH, and negatively correlated with soil organic carbon content. Rajput et al. [18] also reported soils with higher available P as well as organic matter content adsorbed less applied P than soils with lower organic matter content.

However, soils from Bala Langey farm with relatively higher clay content adsorbed less P than the Adele farm soils (Table 1 and Fig. 1). Therefore, higher P adsorption capacity of

Adele farm soils than Bala Langey farm soils can be attributed to its relatively lower organic carbon, higher calcium carbonate and pH value.

The linear and Fruendlich models indicate that soils of Adele farm had higher P adsorption capacity from DAP as well as from KH_2PO_4 solutions than Bala Langey farm soils (Figures. 1 a and b). These reveal that soils of the two farms demand different P fertility management strategies to increase the soils productivity. Nevertheless, the soil P fertility management strategy of the extension offices of the two districts is 100 kg DAP ha^{-1} which is a blanket recommendation rate for P fertilizer application. These soils should therefore be managed differently for P fertility.

The slopes of the linear model for the Adele farm soil were 40.27 and 27.32, respectively for both P sources, DAP and KH_2PO_4 (Table 2). This describes that for 1 unit increases in P concentration adsorption increases by 40.27 and 27.32 units respectively for the soil. Slopes of Fruendlich model were also 0.156 and 0.135 for the same soil, respectively for DAP and KH_2PO_4. These again indicate an increase in P adsorption by 0.156 and 0.135 for a unit increase in P solution concentration. Therefore, these clearly show that phosphorus sources have considerable impact on phosphorus adsorption characteristics of soils.

The Y-intercepts of the linear model were -271.30 (KH_2PO_4) and -77.45 (DAP) for soils of Adele farm (Table 2). These suggest that there is about 271.30 and 77.45 mg kg^{-1} P desorption from the soil when concentration of P is zero in initial solutions. Practically, it is not possible to obtain two observations with such large difference for the same solutions of zero concentration. Therefore, this can be explained as: when the concentration of P in the solutions is very close to zero more P will be desorbed from the soils into KH_2PO_4

solution than into DAP solution. This also indicates soil P-desorption depends on the properties of the P sources applied as fertilizers.

Table 2: Linear model and Freundlich adsorption model parameter for soils of Adele and Bala Langey farms

Soils	P-sources	Linear model parameters			Freundlich model parameters			
		Intercept	Slope	R^2	Intercept Log(Kf)	Kf	Slope (1/n)	R^2
Adele farm	KH_2PO_4	-271.30	27.32	0.944	1.79	61.66	0.135	0.95
	DAP	-77.45	40.27	0.990	1.83	67.61	0.156	0.748
Bala Langey farm	KH_2PO_4	-375.40	26.09	0.953	1.78	60.23	0.162	0.868
	DAP	-230.20	37.41	0.993	2.32	208.93	0.109	0.917

The Y-intercepts for Bala Langey farm soils were also -375.40 (KH_2PO_4) and -230.20 (DAP) (Table 2). As explained above for Adele farm soils, these also show desorption phenomenon at very low concentrations of P. But the Y-intercept values were much higher in magnitude than the Y-intercept values for the Adele farm soils of higher adsorption capacity. This indicates that soils with less adsorption capacity have higher desorption capacity with respect to the phosphorus sources. Therefore, the sorption isotherms clearly depict that phosphorus adsorption/desorption characteristics of soil is a function of soil physico-chemical properties and the chemical and physical properties of fertilizers applied as source of phosphorus.

Phosphorus Intensity and Quantity Factor Windows of Soils of Adele and Bala Langey farms from Adsorption Isotherm Data of DAP Solution

Phosphorus intensity and Quantity Factor regions (windows) for both farm soils were created from the percentages of adsorption isotherm data i.e. %Pa and %EC. By plotting the two percentages against the initial concentration of P, two regions were observed at the left and right sides of the intersection point in between the line joining the points (Figures 2 a and b).

The region to the left side of the intersection point, with higher percentage of phosphorus in solution represents the intensity factor whereas the region to right side with higher percentage of adsorbed phosphorus represents the quantity factor when P fertilizers are applied to the soil systems. The two regions were described as intensity and quantity factor windows.

The widths of the two windows are interdependent i.e. when the width of intensity factor increases the width of the quantity factor decreases. This exactly demonstrates the P dynamics in the soil systems. The two windows for the study soil revealed the same situation. Adele farm soils with lower available P, higher total P and higher adsorption capacity had narrower intensity factor window and wider quantity factor window (Table 1 and Fig. 2a). Contrary to this, Bala Langey farm soils with relatively higher available P, lower total P and lower adsorption capacity had wider intensity factor window and narrower quantity factor window Table 1 and Fig. 2b.

Furthermore, Figures 2 a and b indicate that the two lines can never cross the Y-axis. This describes the real situation that concentration of P can never be zero in solution and/or in adsorbed form for the materials defined as soil. When the two percentages were plotted against the initial concentration of phosphorus solution, two equilibrium points were also observed. One is at the point where the adsorption line crosses the X-axis and the other is at the intersection of the two lines (Figures 2 a and b). The 1st equilibrium point indicates concentration of P at which adsorption was exactly equal to desorption. The 2nd equilibrium point also indicates concentration of P at which concentration of adsorbed P was equal to concentration of P in equilibrium solution i.e. 50% of the applied P was adsorbed and the remaining 50% was in the soil solution.

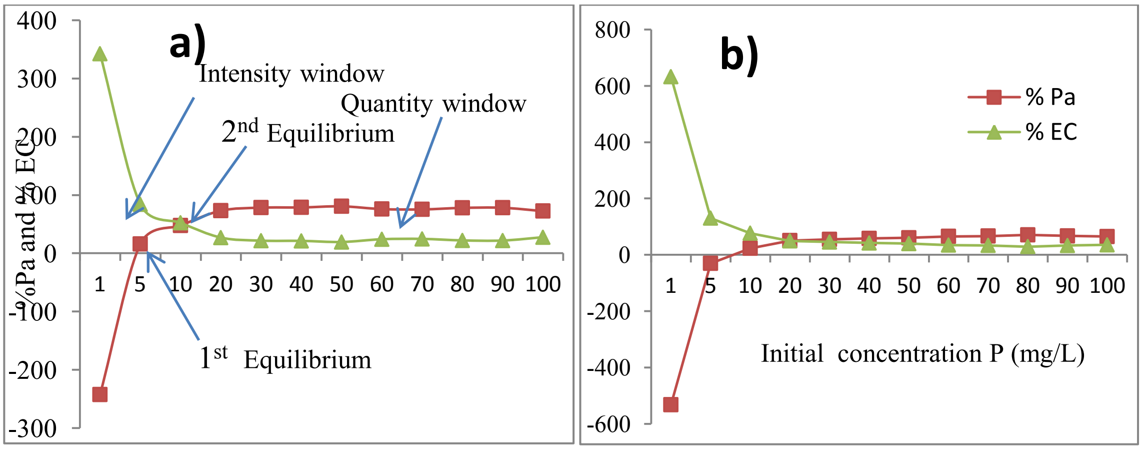

Figure 2: Phosphorus Intensity and quantity factor windows for soils of Adele (a) and Bala Langey (b) farms from adsorption isotherm data of DAP solution

The two equilibrium points have an implication for soil P fertility management. For instance, continuous application of P less than the concentration at the 1st equilibrium point would be resulted in the depletion of native soil P. This is in a way explains the reports by the farmers, "fertilizer is killing our soils". Even though, it was not recommended based on studies farmers of the study farms apply P less than the blanket recommendation of 100 kg DAP ha^{-1}, which is less than the quantity at the 1st equilibrium point. Thus, application of P fertilizer at a rate adjusted to the concentration of P between the two equilibrium points based on the crop requirements maintain more P in soil solution for immediate benefits. More application of P greater than the concentration at the 2nd equilibrium point ends with soil P build up. The above therefore, gives a baseline for soil P fertility management.

The adsorption isotherms (Figures 1 a and b) could not indicate quantity of P to be applied as fertilizers to alleviate the problems associated with higher P adsorption by the soils or to replenish depleted P. But the intensity and quantity factor windows were able to show the quantity of P to be applied either to be in the intensity factor window or in the quantity factor window.

If the manager of Adele farm is for example, interested in immediate benefits from P application at the currently exiting soils conditions, he/she should apply greater than 2.5 ppm (200 kg Pha^{-1} to the depth of 30 cm) and less than 10 ppm (500 kg Pha^{-1} to the depth of 30 cm). Therefore, P fertilizer application for the immediate benefits should be in between the 1st and 2nd equilibrium points for the 1st season and then be applied based on quantity of P taken up or exported, and crop requirements per cropping seasons.

This seems unachievable from economic points. But there are options, for instance the values of Pha^{-1} presented above were calculated from the soil bulk density values. Therefore, if a farmer is able to reduce soil bulk density through organic matter amendment, regardless of the contributions of organic matter to P availability, then he/she could reduce those values calculated above. Because organic matter addition could reduce P adsorption [19; 20], which means organic matter amendment can narrow down the quantity factor window and make wider the intensity factor window.

Thus the soil phosphorus intensity and quantity factor windows help the manager of the farm to make a decision. The manager can decide either to deplete his/her soils by applying less amount of phosphorus up to the point that soil will no longer be productive or maintain the soil phosphorus. Soil P maintenance could be achieved through application of adequate and suitable P fertilizers based on the quantity and intensity factor windows of the soils. Similarly, soil P intensity and quantify factor windows can also be established by studying P sorption isotherm of a particular soil. Therefore, soil phosphorus adsorption isotherm study is a key aspect for soil phosphorus fertility management.

Impacts of Diammonium Phosphate (DAP) Fertilizer on Soil Solution pH

The pH of the equilibrium solution of soils shaken with DAP solution was measured after the equilibrium time to investigate changes in the soil properties induced upon application of DAP to the soil system. Changes in the pH of the equilibrium solution were observed increasing as the concentration of P increased in the initial DAP solution. Changes in pH were rapid for the lower concentration ranges and increased slightly with increased in the P concentration (Fig. 3a). This indicates soil pH buffering capacity against changes in phosphate ions concentration increases with increase in phosphate ions concentrations.

The same was observed for the soil samples collected from the same farms where DAP was applied as P source at the rate of 100 kg ha^{-1} (18 kg N and 46 kg P_2O_5) over two consecutive cropping seasons (Fig. 3b). 100 kg DAP ha^{-1} is the blanket rate for the region. But farmers apply about 4 times less than the recommended rate to plots of selected crops.

The pH increased from 7.28 to 8.01 with 0.75 units for soil from Adele farm and from 6.54 to 7.43 with 0.89 units for soil from Bala Lang farm over the two consecutive cropping seasons (Fig. 3 b). Change in pH for Bala Langey farm soils with relatively lower initial pH was higher than changes in pH for the Adele farm soils. This shows, soils of Adele farm with higher P adsorption capacity had relatively higher pH buffering capacity against DAP application. The pH of equilibrium solutions was also observed increasing as the amount of DAP increased for soil P adsorption characteristics from DAP solution. Similarly, soil pH was also increased upon DAP application at a rate of 100 $kgha^{-1}$for two consecutive cropping seasons. These changes in soil pH over a short periods i.e. two cropping seasons therefore, put under question the suitability of DAP to those soils if the application doses would be increased.

