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

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Authors' contributions

This work was carried out in collaboration between all authors. Author LW designed the study, wrote the protocol, wrote the first draft of the manuscript and managed the literature searches and all laboratory analyses. Author KK edited the data, reviewed and edited the manuscript. Authors JJM and FBRR reviewed and edited the protocol and the manuscript. All authors read and approved the final manuscript.

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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 involving 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 at a depth of 0 – 30 cm. The samples were analyzed following standard methods for soil organic carbon and nutrient contents. Results indicated that distributions of organic

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carbon and nutrients were affected by slope gradients in crop fields and by distances in homesteads at both farms. Results showed 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. Amounts of N transported from Adele and Bala Langey crop fields through haricot bean residue were 4.70 and 5.60 g/kg dry matter, 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.

Keywords: Farm; homesteads; crop fields; slope gradient; farm sustainability.

1. INTRODUCTION

Crop residue removal management practice is as old as the crop-livestock farming system in the eastern part of Ethiopia. Crop residues have been collected 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 is one of the main causes for soil fertility depletion. Yadvinder-Singh et al. [2] indicated 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 organic carbon and nutrient contents and distribution in soil 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. Lal [3,8] have observed that retaining crop residues as surface cover is an important conservation technique for erosion control. Therefore, retention and/or incorporation of crop residue into soil 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.

2. MATERIALS AND METHODS

2.1 Description of the 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 09º24`26``N, 041º58`00``E and 09º24`34`` N, 041º58`04``E and 2075 m.a.s.l. Bala Langey farm at Kersa lies between 09º25`41``N, 041º47` 48``E and 09º25`46``N, 041º47`56``E and 2005 m.a.s.l. Information obtained from Haramaya University Meteorological Station indicates that the mean annual rainfall of Haramaya district was 784 mm while mean maximum and minimum temperatures were 24.36 and 9.61ºC, 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 away 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.

2.2 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 based on the slope gradients; three on the contour lines and three along the slope gradients (3 × 3). 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. Two kilogram 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. Two kilogram soil samples were collected from each sampling site at the depth of 0-30 cm with auger. A total of 15 and 10 soil samples were collected from the homesteads at Adele and Bala Lange farms, respectively. The samples were thoroughly mixed manually and soil piles were made to divide the samples into four equal portions. One portion was taken from each to make composite subsamples with their respective slope gradients in the crop fields and distance from the homes. All composite samples were air-dried and crushed to pass through a 2 mm sieve. Subsamples were reduced to the size of 0.5 mm for analysis of nitrogen and organic carbon.

Organic carbon was determined following the Walklely and Black method [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]. Sulfur content of 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 70ºC 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 [11,14] for plant analyses.

3. RESULTS AND DISCUSSION

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

3.1.1 Organic carbon and nitrogen

The position effect on the distribution of organic carbon in the crop fields of the two farms was higher compared to nitrogen. The content of organic carbon showed a decreasing trend down slope in the crop field at Adele farm (Fig. 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 (Fig.1b).

Quantities of organic carbon in the crop fields of both farms were less than 2% (Figs. 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 (Figs. 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 (Figs. 1a and b). This also showed 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 (Fig. 1c). Accordingly, quantities of organic carbon decreased with increases in distance away from the home. Results of study indicated that 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 (Fig. 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. The results showed that 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. Similarly, organic carbon and nitrogen declined to 0.10 and 0.12% at a distance of 100 m away from the homes at both farms, respectively (Fig. 1c). As was observed for organic carbon, more nitrogen accumulated near the home of Adele farm household compared to 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 (Fig. 1c) 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 Fig. 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.

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 to differences in the quantities of other nutrients like sulfur and phosphorus (Figs. 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.

3.1.2 Phosphorus and sulfur

The position effect on the distribution of available phosphorus and extractable 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 (Figs. 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 (Fig. 2a). At Bala Langey farm (Fig. 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.

Results 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 (Figs. 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 slops 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.

Distribution of available phosphorus and extractable sulfur was also affected by the distance away from the home of the households at both farms (Fig. 2c). About 100 (above very high) and 41 mgkg^{-1}(high) available 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 (Fig. 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 (Fig. 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 (Fig. 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 (Fig.

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 (Fig. 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 available 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] 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.

3.1.3 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 (Figs. 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 (Fig. 3a).

At Bala Langey farm, quantities of exchangeable Ca and Mg increased down the slope gradients in the crop fields (Fig. 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 (Fig. 3c). Quantities of all the exchangeable bases were higher near the homes at a distance of 10 m compared to 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 (Fig. 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.

3.1.4 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 (Fig. 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 (Fig. 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.

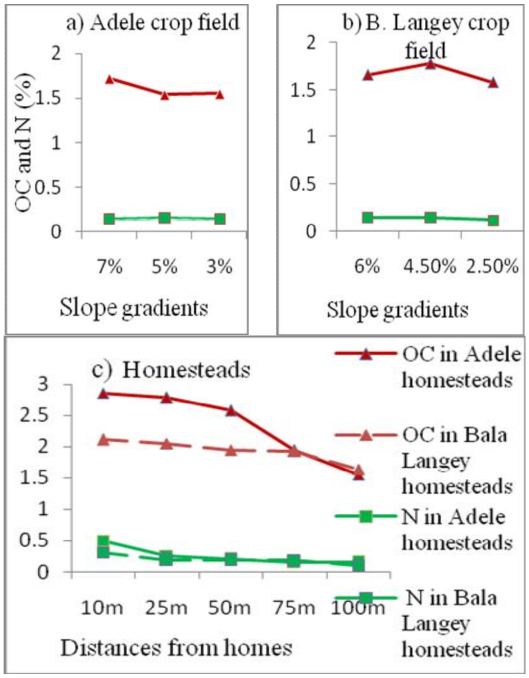

Fig. 1. Distribution of organic carbon and nitrogen at Adele (a) and Bala Langey (b) in crop fields and at homesteads (c)

