academicJournals

Vol. 13(12), pp. 588-595, 22 March, 2018
DOI: 10.5897/AJAR2014.9170
Article Number: E14007456442
ISSN 1991-637X
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http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Addressing soil organic carbon issues in smallholders' farms in Ethiopia: Impact of local land management practices

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Received 24 September, 2014; Accepted 12 November, 2015

Soil organic carbon plays a key role in plant biomass production. On smallholder farms, crop and livestock are traditionally integrated and support each other. However, due to changes in socio-economic factors, this relationship is lost as resources are mismanaged. The present study was conducted in the Central Ethiopian highlands that represent about 90% of the country's smallholder farmers. The objective of this study was to quantify soil organic carbon in different agricultural management systems and to document the contribution of livestock to carbon storage. The study included a socio-economic survey and soil laboratory analysis. Results showed that different land uses and conservation measures had various impacts on soil carbon addition and depletion. The comparison between different land uses showed that the highest soil organic carbon was found in grazing land (27%), followed by fenced-off land (2.59%) at 0 to 15 cm soil depth. It also showed that animal waste and farmyard manure added to soil had the highest amount of organic carbon (3.90 and 1.85%, respectively) at 0-15 cm soil depth. It was concluded that livestock waste, farmyard manure, and crop residues improved soil fertility and soil organic carbon in the top soil indicating that livestock and by-products made a significant contribution to carbon storage.

Key words: Farmyard manure, land uses, organic carbon inputs, socio-economic survey, soil management practices.

INTRODUCTION

Soil carbon storage is defined as the transfer of carbon dioxide (CO_2) from the atmosphere into the soil through crop residues and other organic solids in a form that is not immediately reemitted (FAO, 2004; Lal, 2004). The transfer or "storage" of carbon helps to offset emissions from fossil fuel combustion and other carbon-emitting activities while enhancing soil quality and long-term agronomic productivity (Sundermeier et al., 2005; Barreto

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et al., 2009). It was observed that the depletion of soil carbon is increased by soil degradation and exacerbated by inappropriate land uses and soil mismanagement (Lal, 2004). Thus, the adoption of restorative land management practices can reduce the rate of enrichment of atmospheric CO_2 while having a positive impact on food security, agro-industries, water quality, and the environment. There is a clear correlation between soil organic carbon in the topsoil and crop yield (FAO, 2001; Lal, 2006).

Under smallholder crop and livestock production systems in Ethiopia, crop production is the major cash income earner (IPMS, 2004) while livestock production plays an important role as a source of draught power and organic fertilizer for crop production, and it is a living bank, which provides household income and food (Hadera, 2001). However, although livestock production is associated with environmental degradation (FAO, 2000) and wholesale devastation of rangelands and irreversible desertification (Pearson et al., 2005), there is ample evidence to show that livestock production contributes positively to carbon balance in the soil (de Han et al., 1998). The addition of animal manure and livestock waste to the soil is an alternative management option to ensure carbon input for soil carbon storage (FAO, 2001; Lal, 2002).

However, due to socio-economic factors, traditional land management practices, for instance leaving crop residues in the field after harvest have declined (Lal, 2004). Instead, crop residues are used for animal feed, house construction, firewood or sold as a source of income (FAO, 2001). Crop residues are cut close to ground level, leaving nothing to return back to the soil (Kahsay, 2004), and whatever stubble is left on the ground is extensively grazed and trampled, so that only bare soil remains, which exposes it to wind and water erosion. This type of crop residue management has thus contributed to the low levels of soil organic carbon and soil quality.

Traditionally, animal manure is among the recyclable resources that can be used to increase soil organic carbon. However, due to lack of firewood in the highlands to meet household fuel demand, farmers are using animal manure for fuel needs such as cooking and heating as well as a source of income (Tesfaye et al., 2004). It has also been estimated that the sale of animal manure in the highlands contributes about 25% of the total income from livestock production (Tesfaye et al., 2004). Under the current manure management systems in smallholder mixed agriculture, no animal waste is returned to the soil except urine. This has serious repercussions for soil carbon storage.

In general, permanent removal of crop residues and the use of animal manure for household fuel lower soil organic carbon (FAO, 2001). Nevertheless, long-term trials have shown that carbon losses due to human interventions can be reversed through improved land management practices which enhance carbon storage in the soil (Rosenberg et al., 1999). It is thus important to study the impact of different land management practices under mixed crop-livestock production systems on carbon storage as well as the contribution of livestock production to carbon storage.