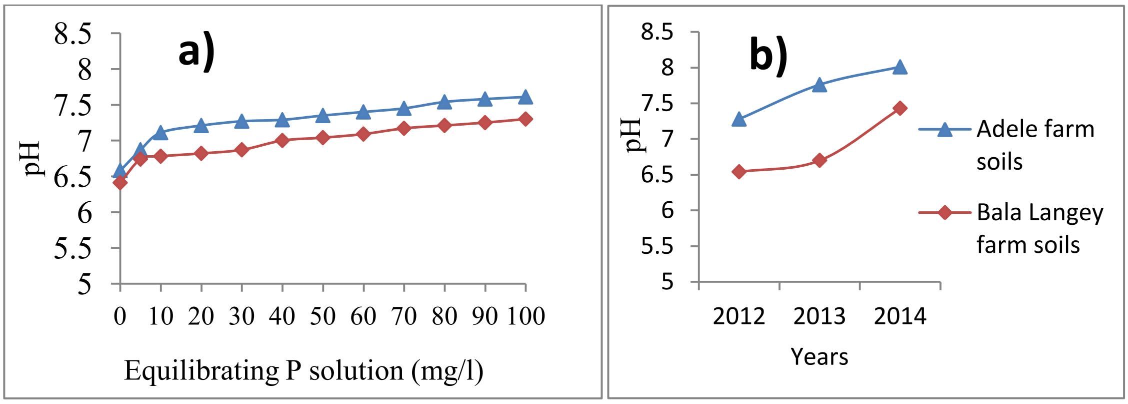

Figure 3: Changes in pH with increase in P concentration of the equilibrium solution from DAP (a) in laboratory and in soil solution upon application of DAP fertilizer (b) at fields

Conclusions

Soils of the two farms had different P adsorption capacity from the two P sources DAP and KH_2PO_4. More P was adsorbed from DAP solution than from KH_2PO_4 solution by soils of the two farms. Phosphorus adsorption capacity of Adele farm soils was higher than that of Bala Langey farm soils. The soils of the two farms should be managed differently for P fertility. Based on these lab results, between 200 and 500 $kgha^{-1}$ P should be applied as fertilizer to soils of Adele farm at 0-30 cm depth for immediate benefits and soil P fertility maintenance. Suitability of DAP as source of phosphorus fertilizer for soils of the study areas should be further investigated at field and in laboratory.

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CHAPTER FOUR

Spatial Distribution of Organic Carbon and Nutrients under Farmers' Crop Residue Management Practices in Eastern Ethiopia

Abstract

Understanding the distribution and transport of organic carbon and nutrients under any management in a farming system is vital for predicting the sustainability of a farming system. This study was conducted to characterize the spatial distribution and transport of organic carbon and nutrients under farmer's crop residues management that involves complete removal of the residues and to identify which nutrients are highly affected by such management practices. Two farms, representing the major farming systems of the study areas, were selected from Adele and Bala Langey villages in Haramaya and Kersa districts, respectively in Eastern Ethiopia. Soil samples were collected along the slope gradient from the crop fields and at a given distance from home in homesteads of each farm from a depth of 0 – 30 cm. The samples were analyzed following standard methods for soil organic carbon and nutrient analyses. Results indicated that distribution of organic carbon and nutrients was affected by slope gradients in crop fields and by distances in homesteads at both farms. Results also indicate that 2.95 and 2.15% OC, 0.52 and 0.25 % N, 100.15 and 41.23 $mgkg^{-1}$ available P, and 25.05 and 1.65 $mgkg^{-1}$ extractable S were accumulated near homes of the households at Adele and Bala Langey farms, respectively. Quantities of OC, N, P, and S were less than 2%, 0.15%, 25 $mgkg^{-1}$ and 2 $mgkg^{-1}$, respectively in the crop fields at both farms. About 4.70 and 5.60 g N/kg dry matter was transported through haricot bean residue from Adele and Bala Langey crop fields, respectively. The extent of crop residue removal management effects on the distribution of the nutrients, from the most to the least affected, follows the order P > OC > S > N > exchangeable bases > micronutrients at both farms. Intervention management should focus on reversing the flow of organic carbon and nutrients from crop fields to the homesteads and minimizing unequal distribution of organic carbon and nutrients in the farming system at both farms.

Key words: farm, homesteads, crop fields, slope gradient, farm sustainability

Introduction

Crop residue removal management practice is as old as the crop-livestock farming system in the eastern part of Ethiopia. After harvesting crop grains, residues have been collected from crop fields and transported to the homesteads for animal feed and domestic fuel consumption. Crop residues are among the main sources of soil organic carbon and nutrients if properly managed. Bahrani *et al.* [1] reported that mismanagement of crop residues such as burning and continuous removal from the crop fields is one of the main causes for soil fertility depletion. Yadvinder-Singh *et al*. [2] reported that crop residues are an important constituent in nutrient cycling in biogeochemical system. Crop residues have also been known to supply organic carbon and nutrients for soil microorganisms and plants [3; 4].

Thus, crop residues removal affects not only soil organic carbon and nutrient contents and distribution in soils and in the farming system but also the biological activities in soils as well as in the farming system. Crop residues removal restrains the in-situ recycling of nutrients in the crop fields and subsequently decline in soil fertility.

Studies by [5; 6; 7; 1] have shown that incorporation of crop residues significantly improved soil pH, organic matter, CEC, available phosphorus, exchangeable bases and grain yields per unit area. Proper crop residues management is also important for monitoring environmental quality and for soil conservation. Retaining crop residues as surface cover has been reported [3] and [8] as an important conservation technique for soil erosion control and soil moisture conservation. Therefore, retention and/or incorporation of crop residues into soils are important for agronomic and ecological benefits.

Crop residues removal has negative impact on all the benefits indicated above. Furthermore, crop residues removal and transport could result into unequal distribution of organic carbon and nutrients in the farming system. Crop residues removal management can also affect flow of organic carbon and nutrients in soil and farming system. Hence, organic carbon and nutrients distribution, flow and cycling are sensitive to management practices being implemented in the farming system. Castillo and Wrightot [9] observed that nutrient dynamics is often highly affected by land use systems and the associated management practices. Therefore, understanding the distribution, transport, flow and cycling of organic carbon and nutrients under any management practice in a farming system is as important as understanding the sustainability of the farming system.

However, distribution and transport of organic carbon and nutrients under farmer's crop residues management practice, which involves all above ground biomass removal, in the eastern part of Ethiopia are not well investigated. Impacts of crop residues removal on soil fertility and environmental quality are not also well documented. Understanding the distribution, transport, flow and cycling of organic carbon and nutrients is also vital for designing the intervention scenarios before the farming systems get threatened. Therefore, the objectives of this study were to characterize the distribution and transport of organic carbon and nutrients under overall crop residues removal management and to identify which nutrients are highly affected by such management practices.

Materials and Methods

Description of the Study Sites

The study sites were selected from two districts, Haramaya and Kersa in Oromia Region, part of Eastern Ethiopia. The specific location of the study sites are at Adele village in Haramaya and Bala Langey village in Kersa districts. One farm was selected from each village in respective districts as representative for the farming system of the districts. The geographical location of Adele farm at Haramaya district is between 09°24`26``N, 041°58`00``E and 09°24`34`` N, 041°58`04``E and 2075 m.a.s.l. Bala Langey farm at Kersa lies between 09°25`41``N, 041°47` 48``E and 09°25`46``N, 041°47`56``E and 2005 m.a.s.l.

Information obtained from Haramaya University Meteorological Station indicates that the mean annual rainfall and mean maximum and minimum temperatures of Haramaya district are 784 mm and, 24.36 and 9.61°C, respectively for the last 7 years (2007-13). Data on rainfall and temperature were not available for Kersa district. The rainfall pattern of Haramaya district is bimodal starting from March to September with high rainfall intensity in July and August.

Structurally, home of the household at the Adele farm is within the farm system at the lower slope whereas home of the household at Bala Langey farm is disconnected from the cultivated land for crop production. The total area of land for the farming system at the Adele farm is 3 ha and 2.5 ha for the Bala Langey farm. Crop field from where soil samples were collected for the study are 250 m far from the home of the household at the Adele farm. Home of the household at Bala Langey farm is about 700 m away from the crop fields. Between home of the household and the crop field at Bala Langey farm, there are other farms that disconnected the crop field from the homesteads.

Soil Sampling and Analysis

For the determination of organic carbon and nutrients distribution in the crop fields, nine soil sampling sites were selected at both farms on the contour line based on the slope gradients. Slope gradients were measured at each sampling site. The distances between the selected sites were 25 m on the contour line and 50 m along the slope gradients from each other at both farms. Soil samples were collected along the slope gradient from each sampling sites at a depth of 0-30 cm with auger.

Soil sampling sites were also selected from the homesteads at a distance of 10, 25, 50, 75 and 100 m away from home to the north, north east and northwest direction at the Adele farm. Directions of soil sampling sites at Bala Langey farm were to the south and east with the same distance from the home as for Adele farm. Soil samples were collected from each sampling site at the depth of 0-30 cm with auger. Composite subsamples were made from collected samples with their respective slope gradients in the crop fields and distance from the homes. All samples were air-dried and crashed to pass through a 2 mm sieve. Subsamples were reduced to the size of 0.5 mm for the analysis of nitrogen and organic carbon.

Organic carbon was determined following the wet oxidation method of Walklely and Black [10]. Nitrogen was analyzed by Kjeldlehl method as described in [11]. Phosphorus was determined by Olsen method [12]. Sulfur was extracted with calcium tetrahydrogen phosphate ($CaH_4(PO_4)_2.H_2O$) [13] and the extract was measured by turbidmetric method as described in [11] using spectrophotometer. Exchangeable bases (Ca, Mg and K) were extracted using ammonium acetate solution buffered at pH 7 [13]. Calcium and Mg were measured by Buck Scientific (AAS) model 210VG atomic absorption spectrophotometer in acetylene-air flame. Potassium was analyzed on Corning flame photometer; model 410.

The micronutrients (Cu, Fe, Mn and Zn) were extracted with EDTA [11] and measured by atomic absorption spectrophotometer.

Crop residue samples were also taken from the sorghum, maize and haricot bean residues collected by the farmer for animal feed and domestic fuel at both farms after harvesting in 2013 cropping season. The residue samples were chopped and air dried. Subsamples were taken and oven dried at 70 ^{o}C to constant weight. The oven dried samples were ground to the size of 0.5 mm for the determination of the nutrient contents of the dry matter of the residues. The nutrient contents of the samples were determined following the procedures described by [11] and [14] for plant analyses.

Results and Discussion

Distribution of Organic Carbon and Nutrients in the Crop Fields and at Homesteads

Organic Carbon and Nitrogen

The position effect on the distribution of organic carbon in the crop fields of the two farms was higher compared with nitrogen. The content of organic carbon showed a decreasing trend down slope in the crop field at Adele farm (Figure 1a). In the crop field at Bala langey farm, the content of organic carbon showed an increasing trend from the upper slope to the middle then decreased at lower slope (Figure1b).