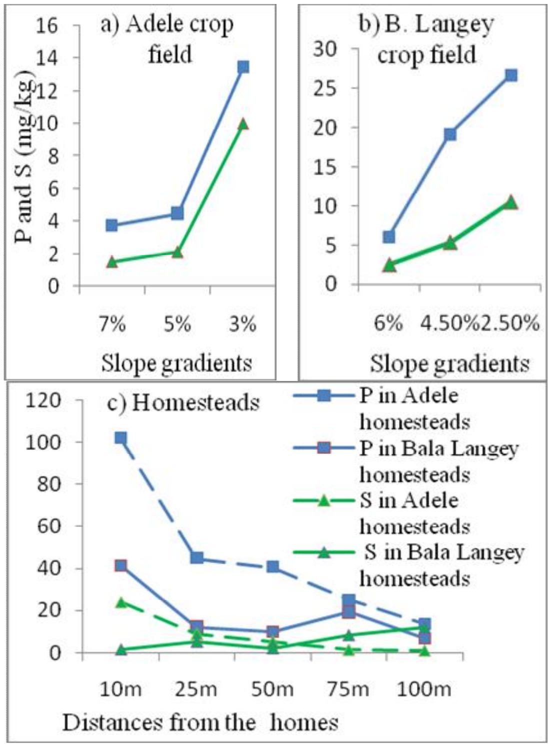

Fig. 2. Distribution of phosphorus and sulfur at Adele (a) and Bala Langey (b) in crop fields and at homesteads (c)

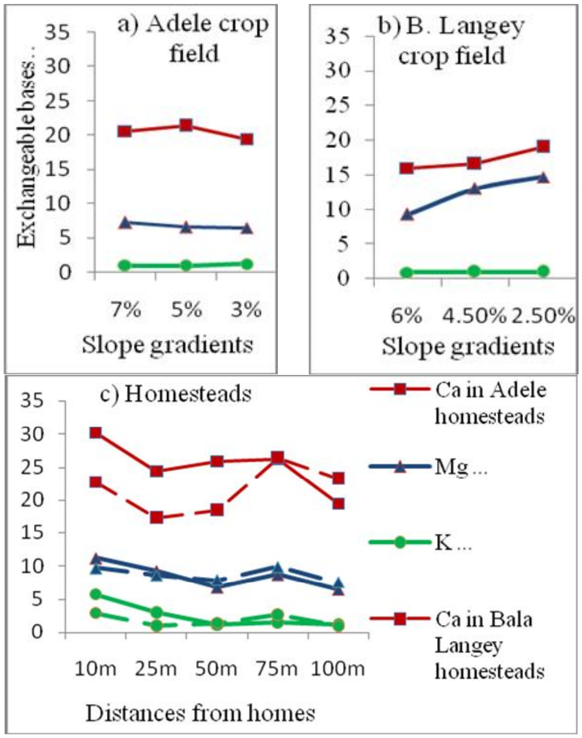

Fig. 3. Distribution of exchangeable bases at Adele (a) and Bala Langey (b) farm in crop fields and at homesteads (c)

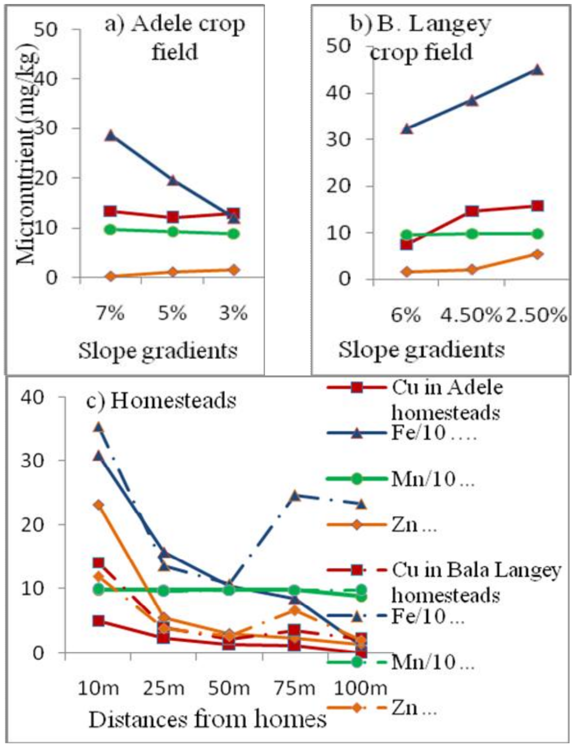

Fig. 4. Distribution of micronutrient at Adele (a) and Bala Langey (b) farm in crop fields and at homesteads (c)

At the homesteads, distribution of micronutrients was also affected by the distances far 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 (Fig. 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 (Fig. 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.

Fig. 4c 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 to 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.

3.2 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 to 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 to 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 in the homesteads 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 was 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.

4. CONCLUSION

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 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 nutrients in the farming system of both farms.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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