Previous studies on carbon storage in Ethiopia examined natural resource management from forestry and soil perspectives (Bojo and Cassells, 1995), whereas in the current study, carbon storage was examined with regard to different land uses including livestock production. Thus, in the current study, the extent to which different local land management systems and organic addition increased soil carbon in mixed crop-livestock production systems was investigated in the central Ethiopian highlands. The research also explored the contribution of livestock to carbon storage and environmental quality.

MATERIALS AND METHODS

Study area

The study was conducted in central Ethiopian highlands that represent 90% of Ethiopian farm lands. In the highlands, the main agricultural activity is smallholder mixed farming dominated by crop production (Constable, 1984). The Ethiopian highlands, based on development potential and resource base, are further subdivided into three zones (Amare, 1980): high potential cereal/livestock (HP/CL), low potential cereal/livestock (LP/CL), and high potential perennial crop/livestock (HP/PL). Ecologically, the study area falls under the high potential livestock/crop zone (IPMS, 2004), which is located southeast of Addis Ababa at latitude 8°46’ 16.20’’ to 8°59’ 16.38’’ N, and longitude 38°51’ 43.63’’ to 39°04’ 58.59’’ E, on the western margin of the Great East African Rift Valley. The altitude of the area ranges from 1500 to 2000 m above sea level. Two major agro-climatic zones were identified in the area (IPMS, 2004): the mountain zone > 2000 m above sea level, which covers 150 km^2 or 9% of the area, and the highland zone at 1500 to 2000 m above sea level, which covers over 1600 km^2 or 91% of the area. The agro-ecology of the area is best suited for diverse agricultural production systems. It is known for its excellent quality Teff grain, which is an important staple food grain in Ethiopia that is used for making bread (Enjera). Wheat is the second most abundant crop, and pulses, especially chickpeas, which grow in the bottomlands and flood basins. Most farmers grow chickpeas in rotation with cereals. Livestock production forms an integral part of the agricultural production system. Livestock provide inputs for crop production such as draft power, transport services and manure for fertilizer and fuel for cooking (Hadera, 2001). Furthermore, livestock is central to nutrient cycling and important for the efficiency, stability and sustainability of farming systems in Ethiopian highlands.

Methodology

The study was designed to quantify soil organic carbon in different land management systems and to compare the effect of adding carbon from different organic sources in to soils. The study combined socio-economic surveys with laboratory analyses. The laboratory data were complemented by land use histories and the current crop and soil management systems. Sample sites represented 12 alternative land uses and soil management practices including fertilization practices. One site was designated as a reference point to represent an area free from human interference for over 30 years. Sample sites were described according to World Overview of Conservation Approaches and Technology (WOCAT, n.d.), classification for conservation and land use management (Appendix 1).

The 12 sites were further reclassified into land use practices and organic matter sources in order to categorize and organize them in broader land use systems and organic matter sources. Means and standard deviations were calculated for these categories. Land use categories were based on World Overview of Conservation Approaches and Technology (WOCAT, n.d) and were classified into the subclasses of crop land (sites 2, 3, 4, 5, 6, 7 and 8), grazing and pasture land (site 9), swamp land (site 12), and fenced land (sites 10 and 11). Organic matter sources were also grouped based on the same system. The carbon yield was calculated based on Adam's (1973) equation for bulk density as follows:

$$BD= [100\backslash(\%OM\backslash0.224)+(100-\%OM\backslash MBD)]$$

where BD = bulk density, OM = organic matter, and MBD = mineral bulk density. A typical value of 1.64 was used for MBD (Mann, 1986).

Soil sampling and analysis

In June 2009, soil samples were taken from the 12 sites. Before sampling, forest litter, grass and any other material on the soil surface was removed. The sites were purposely selected to describe the different land uses and conservation measures implemented such as degradation level, crop history, and level of fertilization, residues left in the field and compost or manure application. A group interview was also conducted with about ten people from the community which included elders, women, youth and extension workers in order to document land uses and conservation measures for each site. Thus, types of crops, soil and land management practices for each site were described based on detailed interviews with the community.

Soil samples were taken at 0 to 15 cm and at 15 to 30 cm soil depth with four sub-samples from each site. Thus, the four sub-samples were pooled to make one composite for each site. The four sub-samples were taken within a radius of 30 to 50 m from each other. The composite samples were stored in plastic bags and transported to the Debrezeit Research Centre Soil Laboratory within 2 h of collection. Twelve (12) composite soil samples with four sub-samples each were used for analyses.