Quantities of organic carbon in the crop fields of both farms were less than 2% (Figures 1a and b), which is in moderate range [15], at every point where measurements were taken. As a result, changes in the quantities of organic carbon along the slope gradients were low in the crop fields of both farms. This shows none or minimal inputs of sources of organic carbon to the crop fields at both farms.

Distribution of nitrogen, on the other hand, was slightly affected by the position or topography in the crop fields at both farms (Figures 1a and b). Changes in the quantity of nitrogen were very low down the slope at both farms. The very small differences in the quantities of nitrogen down the slope gradient may be due to the same amount of nitrogen inputs throughout the crop fields or nonexistence of translocation of nitrogen down the slope gradient. However, quantities of nitrogen were less than 0.2% at every point where measurements were taken in the crop fields at both farms (Figures 1a and b). This also shows none or minimal inputs of nitrogen sources at both farms, suggesting that nitrogen follow a trend of organic carbon.

Lower concentration of organic carbon and nitrogen in the crop fields at both farms can be attributed to crop residues removal during harvesting. Crop residues are the ultimate sources of soil organic carbon and nitrogen [4]. However, in the study areas, farmers remove all the aboveground biomass, leaving very small or none inputs of organic matter into the soil system. In the absence of other external organic matter inputs, it means that quantities of organic carbon and nitrogen in the crop fields at both farms are highly affected by crop residue removal management practices under taken by the farmers.

At the homesteads, organic carbon distribution was affected by the distances from home of the households at both farms (Figure 1c). Accordingly, quantities of organic carbon decreased with increases in distance away from the home. About 2.95 and 2.15% organic carbon were accumulated at 10 m close to the home of the households at Adele and Bala Langey farms, respectively. The values are in high range of soil organic carbon [15]. The values declined to 1.53 and 1.65% (moderate range) at a distance of 100 m away from the homes at both farms (Figure 1c). Comparing the two farms, more organic carbon accumulated near the home at Adele farm than at Bala Langey farm. This indicates the existence of differences between the two farms in the resource use efficiency or differences in the quantities of sources of organic carbon produced by the farming systems.

Nitrogen distribution was also affected by distance from the home at both farms. About 0.52 and 0.25% nitrogen were accumulated at 10 m close to the home of the households at Adele and Bala Langey farms, respectively. Similar to organic carbon, quantities of nitrogen declined to 0.10 and 0.12% at a distance of 100 m away from the homes at both farms, respectively (Figure 1c). As was observed for organic carbon, more nitrogen accumulated near the home of Adele farm household compared with that of Bala Langey farm. This again shows the differences between the two farms in the resource use efficiencies or differences in the quantities of sources of nitrogen produced by the farming systems.

Crop residues, animal manures and household wastes are the ultimate sources of organic carbon and nitrogen. Farmers of Adele and Bala Langey practice crop residues removal management for animal feed and domestic fuel consumption. When crop residues are removed and transported from crop fields for animal feed and domestic fuel uses, the final products are household wastes and animal manures which are sources of soil organic carbon and plant nutrients if taken back to crop fields.

Therefore, higher accumulation of organic carbon and nitrogen near homes (Figure1c) is due to disposal and unequal distribution of household wastes and animal manures in the homesteads. This illustrates that household wastes and animal manures are not being properly managed and equally distributed in the homesteads at both farms.

As indicated in Figure 1c, concentrations of organic carbon and nitrogen were high in the homesteads, small plots at immediate vicinity to homes of the households. But, their concentrations were generally in the range of moderate and low respectively, in the crop fields away from the homes at both farms. Duguma *et al.* [16] also reported high organic carbon and nitrogen content of soils sampled from homesteads at Suba area in the Central Highland of Ethiopia. Results show that organic carbon and nitrogen are transported from crop fields to homesteads with biomass such as crop residues and grains but not back to the crop fields with manures and household wastes. Thus, net flow of organic carbon and nitrogen is from the crop fields to the homesteads at both farms.

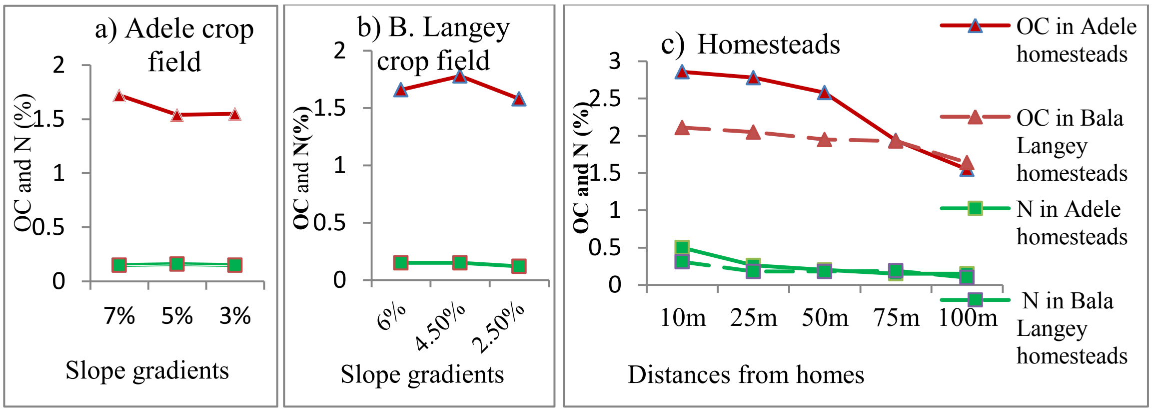

Figure 1: Distribution of organic carbon and nitrogen at Adele (a) and Bala Langey (b) in crop fields and at homesteads (c)

When all biomass are transported from the crop fields toward homesteads, more concentrations of organic carbon and nitrogen is definitely expected. But differences in the concentrations of organic carbon and nitrogen at the homesteads and in the crop fields were low compared with differences in the quantities of other nutrients like sulfur and phosphorus (Figures 1c and 2c). This may be due to loss of carbon and nitrogen as their respective oxides upon burning of crop residues as bio-fuel for cooking purposes.

Burning of crop residue as bio-fuel for cooking purposes is among the causes that lead to losses of organic carbon and nitrogen from a farming system. This subsequently limits the recycling of carbon and nitrogen in the farming systems. Therefore, use of crop residues as bio-fuel has threatened distribution, flow and cycling of organic carbon and nitrogen in the faming system of Adele and Bala Langey farms.

Phosphorus and Sulfur

The position effect on the distribution of extractable phosphorus and sulfur was higher compared to its effect on the distribution of organic carbon and total nitrogen in the crop fields at both farms. Their contents increased down the slope in the crop fields at both farms (Figures 2a and b). A slight increase from the upper to the middle slope and instant increase from the middle to the lower slope were observed for both nutrients at Adele farm (Figure 2a). At Bala Langey farm (Figure 2b) quantities of phosphorus continuously increased while quantity of sulfur slightly increased as the slope gradient decreases. Thus, distribution of phosphorus is more affected by the slope gradients than did the distribution of sulfur in the crop fields at Bala Langey farm. This could be attributed to high phosphorus adsorption of the soils that more P moved with soil down the slope.

Results also reveal that phosphorus and sulfur were transported from upper slope to lower slopes on surface with soil. However, quantities of phosphorus and sulfur transported from upper to lower slopes were not the same at both farms. Less phosphorus and sulfur were transported along the slope gradient at Adele farm with relatively steeper slope than Bala Langey farm (Figures 2a and b). These differences may be due to soil conservation methods being implemented by the farmer at Adele farm.

The famer of Adele farm has made soil band terraces at a distance of 3 to 5 m in the crop fields at the upper and middle slopes but no such terraces in the crop fields at Bala Langey farm. This indicates surface soil transport control is also as important as phosphorus and sulfur soil fertility management at both farms.

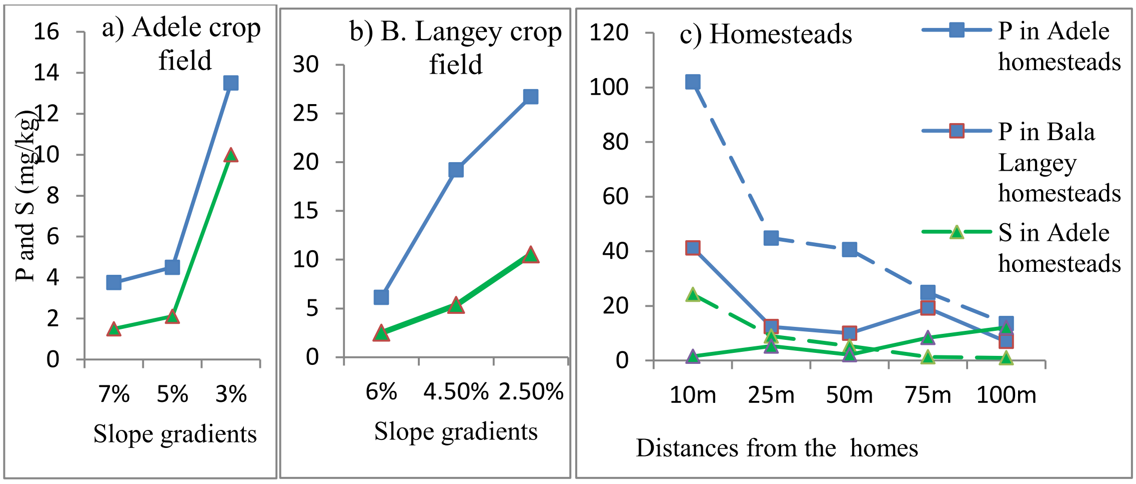

Figure 2: Distribution of extractable phosphorus and sulfur at Adele (a) and Bala Langey (b) in crop fields and at homesteads (c)

Distribution of extractable phosphorus and sulfur was also affected by the distance away from the home of the households at both farms (Figure 2c). About 100 (above very high) and 41 mgkg^{-1} (high) extractable phosphorus were accumulated near the homes at a distance of 10 m at Adele and Bala Langey farms, respectively [17]. The quantities decreased drastically to low and very low ranges with increases in distance away from the homes (Figure 2c). Sulfur followed similar trend with phosphorus. About 25 mgkg^{-1} sulfur (high) accumulated near home at a distance of 10 m at Adele farm (Figure 2c) as compared to1.65 mgkg^{-1} sulfur (very low) accumulated at Bala Langey farm near home [17].

Quantities of phosphorus and sulfur showed increasing trends at a distance between 50 and 75 m away from home at Bala Langey farm (Figure 2c). At this distance, another household at 5 m far disposes household wastes on one side of the plot and is contributing nutrients for the Bala Langey farm. Quantity of P accumulated near the home of the household at Adele farm is higher compared to quantity of P accumulated near the home of the household at Bala Langey farm (Figure 2c). This again shows differences between farmers in their resources utilization and management of sources of the nutrients. Therefore, distribution of these nutrients in the homesteads is more affected by the management of their sources and the location of home of the households.

The concentrations of phosphorus and sulfur were also higher at the homesteads than their concentration in the crop fields at both farms (Figure 2). At Adele farm concentration of phosphorus at the homesteads was about 5 times its concentration in the crop fields. Concentration of sulfur was also about twice its concentration in the crop fields. This confirms transport of these nutrients toward the homesteads. Probably, these nutrients are from the crop fields with biomass. Thus, the flow of phosphorus and sulfur is also from the crop fields toward the homesteads as opposed to their return to the crop fields with manure and household wastes. As a result, small plots of land near the home of the households are over fertilized with phosphorus and sulfur while large areas of the crop fields far from homes are being depleted.

Higher concentration of extractable phosphorus in the homesteads at both farms can be attributed to disposal of phosphorus as oxide forms with ash near the homes. Duguma *et al.* [16] also reported high concentration of total P at the homesteads as a result of disposal of ash in the homesteads close to homes. Sulfur loss as oxide form is also expected when crop residues are used as bio-fuel for cooking purposes. This might have contributed for the lower concentration of sulfur than that of phosphorus in the homesteads at both farms.

Exchangeable Bases

The slope position effect on the distribution of exchangeable bases (Ca, Mg and K) was not as high as its effect on phosphorus and sulfur distribution at both farms (Figures 3a and b). However, there was variation in their quantities down the slope. In the crop field of Adele farm, contents of exchangeable Ca showed a slight increase from the upper to the middle slope and then decreased at the lower slope. Contents of Mg also showed decrease down the slope. Potassium was not much affected by the slope gradient (Figure 3a).

At Bala Langey farm, quantities of exchangeable Ca and Mg increased down the slope gradients in the crop fields (Figure 3b). This indicates that the nutrients were transported down the slope gradients. As observed at Adele farm, however, there was no much slope gradient effect on the distribution of potassium. These differences in the exchangeable bases distribution in the crop fields of both farms could be attributed to the differences in soil conservation methods used by the farmers as it has been explained above for phosphorus and sulfur. Therefore, soil and water conservation is also an important factor at Bala Langey causing differences in distribution of exchangeable bases at farm level.

Distribution of exchangeable bases at the homesteads was also affected by the distances from home of the households (Figure 3c). Quantities of all the exchangeable bases were higher near the homes at a distance of 10 m compared with their quantities far from the homes. However, accumulation of all the exchangeable bases near home was higher at Adele farm than at Bala Langey farm (Figure 3c). Concentration of Ca was exceptionally high at a distance between 50 and 75 m at Bala Langey homesteads.

However, at both farms quantities of the exchangeable bases accumulated near homes were not as high as phosphorus and sulfur. Generally, the exchangeable bases (Ca, Mg and K) contents of the soils of both farms were high at the crop fields and at homesteads. Therefore, the amount removed with crop residues from the crop fields and accumulated at the homesteads might not have accounted for large differences in their quantities.

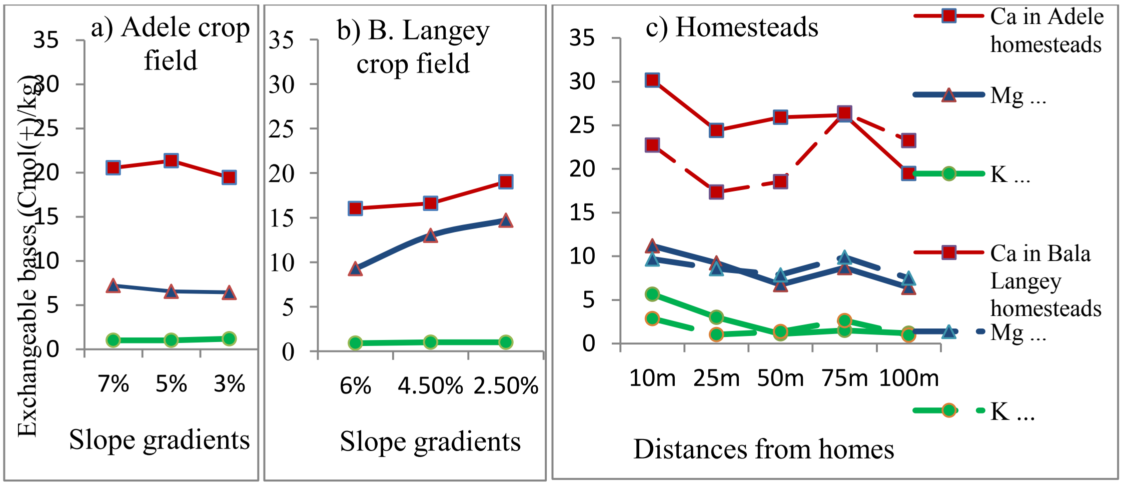

Figure 3: Distribution of exchangeable bases at Adele (a) and Bala Langey (b) farm in crop fields and at homesteads (c)

Micronutrients

The micronutrients (Cu, Fe, Mn and Zn) were differently affected by the slope gradients in the crop fields of both farms. Slope gradient effect on the distribution of Cu, Mn and Zn was less compared to Fe in the crop field at Adele farm (Figure 4a). Contents of Fe drastically decreased down the slope. Quantities of Zn slightly increased down the slope but no considerable changes in the quantities of Cu and Mn.

In the crop field at Bala langey farm, quantities of Fe, Cu and Zn increased down the slope but no changes in the quantities of Mn (Figure 4b). Thus, distribution of Fe, Cu and Zn in crop field was affected by the slope gradients indicating that surface soil transport control down the slope is also much important at Bala Langey farm.

At the homesteads, distribution of micronutrients was also affected by the distances from the homes of the households. More Fe was accumulated at a distance of 10 m near home of the households followed by Zn at Adele farm. At Bala Langey farm more Cu accumulated near home next to Fe (Figure 4c). But no much changes in the quantities of Mn with distance in the homesteads at both farms. Between 50 and 75 m, quantities of Cu, Fe and Zn increased and decreased between 75 and 100 m in Bala Langey homesteads (Figure 4c). This is due to additional nutrient gain from other neighboring farm on one side of the plots. The neighboring household disposes the household wastes to the plots and contributes nutrients to the farm which indicates an inefficient resource utilization of the neighboring farm.

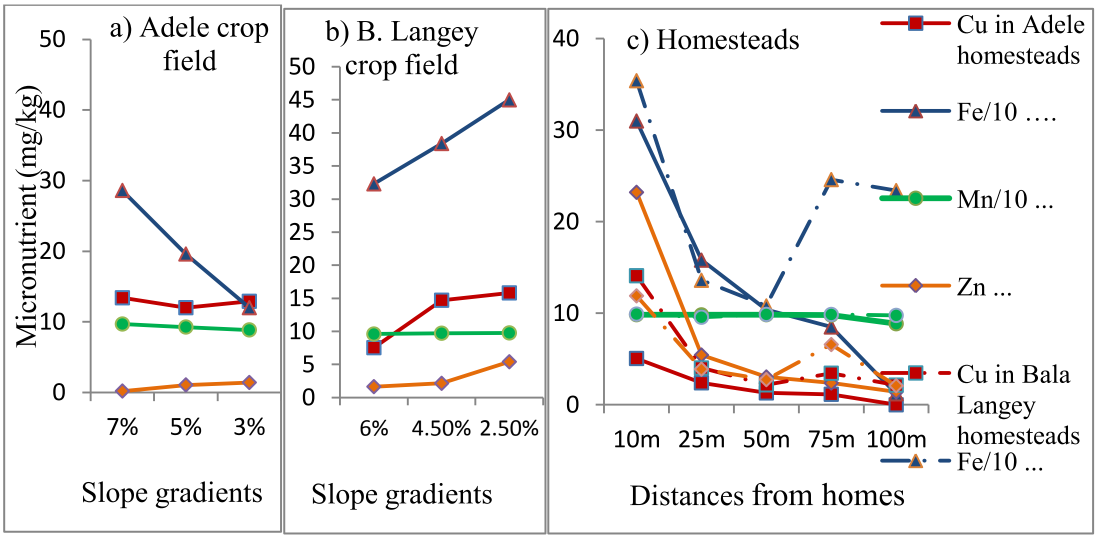

Figure 4: Distribution of micronutrient at Adele (a) and Bala Langey (b) farms in crop fields and at homesteads (c)

Figure 4 c also indicates that micronutrients were highly accumulated near the home of the households. Higher accumulation of the micronutrients near homes may be due to disposal of manures and household wastes near the home, which resulted in unequal distribution of the nutrients in the homesteads.

Differences in the concentration of micronutrients at the homesteads and in crop fields were very small compared with differences in the concentration of other nutrients. Small differences in the concentrations of micronutrients at the homesteads and in the crop fields may be due to small quantities transported with crop residues (Table 1). Since micronutrients are taken by plant in micro levels. However, except Zn, concentrations of Fe, Mn and Cu were higher in the crop fields than their concentration at the homesteads at Bala Langey farm. Iron was exceptionally high in the crop fields.

Nutrient Transported through Crop Residues

The nutrients transported through crop residues varied across the sites where residues were collected and the crop types. At Bala Langey farm, more nitrogen was transported through haricot bean residue compared with the amount transported through sorghum and maize residues. The same trend was observed at Adele farm (Table 1). Higher quantity of nitrogen transport through haricot bean residue at both farms might be ascribed to the N fixing capacity of the legume crops. As a result, more nitrogen was accumulated in the haricot bean residue than that of sorghum and maize. This implies that transport of residues of leguminous plants could result in loss of huge amount of nitrogen from farms as compared with none-leguminous crops.

Except potassium, the amount of nutrients transported from crop field through crop residues at Bala Langey farm was greater than the amount transported from crop field at

Adele farm (Table 1). These differences in the amounts of nutrients transported with residues are due to the differences in the fertility status of soils of the two farms. Fertility status of soils at Bala Langey farm is better than that of the soils at Adele farm.

Table 1: Quantity of nutrients transported with crop residues from crop fields at Adele and Bala Langey farms in 2013 cropping season

Nutrients/ dry matter	Crop Residues					
	Sorghum		Maize		Haricot bean	
	Adele farm	Bala Langey farm	Adele farm	Bala Langey farm	Adele farm	Bala Langey farm
N (gkg^{-1})	2.70	3.60	3.80	3.80	4.70	5.60
P (gkg^{-1})	2.50	7.10	1.90	4.30	3.60	4.80
K (gkg^{-1})	21.70	17.20	12.40	9.90	17.50	9.10
Ca (gkg^{-1})	13.00	14.30	16.00	19.10	10.70	15.10
Mg (gkg^{-1})	4.90	7.60	8.40	8.50	4.80	5.80
S (gkg^{-1})	5.00	7.10	7.40	7.80	5.20	5.70
Cu ($mg\ kg^{-1}$)	35.47	66.86	41.91	47.90	23.95	39.92
Fe ($mg\ kg^{-1}$)	85.47	139.31	142.40	162.12	94.02	163.21
Mn($mg\ kg^{-1}$)	607.95	841.42	453.03	485.43	194.02	265.05
Zn ($mg\ kg^{-1}$)	24.66	25.73	11.45	16.31	12.09	22.14

Nevertheless, results of nutrients distribution indicate that more nutrients accumulated in homesteads at Adele farm than at Bala Langey farm, which suggests that amount of nutrients transported from crop field with residues is higher at Adele farm than at Bala Langey farm. But higher accumulation of nutrients at the homestead at Adele farm is due to poor management of manure and household wastes, and location of the home of the households. Home of the household at Adele farm is within the farm system whereas home of the household at Bala Langey is structurally disconnected from the crop fields. The data in Table 1 also indicate that feed quality of crop residues at Bala Langey farm is higher than that at Adele farm. Furthermore, nutrient mining at Bala Langey farm is higher than at Adele farm since more nutrients were taken up and transported from the crop field with residues. In general, phosphorus followed by organic carbon were the most affected nutrient by the crop residues management practices undertaken by the farmers at both farms. Exchangeable bases and micronutrients were not affected that much. The extent of the effects of crop residues removal management on the distribution of organic carbon and nutrients from the most to the least affected follow the order P > OC > S > N > exchangeable bases > micronutrients.