Soil samples were air dried and ground with a mortar and pestle and sieved through a 2-mm sieve, from which soil organic carbon content was determined by using the procedure described by Walkely and Black (1934). Soil moisture analysis was done by oven drying for 24 h at 105°C. Soil bulk density was also estimated by using the Adams equation described earlier (Adams, 1973). A typical value of 1.64 was used for mineral bulk density (Mann, 1986). Carbon per unit area was calculated using the formula described by Pearson et al. (2005) as:

$$C\ (t/ha) = [(\text{soil bulk density } (g/cm^3) \times \text{soil depth (cm)} \times \%\ C)] \times 100.$$

The carbon content was expressed as a decimal fraction, that is, 2.2% C was expressed as 0.022.

Statistical analysis

Composite topsoil samples from 0 to 15 cm and 15 to 30 cm soil depth from all sites were taken from representative areas using an augur. The proportion of organic carbon in the sampled soils was determined using the wet oxidation method (Walkley and Black, 1934). Data were captured on MS Excel and exported to SPSS Version 17.0.1 (2008) for statistical analysis. The data were then analysed by SPSS version 17.0.1 (2008) to determine means and standard deviations of soil organic carbon.

RESULTS AND DISCUSSION

Soil organic carbon content of the study sites

According to FAO (2001), when the woody biomass on the ground increases it can act as a permanent carbon sink. Woody vegetation with deep and extensive root systems can capture nutrients that are not accessible by crops to make them available through litter fall and nitrogen fixation by leguminous trees (Lal, 2002). Therefore, site 1 was chosen as a reference point or control site for comparison with other alternative soil conservation and land use management practices that have changed over time due to human interference.

Results showed that the topsoil at 0 to 15 cm depth had higher soil organic carbon (Mean 1.543%) than the subsoil at 15 to 30 cm depth (1.151%), as shown in Table 1. This was expected as reported earlier by Post and Kwon (2000), who observed that land use and management practices determined the direction and rate of change in organic carbon content. Site 1 (the reference point) had a soil organic carbon content of 1.27% at 0 to 15 cm and 0.31% at 15 to 30 cm soil depth which were below the mean at both depths as shown in Table 1. Site 11 had the highest organic carbon content (3.90%) at 0 to 15 cm followed by site 10, 9, 3, 5, 4 and 2, which had 2.32, 2.21, 2.13, 1.85, 166 and 1.65% at the same depth, respectively. This was attributed to more carbon addition from rich sources such as animal waste (site 11), fenced off grazing land (site 10), manure and urine deposits (site 9), crop rotation of cereals and pulses (site 3), crop land on farmyard manure (site 5), conservation tillage (site 4), and commercial mixed farm on farmyard manure. Sites 12, 7 and 8 had the lowest organic carbon content (0.27 and 0.07%) at the same depth compared to the reference point. This could be due to the leaching of carbon and nitrogen from the topsoil.

At 15 to 30 cm depth different results were observed. Site 12 which had among the least proportion of organic carbon content (0.27%) at the topsoil, had the highest organic carbon content (3.23%) as shown in Table 1. This could have been due to seasonal accumulation of deposits from runoffs in the swamps. Other sites which had above average organic carbon included site 9, 5, 10, 6, 11 and 3 (2.16, 1.33, 1.23, 1.17, 1.15 and 1.02%), respectively. The sites (9, 10, 5 and 6) where manure, compost or animal waste were added or where degraded lands were conserved and used for grazing or cut and carry of forage had above average amount of organic carbon content. Table 1 shows a summary of the organic carbon contents of all sites.

Table 1. Soil organic carbon content of sample sites.

Site	Land uses and conservation measure	Soil organic carbon at 0-15 cm depth (%)	Soil organic carbon at 15-30 cm depth (%)
1	Fenced and undisturbed land	1.27	0.31
2	Commercial mixed farm on manure	1.65	0.73
3	Crop land and crop rotation	2.13	1.02
4	Crop land and conservation tillage	1.66	0.34
5	Crop land and manure	1.85	1.33
6	Crop land and compost	1.12	1.17
7	Crop land, better residue management	0.07	0.80
8	Crop land and chemical fertilization	0.07	0.25
9	Degraded land and grazing site	2.21	2.16
10	Degraded, fenced, cut and carry feeding	2.32	1.23
11	Animal waste disposal and uncultivated	3.90	1.15
12	Swampy	0.27	3.23
	Mean soil organic carbon content	1.543	1.151

Table 2. Soil organic carbon content for various land use categories at 15 and 30 cm depth (Mean ±SD).