At both farms, poor management of manure and household wastes resulted in accumulation and unequal distribution of organic carbon and nutrients at the homesteads. On the other hand, removal and transport of crop residues for animal feed and domestic fuel resulted in organic carbon and nutrients depletion in the crop fields. This again may restrain the in-situ biogeochemical nutrient recycling at the crop fields. Therefore, these contradicting scenarios are likely threatening the sustainability of the farming system of Adele and Bala Langey farms. As a result, the sustainability of the farming system of the two farms is under question if all continue under the currently existing conditions.

Conclusions

Organic carbon and nutrient distribution in the crop fields of both farms were affected by the slope gradients. At homesteads distribution of organic carbon and nutrients was highly affected by poor management of manure and household wastes.

At both farms net transport of organic carbon and nutrients was from the crop fields to the homesteads except for Mg at Adele farm and Fe at Bala Lange Farm. There is no in-situ nutrient recycling at the crop fields of both farms. In general, sustainability of both farms is likely be threatened by removal of crop residues for animal feed and domestic fuel from crop fields and disposal or accumulation of manure and household wastes near home. Intervention management should, therefore, focus on:-

- Reversing the flow of organic carbon and nutrients from the crop fields toward homesteads at both farms through either retaining crop residues or applying manure to the crop fields.
- Equal distribution of organic carbon and nutrient in the farming system of both farms.

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CHAPTER FIVE

Effects of Haricot Bean Residue Incorporation on Selected Soil Properties and Maize Grain Yield under Maize-Haricot Bean Intercropping System in Eastern Ethiopia

Abstract

The off-site uses of crop residues for animal feed and domestic fuel consumption are dominant over the on-site uses for soil fertility enhancement in the Ethiopian agriculture in general and the eastern part in particular. As a result, soil fertility is being depleted and soil productivity is declining. The objectives of this study were to assess the effects of haricot bean residue incorporation on selected soil properties and maize grain yield under maize-haricot bean intercropping system. Studies were carried out for two cropping seasons (2012 -13) at Adele and Bala Langey sites in Haramaya and Kersa districts, respectively in eastern Ethiopia. The experimental design used was randomized complete block design (RCBD) with four replications. The treatments were levels of haricot bean residue incorporation at varied number of haricot bean rows (R0, R1, R2, and R3) grown between maize plants. Soil samples were collected from each plot after 7 months of residue incorporation and analyzed for selected soil properties. Soil bulk density decreased from 1.38 to 1.21 gcm^{-3} at Adele site and from 1.34 to 1.20 gcm^{-3} at Bala Langey site. The pH of soils decreased from 8.19 to 7.46 at Adele site and from 6.70 to 6.52 at Bala Langey site. Soil organic carbon increased from 1.21 to 1.99% at Adele site and from 1.19 to 2.14% at Bala Langey site. Extractable phosphorus increased from 4.21 to 9.15 $mgkg^{-1}$ at Bala Langey site. CEC increased from 56.50 to 66.58 $cmol(+)kg^{-1}$ at Adele site and from 56.77 to 59.13 $cmol(+)kg^{-1}$ at Bala Langey site. There was significant ($p < 0.05$) haricot bean residue incorporation effect on maize grain yield at both sites. In general, results indicate improvements in soil fertility and maize grain yield at both sites. Furthermore, growing two rows of haricot beans between maize plants were found to be effective in improving soil fertility and maize grain yield through incorporation of haricot beans residue at both sites. Therefore, farmers at Adele and Bala Langey sites can be benefited through incorporation of haricot bean residue, growing two rows of haricot beans between maize plants under intercropping system.

Key words: soil, yield, rows, organic carbon, management

Introduction

Maize/sorghum intercropped with haricot beans is the dominant cropping system in the eastern part of Ethiopia. The dominance of such cropping system is because of the multiple uses of the crop residues. Crop residues are removed from crop fields for animal feed and domestic fuel instead of being incorporated into soils for the enhancement of soil fertility.

Crop residues are important renewable natural resources and play significant roles in biogeochemical recycling of carbon and nutrients (Yadvinder-Singh *et al*., 2005; Kumar and Goh, 2000). As a result, crop residue management is receiving a great deal of attention in agriculture and environment (Kumar and Goh, 2000). Lal (2005) grouped uses of crop residues as off-site and on-site uses, where the off-site uses include crop residue as fodder for animal feed, fiber, industrial raw materials and bio-fuel, whereas the on-site uses are soil fertility enhancement, soil water conservation and subsequently biodiversity improvements.

In agriculture, effects of crop residues management on soil properties and crop yields have been reported by several investigators (van Donk *et al*., 2012; Hejazi et al., 2010; Tim Shaver, 2010; David *et al., 2009*). Van Donk *et al*., (2012) reported that removal of crop residue annually had negatively affected soil qualities such as soil organic matter content, soil residual nitrate levels, and soil pH. On the other hand, Tim Shaver (2010) and Ahmad Za.re Feizabady (2013) reported that higher return of crop residue decreased soil bulk density, increased porosity and macro-aggregation and subsequently decreased runoff, erosion and evaporation.

Crop residues supply organic C and nutrients for soil microorganisms and plants (Lal, 2009; Malhi and Lemke, 2007). Studies by Bakht *et al*. (2009), Bahrani *et al.* (2007) and Shafi *et al.* (2007) have shown that incorporation of crop residues significantly improved soil pH, organic matter, CEC, available phosphorus, exchangeable bases and grain yields per unit area. Bahrani *et al.* (2007) reported that burning and continuous removal of crop residues is one of the main causes for soil fertility depletion. Lal, (2009) and Wilson *et al.* (2008) have observed retaining crop residues as surface cover is an important conservation technique for erosion control. According to the quoted literatures, crop residues have positive effects on soil properties and crop yields when incorporate into soils or remain on the crop fields (on-site uses) but negative effects when removed from the crop fields (off-site uses).

The off-site uses of crop residues are dominant over the on-site uses in the Ethiopian agriculture in general and the eastern part in particular. Crop residues are mostly used as fodder for animal feed and domestic household fuel consumption (Gebraegziabher, 2007) and in some places for construction purposes. As a result, crop residues return to the soil is minimal in the farming systems of the country. The cropping and livestock systems are strongly interconnected in the farming systems of Ethiopia. Animals are being used as draught power for cultivation of land and for transportation. The cropping system provides crop residues for animal feeds. Thus, each of the system cannot operate independently in areas where agro-climate is permissive for crop production.

Farmers practice crop residues removal because of lack of alternatives for animal feeds and for domestic fuel since grazing lands are cultivated for crop production. The possible alternative option to bring in the benefits of crop residues in the farming systems of the region could be only through the cropping systems where farmers can grow different crops on the same plot. Therefore, intercropping system could be the alternative intervention option where legumes would be intercropped with cereals such as maize, sorghum and others. Through such systems farmers may collect the residues of the cereals and leave or incorporate legume residues into soils for the improvement of soil quality and for soil water conservation purposes.

Farmers have already been practicing intercropping systems of legumes with cereals particularly, haricot beans with maize or sorghum. Nonetheless, the intercropping systems are not well established through experimental studies and the objectives of intercropping of legumes with cereals are not well understood by the farmers. For instance, effective numbers of rows of legume and spacing for the intercropping system have not been established for the region. Furthermore, farmers have been removing all the residues of both crops. As a result, soil fertility is depleted and farmers are reporting that soil productivity is declining. The objectives of this experiment were to assess the effects of haricot bean residue incorporation on selected soil properties and maize grain yield under maize-haricot bean intercropping system, and to establish effective number of rows of haricot beans between maize plants for the improvement of soil fertility and crop yield.

Materials and Methods

Description of the Experimental Sites

The experiments were conducted for two cropping seasons (2012 -13) in the eastern part of Ethiopia at Haramaya and Kersa districts in Oromia Regional State. The two districts were selected based on the cropping systems. From each district one site was selected. Adele site was selected from Haramaya district and Bala langey site from Kersa district. Experimental sites were selected based on farmers' interest in providing plot of land for experimental purposes and their participation in the processes of experiments from land preparation up to harvesting.

The geographical location of Adele site at Haramaya district is between 09°24`26``N, 041°58`00``E and 09°24`34`` N, 041°58`04``E with an average altitude of 2075 m.a.s.l. Bala Langey site at Kersa lies between 09°25`41``N, 041°47` 48``E and 09°25`46``N, 041°47`56``E with an average altitude of 2005 m.a.s.l. The study sites are presented by (Fig.1).

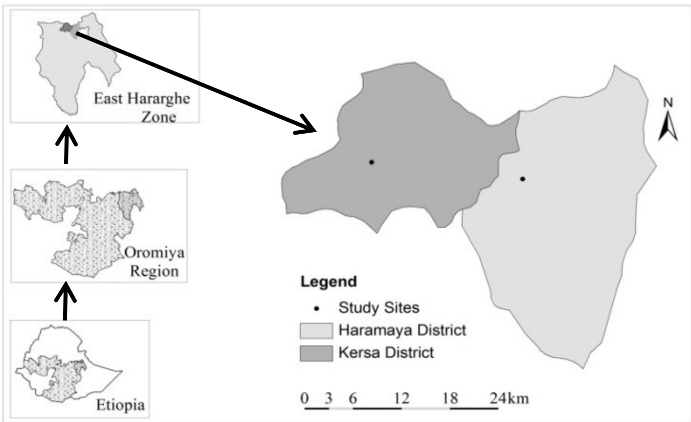

Figure 1: Location of the study sites

Information obtained from Haramaya University Meteorological Station indicates that the mean annual rainfall and mean maximum and minimum temperatures of Haramaya district are 784 mm and, 24.36 and 9.61°C, respectively for the last 7 years (2007-13). Data on rainfall and temperature were not available for Kersa district. Soils of the study sites were characterized as Chromic Luvisoils at Adele site and Vertic Luvisols at Bala Langey site (FAO, 1984).

The rainfall pattern of the Haramay district is bimodal starting from March to September with high rainfall intensity in July and August. The rainy season with low rainfall intensity is called *afrasaa,* which extends from February/March to end of May, while the main rainy season with high rainfall intensity is called *goanna* stretching from July to early September. The rainfall and temperature data of Haramaya district for the two experimental seasons (2012 - 13) are presented in Fig. 2.

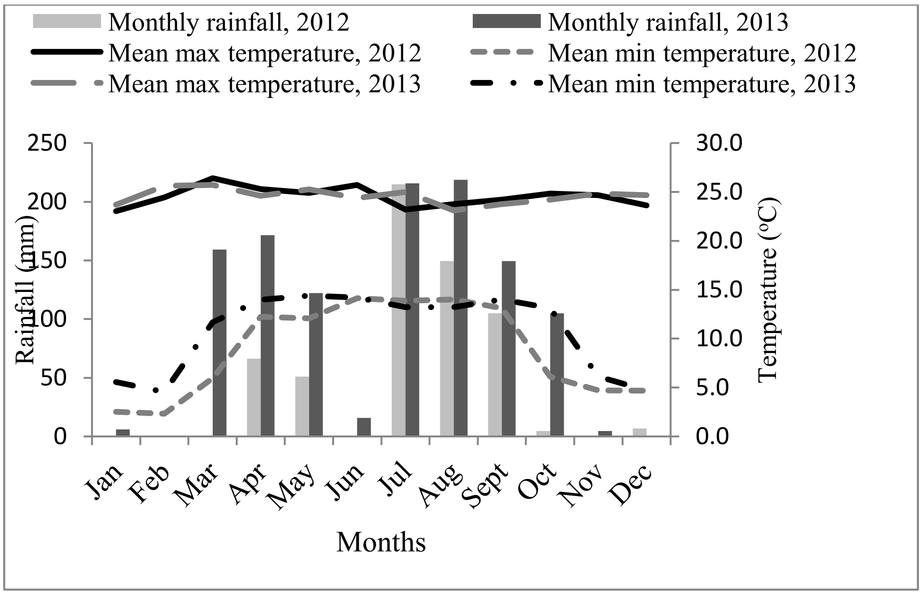

Figure 2: Monthly rainfall and mean maximum and minimum temperature of Haramaya district (2012 -13)

Field Experiment: Year I

Experimental Design and Treatments

The experimental design was randomized complete block design (RCBD) with four replications. Plots size was (3 x 1.5) m^2 with a buffering border of 1m spaces in between plots. The treatments were levels of haricot bean residue incorporation at varied number of rows (0, 1, 2, and 3) of haricot bean grown between maize plants under maize-haricot bean intercropping system. The maize variety was Rare I (EV-1) and haricot bean variety was Dursitu (DOR-811). Both varieties are widely grown in Eastern Ethiopia. The spacing between maize plants was 75 cm x 30 cm and for the haricot beans spacing was 15 cm x 10 cm. Maize was planted on 07 and 08 May, haricot bean on 21 and 22 June, 2012 at Adele and Bala Langey sites, respectively. The population of maize plants and spacing between maize plants were kept constant in all the plots.

However, the population of legume plants (haricot beans) in between maize plant rows were varied, representing varied amounts of legume crop residue incorporated into the soil, which were represented by varied number of rows (0, 1, 2, and 3) of haricot beans grown in between maize plant rows. Fertilizer (DAP) containing 18 kg N and 46 kg P_2O_5 was applied at a constant rate of (18 kg N and 20.077 kg P) ha^{-1} to all plots. All other management practices were implemented in similar ways as farmers' experience.

After physiological maturity, only pods of haricot bean were collected. Two plant samples of haricot bean were collected from each plot for the characterization of nutrient contents of the residue incorporated into soils. The residue was incorporated into soil in the respective rows. Maize was harvested and residue was taken by the farmer for animal feed and domestic fuel.

Grain yield of maize in kg ha^{-1} was calculated for each plot. Results were analyzed using descriptive and inferential statistics. The experiments were repeated at both sites, on same plots in year II to assess effects of haricot bean residue incorporation on selected soil properties and maize grain yield. Nutrients content of incorporated haricot bean residue was analyzed following Okalebo *et al.* (2002) and Kalra and Maynard (1991) methods for plant analyses.

Soil Sampling and Analyses

Disturbed soil samples were collected with auger from all plots at a depth of 0-30 cm before preparation for planting in year II at both sites. Composites samples were made of samples from plots that incorporated with the same number of rows of haricot bean residue. Plots incorporated with different number of rows of haricot bean residue were randomly selected from each block for core sampling for determination of soil bulk density. Disturbed soil samples were air-dried and crushed to pass through 2 mm sieve. Subsamples were ground to pass through 0.25 mm sieve for nitrogen and organic carbon analysis.

Soil bulk density was determined following the procedure described by Blake (1965). Soil pH was measured in 1:2.5 soil water ratios as described by Okalebo *et al,* (2002). Organic carbon and nitrogen were determined following the Walklely and Black (1934) and Kjeldlehl methods, as described by Okalebo *et al,* (2002), respectively. Phosphorus was determined by the Olsen method (Olsen *et al*., 1954).

Cation exchange capacity (CEC) of the soils was estimated after exchanging the NH_4^+ ions by Na^+ ions from the soils leached with ammonium acetate solution buffered at pH 7. The NH_4^+ ions were determined by ammonia (NH_3) distillation into acid solution and then by back titration with dilute sulfuric acid (Okalebo *et al.,* 2002).

Field Experiment: Year II

For year II, maize was planted on 10 and 11 May, 2013 whereas haricot bean was planted on 03 and 05 June, 2013 at Adele and Bala Langey sites, respectively. The spacing between maize plants and haricot bean plants were as in year I with similar varieties and managements. Similar to year I, after physiological maturity, pods of haricot bean were collected and the residue was incorporated into soils. Maize was harvested and residue was taken by the farmer. Maize grain yield in kg ha^{-1} was calculated for each plot. Results were analyzed using descriptive and inferential statistics.

Results and Discussion

Nutrients Content of Haricot Bean Residue Incorporated at Adele and Bala Langey Sites

The nutrient contents of haricot bean residue sample from Bala Langey site were higher than the residue sample from Adele site. Except potassium which was higher for residue sample from Adele site (Table 1). This indicates that more nutrients were extracted from the soil by the crop at Bala Langey site. Higher nutrients content of the residue sample from Bala Langey site can be attributed to lower pH value of the soil of the site relative to pH value of soils of Adele site (Table 2).

Differences in macronutrients (N, P, K, Ca, Mg and S) content of the residue samples from both sites were lower than differences in the micronutrients (Cu, Fe, Mn and Zn) content. Therefore, quantities of nutrients incorporated into soils through haricot residue at Bala Langey site were higher than quantities of nutrients incorporated at Adele site.

The bulk density values for soils sampled from Adele site plots varied from 1.21 to1.38 gcm^{-3}. For the soils sampled from Bala Langey site plots, the bulk density values ranged from 1.20 to1.34 gcm^{-3} (Table 1). The data indicate that bulk density values of soils sampled from plots incorporated with residue decreased and were lower compared to the control plot which was not incorporated with residue at both sites.

At Adele site the bulk density value of soils sampled from plot incorporated with one row of residue decreased by 11.59 % over the control. The decreases in the bulk density values of soils sampled from plots incorporated with 2 and 3 rows of residue were 10.86 and 12.32%, respectively over the control (Table 1). The decrease in the bulk density value of soils sampled from plot incorporated with 3 rows of residue was the highest relative to that of the other plots.

Table 1: Nutrients content of haricot bean residue incorporated at Adele and Bala Langey sites

Sites	Incorporated residue nutrient contents									
	Macronutrients (%)						Micronutrients (mgkg^{-1})			
	N	P	K	Ca	Mg	S	Cu	Fe	Mn	Zn
Adele	0.47	0.36	1.75	1.07	0.48	0.52	23.95	94.02	94.02	12.09
Bala Langey	0.56	0.48	0.91	1.51	0.58	0.57	39.92	163.21	165.05	22.14

Haricot Bean Residue Incorporation Effects on Selected Soil Properties

At Bala Langey site, decrease in the bulk density value was 8.20% for soils sampled from plot incorporated with one row of residue whereas decreases in the values were 10.45 and 8.96% for soils sampled from plots incorporated with 2 and 3 rows of residue, respectively over the control (Table 2). The decrease in the bulk density value was the highest for soils sampled from plot incorporated with 2 rows of residue relative to bulk density values of soils sampled from the other plots. The decreases in soil bulk density at both sites may be due to an increase in soil organic carbon content (Table 2) that enhances soil aggregation and subsequently increases number and sizes of soil pore spaces.

In general, decrease in the soil bulk density value was higher for soils of Adele site than soils of Bala Langey site. Similarly, the overall bulk density value of soils of Adele site was higher compared with values for soils of Bala Langey site. Therefore, improvement in soil bulk density through crop residue incorporation could be more effective when used as an amendment for soil with higher bulk density values.

The pH values varied from 7.19 to 8.19 for soils sampled from plots after residue incorporation at the Adele site (Table 1). At Bala Langey site pH values ranged from 6.52 to 6.70. The results indicate slight increase in the pH values of soils of Adele site plots and slight decrease for soils of Bala Langey site plots with increased rows of residue incorporated. At both sites the pH values of soils sampled from plots incorporated with residue less than that of the control plots. Therefore, crop residue incorporation might be used as an amendment for reducing higher soil pH values.

The organic carbon content of soils of Adele site plots ranged from 1.21 to 1.99% while that of Bala Langey site plots varied from 1.19 to 2.14% (Table 2). Thus, the results indicate an increase in the organic carbon contents of the soils at both sites. The increase in the organic carbon content of soils sampled from Adele site plot incorporated with 1 row of residue over the control was 19.00%. For plots incorporated with 2 and 3 rows of residue were 64 and 52%, respectively over the control.

An increase in the organic carbon content of soil of Bala Langey site plot incorporated with 1 row of residue was 69.75% over the control. For soils sampled from plots incorporated with 2 and 3 rows of residue, organic carbon content increased by 78.83 and 73.11%, respectively over the control (Table 2). Increase in the organic carbon content was the highest for soils of plots incorporated with 2 rows of residues at both sites.

In general, increase in the organic carbon content of the soils as a result of residue incorporation was higher for Bala Langey site soils than Adele site soils. This is due to the differences in the soil fertility status which affect the amount of the biomass incorporated. The fertility status of soils of Bala Langey site is better than that of Adele site. This suggests that the biomass incorporated at Bala Lange site was relatively higher than the biomass incorporated at Adele site.

The results indicate an increase in soil organic carbon content at both sites, even though it is not possible to build up soil organic carbon to the targeted level within one season residue incorporation. However, this study can serve as baseline for further work to build up soil organic carbon through legume reside incorporation under cereals/legume intercropping system.

The nitrogen content varied from 0.12 to 0.15% for soils sampled from Adele site plots. For soils sampled from Bala Langey site plots nitrogen contents varied from 0.13 to 0.16%. Thus, there was no much increase in nitrogen content of the soil at both sites as a result of crop residue incorporation.

Olsen extractable phosphorus content varied from 3.34 to 4.79 $mgkg^{-1}$ for soils sampled from Adele site plots whereas the P content for soils sampled from Bala Langey site plots varied from 4.21 to 9.15 $mgkg^{-1}$ indicating differences in the P contents of the soils of the plots. The highest available P was recorded for the plot incorporated with 1 row of residue at Adele site. At Bala Langey site the highest available P was recorded for plot incorporated with 2 rows of residue. Lower available P content of soils sampled from plots incorporated with more rows of residue may be due to the higher population of the haricot beans between maize plants. As a result, more P may be taken up and transported with grain.