Land use category	Soil organic carbon at 0-15 cm (%)	Soil organic carbon at 15-30 cm (%)
Crop land (n=7)	1.14 ± 0.73	0.81 ± 0.55
Grazing land (n=2)	2.27 ± 0.08	1.70 ± 0.66
Swampy (n=1)	0.27	3.23
Fenced land (n=2)	2.59 ± 1.86	0.73 ± 0.59
Total	1.40 ± 1.03	0.99 ± 0.73

The influence of different land uses on soil organic carbon content and the contribution of livestock

There are many factors and processes that determine the direction and rate of change in soil organic carbon content when different land use management practices are applied (Post and Kwon, 2000). The land uses in the study area were categorized as crop land, grazing land, swamp land and land fenced without tillage. The analysis of variance at 95% level of confidence showed that there were significant differences in carbon content for the different land uses as shown in Table 2.

Categorization of sample sites based on WOCAT categories

The mean soil organic carbon content for the land use categories were 2.6, 2.27, 1.14 and 0.27% for fenced land, grazing land, crop land and swamp land, respectively, at 0 to 15 cm depth (Table 2). The carbon content was acceptable and supported the findings of other researchers (Post and Kwon, 2000), except for the lower carbon content of swamp land. The reason for the lower carbon content in swamps at 0 to 15 cm depth was due to the leaching of carbon and nitrogen to the bottom layers (FAO, 2001). This was also supported by the evidence that higher carbon content was observed in 15 to 30 cm depth for swamp land. The carbon content in grazing land in both degraded and fenced sites came second and was attributed to the addition of dung and urine to the soil (Hoffmann and Gerling, 2001) as well as the ability of livestock to move organic material from place to place and mix it with soil particles (FAO, 2004). The other plausible reason could be that grazing land might have been damaged physically but not degraded chemically as it appeared. Crop land had the lowest organic carbon because of the tillage practices.

These results have validated the importance of livestock production in soil organic carbon storage under two different grazing sites, degraded and fenced land. However, the results of this study did not support the findings of many other reports (FAO, 2006) which showed that livestock production was responsible for both physical and chemical degradation of the soil. The current findings thus call for further investigation into the role of livestock in soil degradation as well as carbon storage in other areas.

Table 3. The carbon yield from carbon inputs at 0-15 cm soil depth.

Carbon input	Carbon at (15cm) depth (%)	Bulk density (g/cm^3	Years carbon input added	Estimated current carbon (t/ha)	Difference in carbon from base site (t/ha)	Estimated carbon (g/m^2/year)
Animal waste	3.9	0.869	50	50.84	(+)32.69	102
Crop rotation	2.13	0.924	3	29.52	(+)11.37	984
Farm manure	1.75	0.937	7	24.60	(+)6.45	351
Fenced off area	1.20	0.956	10	17.21	(-)0.94	172
Compost	1.12	0.959	4	16.80	(-)1.35	402
Minimum tillage	1.06	0.961	6	15.28	(-)2.87	254
Deep tillage	0.79	0.970	3	11.50	(-)6.65	383
Crop residue and deep tillage	0.07	0.977	3	1.03	(-)17.12	34.0
Base site	1.27	0.953	30	18.15	(0)	60.5

Organic matter input and carbon storage in the soil

According to FAO (2004), the addition of organic matter to the soil through the use of farmyard manure, green manure, legumes in rotations, vermin-compost and fallows in rotations, increase soil carbon and agricultural yields. But when inorganic fertilizers were used alone they resulted in the decline of organic carbon in soil in all systems, and when they were used with no-tillage, only minimal increase in yield was realised (FAO, 2001). No-tillage increases soil organic carbon, although the accumulation is greatest when organic matter is added to the soil (Lal, 2006). Similar scenarios have shown that carbon storage in tropical dry lands can also be achieved at the different sites (Hernanz et al., 2009).

In order to improve soil organic carbon the best land management practices have to be selected based on existing farming systems (FAO, 2002). Thus, for example, the application rate of organic matter to the soil needs to correspond with quantities that are available to local farmers. However, at the field level, important trade-offs may not occur, which prevent the adoption of the best strategies for carbon storage. Crop residues may be required for livestock feed, fuel, construction material or may be sold for cash in difficult times (Kahsay, 2004). Similarly, farmyard manure may be used for energy and cash income (Tesfaye et al., 2004). Thus, many socio-economic factors interact to determine which scenario or combination of scenarios may be implemented in each growing season (FAO, 2000).

According to some research reports, soil carbon can be restored to pre-cultivation levels, and in certain circumstances to above the original level (FAO, 2004). However, the true “indigenous soil carbon level” is often difficult to establish in systems where agricultural activities have remained the same for several centuries or even millennia (Constable, 1984), like the farming systems practiced in the Ethiopian highlands. To achieve quantities of soil carbon in excess of the “original level” implies that the agricultural system had greater productivity than the native system (FAO, 2004). The scenario that predicted the highest carbon storage rate was often associated with the introduction of trees in the system (Pearson et al., 2005). It was shown that the inputs of carbon from trees were more resistant to decomposition than those from herbaceous crops and caused marked increases in the level of soil carbon (Falloon and Smith, 2002).

In the current study, nine carbon input methods were examined and compared as shown in Table 3. The highest carbon input sources were from animal waste disposal. They represented city abattoir wastes where animal offals and other wastes were deposited on the fields. For this site the soil organic carbon content was 3.9% at the depth of 0 to 15 cm and 1.15% at the depth of 15 to 30 cm. The soil organic carbon content at the depth of 0 to 15 cm showed that there was excess nutrient deposition in the topsoil than in the subsoil. Carbon yield of animal waste at 0 to15 cm depth was the highest at 50.86 t/ha, and a carbon yield of 102 gm/cm^2/year, which indicated that there was carbon saturation after a certain level of storage (Table 3). Urban dairies and abattoirs were net importers of nutrients from rural farming systems, since excess deposition of nutrients was found in their systems (Yoseph et al., 2002). It is thus worth mentioning that an alternative mechanism has to be designed in order to balance nutrient flow from one system into another.

The second best practice which contributed to soil carbon input was crop rotation of cereals and pulses which was practised for a period of over three years. The crop rotation usually involved Teff, chickpea and wheat. Soil organic carbon for crop rotation was 2.13% at 0 to 15 cm and 1.02% at 15 to 30 cm depth. The carbon yield from crop rotation at 0 to 15 cm depth was 984 g/m^2/year (Table 3).

The third most important management practice for carbon input was the use of farmyard manure. The application of farmyard manure has long been treated as a valuable source of organic matter to enhance soil fertility (FAO, 2001). According to Kapkiyai et al. (1999), for the same carbon input, carbon storage was higher with manure application than with crop residues ploughed into the soil. The reason for this difference is that manure helps the formation and stabilization of soil macro aggregates (Whalen and Chang, 2002) and particulate organic matter (Kapkiyai et al., 1999). Manure is also more resistant to microbial decomposition than crop residues (FAO, 2001). The organic carbon content of a farmyard manure plot at 0 to 15 cm depth was 1.75% and at 15 to 30 cm it was 1.03%. The carbon yield of farmyard manure application at 0 to 15 cm depth was 351 g/m^2/year, which was one of the highest carbon content storage in a short period of time (Table 3).

The area that was fenced off from grazing had a carbon yield of 172 g/m^2/year as shown in Table 3. White et al. (1987) found a value of 21 g C m^{-2}year^{-1}, while Burke et al. (1995) reported an accumulation of 3.1 g C m^{-2}year^{-1} in a short grass steppe on unimproved and abandoned crop fields. These results suggested that longer periods are required for more pronounced increases in total soil organic carbon under conditions of low productivity. The fenced land had a higher soil carbon level in terms of carbon yield per hectare than croplands that were subjected to different tillage types. This finding was supported by similar results reported by Franzluebbers et al. (2000) and Reeder and Schuman (2002). They found that there was an accumulation of litter in an enclosed area that was shielded from any interference in a semi-arid system. As a result the soil carbon level was higher in fenced land than in cultivated and grazed lands.

In general, the current soil carbon data were variable but slightly more beneficial and associated with the addition of different carbon inputs. A positive carbon yield value greater than base site (18.15 t/ha) indicated a response to carbon addition to the soil (Table 3). There was ample evidence on the benefits associated with using organic amendments on soils. These were based on GHG emission benefits as well as increased soil health in cases where organic amendments were frequently applied. A large number of studies have shown improvements in soil carbon concentrations when manures, composts or municipal bio-solids were applied (Albaladejo et al., 2008; Kong et al., 2005; Lal, 2007; Mann, 2008).