In general, differences in the available P contents of soils sampled from Adele site plots were lower than differences in the P contents of soils sampled from Bala Langey site plots. This can be attributed to the differences in the fertility status of the soils of the two sites.

Cation exchange capacity of the soils sampled from Adele site plots varied from 56.50 to 66.68 cmol(+)kg^{-1} while CEC of soils sampled from Bala Langey site plots varied from 56.77 to 59.13 cmol(+)kg^{-1}. The results indicate differences in the CEC of the soils sampled from each plots from both sites.

Differences in the CEC values of soils sampled from plots at both sites follow the same trend as organic carbon contents. Similar to organic carbon content, the highest CEC was recorded for plots incorporated with 2 rows of residues at both sites (Table 2). Therefore, residue incorporation directly improves soil organic carbon and indirectly CEC of the soils.

Table 2: Effect of residue incorporation on selected properties of soils sampled from Adele and Bala Lange site plots

	Adele site						Bala Langey site					
Levels of residue incorporated	Bd (gcm^3)	pH	OC (%)	N (%)	P ($mgkg^{-1}$)	CEC ($cmol(+)kg^{-1}$)	Bd (gcm^{-3})	pH	OC (%)	N (%)	P ($mgkg^{-1}$)	CEC ($cmol(+)kg^{-1}$)
0 row	1.38	8.19	1.21	0.12	3.92	56.50	1.34	6.70	1.19	0.13	4.21	56.77
1 row	1.22	7.46	1.44	0.12	4.79	61.42	1.23	6.66	2.02	0.15	4.25	57.48
2 rows	1.23	7.82	1.99	0.15	3.63	66.68	1.20	6.53	2.14	0.16	9.15	59.13
3 rows	1.21	7.78	1.84	0.15	3.34	64.05	1.22	6.52	2.06	0.15	7.12	57.81

*R = Rows of Haricot bean between maize plants which represent levels of residue incorporated

Effective Number of Haricot Bean Rows between Maize Plants for Soil fertility Improvement at Adele and Bala Langey Sites

The data in Table 2 indicate improvements in the selected properties of soils sampled from the two sites as a result of residue incorporation. However, the improvements in soil properties vary with the levels of residue incorporated which represented by the number of rows of haricot beans between maize plants. For instance, better improvement in soil bulk density was observed for soils sampled from plots incorporated with 3 rows of residue at Adele site.

At Bala Langey site, improvement in bulk density was better for soils sampled from plot incorporated with 2 rows of residue. Therefore, 3 rows of haricot beans between maize plants were effective for soil bulk density improvement through haricot beans residue incorporation at Adele site and 2 rows at Bala Langey site. Table 3 presents effective number of haricot bean rows between maize plants for the improvement of selected soil properties through incorporation of haricot bean residue under maize/bean intercropping system.

As indicated in Table 3, improvements in selected soil properties were observed for soils sampled from plots incorporated with 2 rows of residue at both site except P and bulk density at Adele site. Therefore, 2 rows of haricot beans between maize plants at a distance of 30 cm from maize plants are effective for the improvements of selected soil properties as a result of haricot beans residue incorporation.

This study was conducted for 2 years of cropping seasons. Year I was to establish the residue. Year II was to assess the effects of residue incorporation on selected soil properties. In general, incorporation of the residue resulted in improvements in selected soil properties. However, further studies should be carried out for the establishment of effective number of rows of haricot bean between maize plants for the improvement of soil properties through residue incorporation under maize haricot bean intercropping system at both sites.

Table 3: Effective number of haricot bean rows between maize plants for soil fertility improvement through haricot bean residue incorporation under maize/haricot bean intercropping system at Adele and Bala Langey sites

Soil Properties	Effective number of haricot bean rows between maize plants	
	Adele site	Bala Langey site
Bulk density	3 rows	2 rows
Organic carbon	2 rows	2 rows
Nitrogen	2 rows	2 rows
Phosphorus	1 row	2 rows
Cation exchange capacity	2 rows	2 rows

Effect of Haricot Bean Intercropping on Maize Grain Yield

In year I, effect of haricot bean intercropping on maize grain yield was not significant ($P>0.05$). Even though, there was no statistically significant effect of intercropping on maize grain yield of the plots. Mean maize grain yield of the plots intercropped with haricot beans at both sites were lower than the control plot with no haricot beans between the maize plants (Table 4).

At Adele site, mean maize grain yield recorded for plots with 3 rows of legume was the lowest whereas at Bala Langey site the lowest mean maize grain yield was recorded for plots with 2 rows of legume in between maize plants. Lower maize grain yields of the plots with more rows of haricot beans than 1 row of haricot beans and the control may be due to competition for moisture and nutrients among the maize and legume plants. Probably, this resulted in lower maize grain yield of plots with higher population of plants.

In year II, treatments were levels of incorporated haricot bean residue produced in year I represented by {R0 = no residue i.e. control, R1 = 1 row of haricot bean residue, R2 = 2 rows of haricot bean residue and R3 = 3 rows of haricot bean residue}. The treatments effect on the maize grain yield was significant ($P \leq 0.05$) at both sites. Thus, there were significant differences in mean maize grain yield of the plots as a result of haricot bean residue incorporation at both sites. At Adele site, mean maize grain yield of plots with 1 row of haricot bean residue incorporation increased by 24% over the control (Table 4). The mean grain yield increase for plots incorporated with 2 rows haricot bean residue was 43% whereas increase in yield for plots incorporated with 3 rows of residue was 47% over the control.

At Bala Langey site, maize grain yield of plots incorporated with 1 row of haricot bean residue was increased by 6% over the control. Mean grain yield of plots incorporated with 2 and 3 rows of residue were 23 and 22% respectively (Table 4). At both sites change in the percentages of mean maize grain yield of the plots decreased as the number of rows of haricot bean plants (represent amount of residue incorporated) in between maize plants increased. Percentages of maize grain yield of each plot with respective rows of haricot bean residue incorporated over the control plots at Adele site were greater than their respective plots at Bala Langey site. This shows that response to residue incorporation in terms of grain yield is higher at Adele site than at Bala Langey site.

However, the overall maize grain yield was higher at Bala Langey site than at Adele site. This could be attributed to the differences in the quantities of nutrients incorporated through residue at both sites (Table 1) which resulted from the differences in soil fertility status. The soil fertility status of Bala Langey site is relatively better than that of Adele site.

Table 4: Effect of haricot bean maize intercropping (year I) and haricot bean residue incorporation (year II) on mean maize grain yield in kg ha^{-1} at Adele and Bala Langey sites

Levels of residue incorporated	Adele site		Bala Langey site	
	Year I	Year II	Year I	Year II
R0	3695 a	4156 a	5476 a	6372 a
R1	3453 a	5161 ab	5367 a	6768 ab
R2	3517 a	5973 b	5017 a	7890 b
R3	3289 a	6111 b	5208 a	7795 b

*Means in each column with same letter are not significantly different at $p \leq 0.05$ according to Duncan multiple comparison

*R = Rows of Haricot bean between maize plants which represent levels of residue incorporated

In general, incorporation of residue indicates improvements in selected soil properties as well as maize grain yield. Therefore, this study indicates that in a farming system, where there is no option for retaining or incorporating cereals residue because of other uses, cereals/legume intercropping system could be a better option for soil fertility enhancement and crop yield improvement through legume residue incorporation into soils.

Effective Number of Rows of Haricot Bean between Maize Plants for the Improvement of Maize Grain Yield

Mean maize grain yield was increased as the number of rows of haricot bean (representing levels of residue incorporated) between maize plants increased (Figure 3). As indicted by Figure 3 a and b , the mean maize grain yield for plots incorporated with two rows was higher than for plots incorporated with one row of residue and the control at both sites. There is no much difference in mean maize grain yield between plots incorporated with two and three rows of residues at both sites.

The results indicate that mean maize grain yield was the highest for plots incorporated with 3 and 2 rows of haricot bean residue at Adele and Bala Langey sites, respectively. Therefore, effective numbers of haricot bean rows between maize plants are 3 and 2 for Adele and Bala Langey sites, respectively for maize grain yield improvement under maize haricot bean intercropping system.

On the other hand, mean haricot bean grain yield was the highest for plots of three rows. For soil fertility improvement, two rows were found to be effective at both sites. Thus, two rows of haricot bean between maize plants could be effective for maize grain yield improvement through haricot bean residue incorporation under maize haricot bean intercropping system at both sites

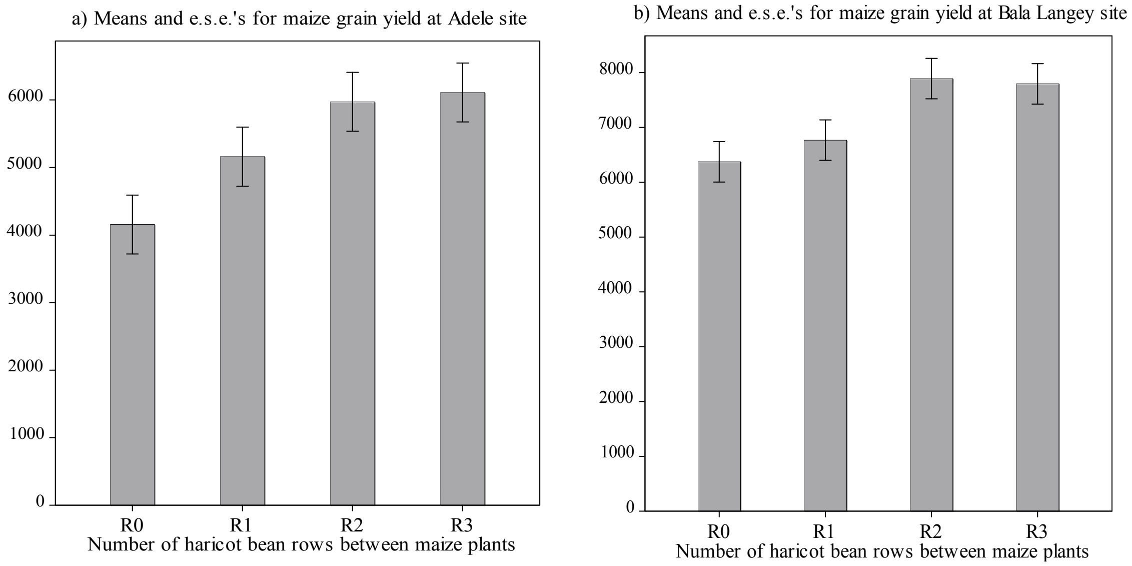

Figure 3: Effective number of rows of haricot bean between maize plants for the improvement of maize grain yield

Conclusions

The study results indicated that there were improvements in soil properties and maize grain yields within two cropping seasons. Soil bulk density and pH decreased while organic carbon, CEC and maize grain yield increased at both sites as a result of haricot bean residue incorporation. This study was conducted for two seasons, where season I was for residue production and season II for residue incorporation trials.

Therefore, it needs further studies for the establishment of the system for the study sites. However, it indicates that cereals/legume intercropping system could be a better option for soil fertility enhancement and crop yield improvement through legume residue incorporation into soils.

Furthermore, farmers of Adele and Bala Langey areas could improve their soil fertility and maize grain yield by:

- Growing 2 rows of haricot bean between maize plants.
- Incorporating haricot bean residue into soil for the enhancement of soil fertility.

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CHAPTER SIX

GENERAL CONCLUSIONS AND RECOMMENDATIONS

These studies were aimed at identifying the status of soil properties under crop-livestock farming system, characterizing the phosphorus adsorption capacity of soils of Adele and Bala Langey farms, investigating the spatial distribution of organic carbon and nutrients under farmers crop residues management practices at both farms and crop residue incorporation effects on soil properties and maize grain yield under maize haricot bean intercropping system at Adele and Bala Langey sites in the eastern part of Ethiopia.

Data on soil properties revealed that the textural class of soils at both farms is sandy clay loam. From the textural class point of view, soils at both farms can be managed similarly for crop production. The soil bulk density values for soils at both farms were below the value at which soil compaction might be expected. Thus, at both farms the soils do not have problems associated with bulk densities.

The pH of the soils is in the range that is conducive for most crops grown in the region. Furthermore, there are no salinity or sodicity problems at both farms. On the contrary, organic carbon and nitrogen are low whereas, phosphorus and sulfur are very low at both farms but nitrogen is in the moderate range for soils of Bala Langey farm. Cation exchange capacity and exchangeable bases are very high for Adele farm soils and high for Bala Langey soils and are sufficient for crop production. Micronutrient contents of the soils are also in sufficient range.

Available phosphorus, organic carbon and nitrogen followed by sulfur are the most limiting soil fertility factors contributing to the lowest productivity of both farms.

Enhancement of soil organic carbon, phosphorus, nitrogen and sulfur is a mandatory intervention management to improve soil fertility status and subsequently increase productivity at both farms. Phosphorus, nitrogen and sulfur fertilizers application rates should be studied at field and in glasshouse and applied based on the study results. Incorporation of crop residues or manure application is mandatory for enhancement of SOC at both farms.

The P-adsorption capacity of the soils at both farms was high. However, the adsorption capacity varies among the soils and the P-sources solutions used for the study. The P-adsorption capacity of Adele soils from DAP and KH_2PO_4 solutions was higher than that of Bala Langey soils indicating that soils of both farms demand different P fertility management. Similarly, P adsorption capacity of soils was higher from DAP than from KH_2PO_4 solution, which shows P-adsorption isotherm is a function of soil factors and the P sources used for the study. P-adsorption isotherm study should therefore be carried out using the P source that might be applied as fertilizer for soil P fertility management.

The phosphorus intensity and quantity factor windows established for soils was able to indicate amount of P that should be applied as fertilizer for the immediate benefit from the applied fertilizer or for soil P build up. Accordingly, between 200 and 500 kg P ha^{-1} should be applied as fertilizer to soils of Adele farm at 0-30 cm depth for immediate benefits based on crop P requirements for soil P fertility maintenance at the currently existing soil condition.

The pH value of the equilibrium solutions of DAP for the P-adsorption isotherm study showed increasing with increase in concentration of DAP. Similarly, pH of soils sampled from plots, where DAP was applied at the rate of 100 $kgha^{-1}$ for two cropping season showed increasing. This puts the suitability of DAP as source of P fertilizer for the study areas. Suitability of DAP as source of phosphorus fertilizer for soils of the study areas should therefore be further investigated at field and in laboratory.

The distribution of organic carbon and nutrient in the crop fields of both farms were affected by the slope gradients. At homesteads distribution of organic carbon and nutrients was also affected by the distance from homes of the households, indicating that distribution of organic carbon and nutrients is highly affected by disposal of manure and household wastes near homes.

Amount of organic carbon and concentration of nutrients were higher in the homesteads than in the crop fields at both farms. Concentration of phosphorus was the highest compared to other nutrients near homes in the homesteads at both farms.

At both farms, transport of organic carbon and nutrients was from the crop fields to the homesteads except for Mg at Adele farm and Fe at Bala Lange Farm. There is no in-situ nutrient recycling at the crop fields of both farms. In general, sustainability of both farms is likely be threatened by removal of crop residues for animal feed and domestic fuel from crop fields and disposal or accumulation of manure and household wastes near home. Intervention management should, therefore, focus on:-

- Reversing the flow of organic carbon and nutrients from the crop fields toward homesteads at both farms through either retaining crop residues or applying manure to the crop fields.
- Equal distribution of manure and household wastes in the farming system of both farms.

The crop residue incorporation study results indicated that there are improvements in soil properties and maize grain yields within two cropping seasons. Soil bulk density and pH decreased while organic carbon, CEC and maize grain yield increased at both sites.

Growing two rows of haricot bean between maize plants at a distance of 30 cm from maize plants were found to be effective for soil fertility enhancement and maize grain yield improvement through haricot bean residue incorporation under maize/bean intercropping system. However, the study was conducted for two seasons, where season I was for residue production and season II for residue incorporation trials. It needs further studies for the establishment of the system for the study sites. In general, it indicates that cereals/legume intercropping system could be a better option for soil fertility enhancement and crop yield improvement through legume residue incorporation into soils.

Furthermore, farmers of Adele and Bala Langey areas could improve their soil fertility and maize grain yield by growing two rows of haricot bean between maize plants through incorporating haricot bean residue into soil for the enhancement of soil fertility. The system could be better option for soil fertility enhancement for areas where farming systems do not permissive for crop residues retention or incorporation because of the other uses of residues. Through the cereals/legume intercropping system farmers may collect the residues of the cereals for either animal feed or domestic fuel consumption and incorporate legume residues for soil fertility enhancement.

Appendices

Appendix 1: Phosphorus adsorption data from KH_2PO_4 and DAP solution by soils from Adele and Bala Langey farms

P added to 1.0 g oven dry (<2mm) soil (mg/l)	P adsorbed by Adele soil (mg/kg)		P adsorbed by Bala Langey soil (mg/kg)	
	KH_2PO_4 solution	DAP solution	KH_2PO_4 solution	DAP solution
1	1.47	5.65	-94.12	-107.30
5	88.24	92.74	-82.35	-37.90
10	135.29	185.48	-64.71	58.07
20	204.41	432.26	74.47	253.23
30	347.06	654.84	222.06	411.29
40	507.35	854.84	402.94	582.26
50	602.94	1075.80	576.47	754.84
60	844.12	1206.50	760.29	983.87
70	1020.60	1387.10	913.24	1167.70
80	1229.40	1627.40	1045.60	1416.10
90	1401.50	1827.40	1260.30	1587.10
100	1529.40	1950.00	1439.70	1733.90

Appendix 2: Organic carbon and nutrients distribution data in the crop fields along slope gradients at Adele and Bala Langey farms

Organic carbon and nutrients	Adele crop field slope gradient (%)			Bala Langey crop field slope gradient (%)		
	7	5	3	6	4.5	2.5
OC (%)	1.72	1.54	1.55	1.66	1.78	1.58
N (%)	0.15	0.16	0.15	0.15	0.15	0.12
P ($mgkg^{-1}$)	3.76	4.50	13.50	6.12	19.20	26.70
S ($mgkg^{-1}$)	1.50	2.11	10.00	2.50	5.35	10.53
Exchangeble bases ($cmol(+)kg^{-1}$)						
Ca	20.55	21.35	19.45	16.02	16.60	19.02
Mg	7.22	6.56	6.43	9.28	13.01	14.71
K	1.02	1.02	1.19	0.92	1.02	1.01
Micronutrients ($mgkg^{-1}$)						
Cu	13.40	12.00	12.90	7.54	14.71	15.82
Fe	286.00	196.00	120.00	323.00	384	450.00
Mn	96.90	92.60	88.55	96.04	97.25	97.73
Zn	0.20	1.07	1.41	1.65	2.15	5.41

Appendix 3: Organic carbon and nutrients distribution data in the homesteads at a distance from homes at Adele farm

Organic carbon and nutrients	Distribution at a distance from home (m)				
	10	25	50	75	100
OC (%)	2.86	2.78	2.58	1.94	1.55
N (%)	0.50	0.26	0.20	0.15	0.15
P ($mgkg^{-1}$)	102.00	44.80	40.80	22.90	13.5
S ($mgkg^{-1}$)	24.21	8.95	5.26	1.35	1.00
Exchangeble bases ($cmol(+)kg^{-1}$)					
Ca	30.17	24.41	25.92	26.19	19.48
Mg	11.20	9.25	6.75	8.70	6.43
K	5.65	3.01	1.12	1.52	1.19
Micronutrients ($mgkg^{-1}$)					
Cu	5.06	2.40	1.30	1.15	1.20
Fe	310.00	158.00	104.00	85.00	12.00
Mn	98.45	98.24	98.43	98.04	88.55
Zn	23.21	5.44	3.04	2.38	1.41

Appendix 4: Organic carbon and nutrients distribution data in the homesteads at a distance from homes at Bala Langey farm

Organic carbon and nutrients	Distribution at a distance from home (m)				
	10	25	50	75	100
OC (%)	2.11	1.95	1.95	1.93	1.64
N (%)	0.21	0.18	0.18	0.19	0.10
P ($mgkg^{-1}$)	41.20	12.40	9.96	19.20	6.99
S ($mgkg^{-1}$)	5.26	2.11	1.53	12.11	8.42
Exchangeble bases ($cmol(+)kg^{-1}$)					
Ca	22.73	17.35	18.54	26.42	23.25
Mg	9.68	8.58	7.87	9.90	7.50
K	2.86	1.03	1.38	2.63	0.96
Micronutrients ($mgkg^{-1}$)					
Cu	14.10	4.02	2.18	3.45	2.15
Fe	354.00	136.00	108.00	246.00	234.00
Mn	99.07	95.67	98.76	98.66	97.65
Zn	11.90	3.89	2.75	6.58	2.08

Appendix 5: Crops grain yield (kg/ha) at Adele and Bala Langey sites in 2012-13 cropping seasons

Levels of treatments	Adele site				Langey site			
	Season I		Season II		Season I		Season II	
	Maize	Haricot bean	Maize	Haricot bean	Maize	Haricot bean	Maize	Haricot bean
R0	4225	----	5756	----	4656	----	6467	----
R0	3489	----	3334	----	5823	----	6378	----
R0	3067	----	4311	----	5667	----	5867	----
R0	4000	----	3323	----	5756	----	6778	----
R1	4267	822	8133	1000	4445	667	7156	978
R1	3112	445	4445	400	5234	1221	6489	1289
R1	3067	489	3867	534	5845	1445	6800	1533
R1	3367	778	4200	622	5945	1000	6667	1422
R2	4269	778	7223	934	4123	1889	8067	1911
R2	4000	1112	4245	978	4445	2778	9511	1889
R2	3200	778	6000	867	5223	2332	6869	2400
R2	2600	778	6423	867	6278	1956	7112	2112
R3	4823	1333	8800	1334	4332	2112	7556	2133
R3	2889	1000	5067	1112	4889	2667	7311	2778
R3	2667	889	4400	1022	5500	2778	7956	2889
R3	3378	1000	6178	1022	6112	2333	8356	3222