Mean values of carbon per hectare in Table 3 was estimated using the formula described by Pearson et al. (2005). The 9 sites were selected from the 12 sites with potential organic carbon addition and depletion, according to the recollection of the interviewees. Animal waste included bones, horns, stomach, intestinal contents and blood disposed from the slaughter houses. Minimum tillage refers to conservation tillage of ploughing only once at the depth of less than 18 cm using traditional ploughs known locally as *Maresha*. Deep tillage refers to mechanized tractor ploughing deeper that 20 cm. Crop residues from cereals were left over in the fields after grain harvest. The base or reference site was protected from human and animal interference.

Deep tillage was a carbon negative practice. Even with the addition of crop residues, deep tillage produced negative carbon storage as shown in Table 3. And in general, for all the top three carbon input practices, livestock products and by-products played a greater role in carbon storage and hence the role of livestock production in soil carbon storage is vital. At the same time, livestock played a big role in increased grain and straw yield.

Conclusions

This data were collected under uncontrolled environment where management practices were exercised by individual smallholder farmers. However, the data analysis showed a trend of carbon storage similar to those managed under controlled experimental situations. In general, the comparison among different land uses in line with their ecological history showed that grazing land had higher soil organic carbon, followed by fallow or undisturbed land. Grazing land had higher soil organic carbon because of dung and urine added into the soil and the ability of livestock to move organic material from place to place. The results of this study showed that although livestock affects the topsoil structure and vegetation they contribute much more by adding organic carbon into the soil than they are depleting. When different sources of carbon inputs were added into the soil and compared, it was found that animal waste, farmyard manure and crop rotation lead to a higher organic carbon yield in the soil. Similarly, if livestock are managed well they can play an important role in maintaining ecosystem balance.

It is important to suggest here that future research direction in carbon sequestration should be down scaled to community level resource management with emphasis on their positive and negative contribution to environmental sustainability. The research strategy should focus on experimental designs that produce empirical information for decision making on environmental protection by producers, service providers and policy makers.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

ACKNOWLEDGEMENTS

The authors thank Dr. Abele Ebro for the constructive comments on the manuscripts. They also thank the International Livestock Research Institute for financial and research support.

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Appendix 1

Sample sites used for the study

Site 1: This site was undisturbed and unploughed for over 30 years. The land was covered with grass and shrubs. It was chosen as a reference point in order to compare it with other alternative soil, crop and land management practices. According to FAO (2001), when the woody biomass increases it acts as a permanent carbon sink. Woody vegetation with deep and extensive root systems can access nutrients that are not accessible to crops to make them available to crop production through the litter, and fixing of nitrogen in leguminous plants (Lal, 2002).

Site 2: This site was a commercial farm with integrated vegetable, poultry and dairy production, where farmyard manure was used for seven years. The land was cultivated continuously without rest and farm operations were carried out with heavy duty machinery.

Site 3: This site had previous crop rotations of cereals and pulses, following a pattern of Teff-chickpeas-wheat-chickpeas for three consecutive years. Crop rotation is considered to be one of the agricultural management practices that recycle nutrients in the soil (Lal, 2001).

Site 4: The land was ploughed once and herbicides were applied during or just before seeding of cereals (Teff and wheat).

Site 5: This site was a smallholder plot closer to the homestead where backyard manure was regularly applied.

Site 6: This site was a field where compost was applied for four years. The compost was made up of household waste, ashes, leaf litter, and crop and vegetable residues.

Site 7: This site was a field where crop residues were well managed. The crop residues were left in the field and ploughed into the soil at the end of the cropping season.

Site 8: Chemical fertilizers were applied at the rate of 200 kg/ha of di-ammonium phosphate and 100 kg/ha of urea for cereals every year.

Site 9: This site was an open grazing land which was overgrazed, degraded and eroded.

Site 10: This site was previously degraded and fenced off for more than 15 years. It was adjacent to Site 9. Fencing is a well-known practice for replenishing nutrients in the soil. Fenced areas are usually hillsides that cannot be used for cultivation but are rested for certain periods of time until the vegetation is regenerated (Constable, 1984). Later on beneficiaries are allowed to utilize the vegetation on a cut-and-carry basis only.

Site 11: This site was used as an animal waste disposal pilot for over 40 years without any cultivation. The site had a gentle slope and the soil was highly eroded. Animal waste such as bones, blood and offals were deposited on this site in pits which were already full.

Site 12: This site was a swampy area where run-off from mountains leached away nutrients from the farms and deposited them in the swamp. Run-off from urban areas also accumulated there during the rainy season. When the swamp dried up during the dry season (March to June) the site was used for grazing.