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Impact of Household Level Tree Planting on Key Soil Properties in Tigray, Northern Highlands of Ethiopia

KEYWORDS: degraded hillsides, landless, tree planting, soil properties

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ABSTRACT *Degraded hillsides have been allocated for tree planting since the last two decades to find land for landless farmers. The study was conducted to assess the effect of household tree growing on some soil properties. Eighteen soil samples were taken randomly from managed and disturbed hillsides. Farmers (n=30) were also incidentally selected for interview on the ecological indicators between the two land uses. The findings showed that plantation had higher organic matter (p=0.00), total nitrogen (p=0.00), available phosphorus p<0.001 and available potassium p<0.001 compared to disturbed hillsides. However, there was no significant (p>0.05) difference on pH and electrical conductivity of the soils between the land uses. On the subject of soil physical properties, the bulk density of the disturbed hillsides was significantly higher (p=0.00) than the managed hillsides. Farmers perceived that soils of the disturbed hillsides have poor drainage system, outcropping debris and poor water holding capacity compared to hillside plantation. Thus findings showed that tree planting on previously degraded hillsides have brought positive impact on the soil quality in the study area. Therefore, allocation of degraded hillsides for tree planting should be scaled-up to other highland regions where extreme shortage of land and soil erosion persists.*

1. INTRODUCTION

Land is an essential natural resource for the survival of man in his environment. More than 97% of the total food for the world's population is derived from land resources. However, land degradation is a serious problem in the globe (Hurni, 1986). Similarly, it is a pressing challenge that decreases agricultural productivity in Ethiopia. Rugged topography, erosive rainfall and suseptible soils are causes of land degradation in the country. Moreover, population pressure, inappropriate land use practices and policies that fit to the socio-economic conditions of the farmers have been underlying causes of land degradation (Hurni et al., 2005). Consequently, about 45% of Ethiopian highlands were significantly eroded with continued extrme erosion rates. Furthermore, deforestation accelerated the exposure of soil to geomorphic processes such as sheet, rill and gully erosion (Nyssen et al., 2009). As the capacity of the soil to function is determined by its physico-chemical properties, degradation of soil properties caused substantial costs to agriculture and affected the livelihoods of 85 % people in the Ethiopian highlands (Munro et al., 2008).

The early settlement, expansion of agriculture to the steep terrain and the erratic nature of the rainfall caused erosion, which is a major problem in the highlands of Tigray than elsewhere in the country (Nyssen et al., 2009). The average rate of soil erosion was about 17 metric ton per hectare per year that led to a permanent degradation of land productivity (Feoli et al., 2002). Also burning of dung and crop residues to satisfy household energy has resulted in high removal of nutrients. Consequently, soil erosion increased the intensity of drought; low crop yield; frequent famine; water scarcity and social stress since the 1970s. These have induced additional pressure on natural environment to compensate for lost incomes and farmers' ability/willingness to invest in conserving their land (Mekoya et al., 2008).

Land rehabilitation efforts have been introduced to arrest soil erosion since 25 years in the highlands of Tigray (Hurni et al., 2005). Exclosure, woodlot and forest development have been practiced to improve vegetation cover, promote food security and secure water resources (e.g. Gebremichael et al., 2005). Furthermore, reclaiming eroded lands through collective action and productive safety net programs were carried out to reduce run-off, stimulate sedimentation and halt widening of the gully (Mekuria et al., 2009). Population interference was restricted to encourage natural regeneration in exclosures. There was no, however, institutional mechanisms to deal with sharing of grasses and dead trees inside exclosures (Betru et al., 2005). Low seedling survival rates and poor tree establishment were also observed in the community woodlots (Jagger et al., 2005). Moreover, increasing population pressure and limited supply of cultivable land increased landlessness, thus steeper and more marginal lands were brought into cultivation to feed the increasing population.

As a response to these problems, the local communities proposed that degraded hillsides allocation for tree planting to enhance land husbandry while improving the lives of landless farmers. After internal meeting and pilot projects, the innovation has been promoted to other districts with technical assistance (Hooton & Hagos, 2007). To this effect, each applicant was given 0.25 ha for tree planting. Additionally hillside plot was given in other hillside if s/he the managed properly that brought positive effect on the land sustainability and poverty reduction. In these allocated hillside plots, farmers established both multipurpose fodder and tree species that mainly provide timber and non-timber tree products.

Except for a case study report about the redistribution history and process by Hooton & Hagos (2007), little is known about the contribution of gullies and hillsides allocation on the improving soil quality. Comparing changes with soil properties between hillside plantation and free grazing hillsides contribute information for further improvement of degraded hillsides allocation. Therefore, the study was aimed at assessing the key soil quality indicators by asking the following questions: (1) Did tree planting by land poor farmers improve selected soil physic-chemical properties? (2) What was the reflection of farmers on ecological changes before-and-after tree growing?

2. METHOD AND MATERIALS

Characteristics of the study area

The study was carried out in Tigray, located at the northern limit of Ethiopia. According to Hurni (1986), 58 % of the Tigray area is lowland ("Kolla-less than 1500 m), 41% is medium highland ("Woina Degua"-1500 to 2300 m), and 1% is

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upper highland ("Degua"-2300 to 3000 m). The study area, Hawzen, is one of the rural districts located in the Eastern Zone of Tigray (Figure 1). Hawzen is located between 13° 58′ 39″N and 39° 25′ 45″E. The average altitude and total area of the study area is 2100 m.a.s.l and 8576.64 km2, respectively. The topographic feature of the study areas is flat (40%), escarpments (15%) and hillside (45%) with variable rainfall. Hawzen district has an average temperature of 21^{0}c and mean rainfall of 519 mm. The dominant staple crops are Eleusine coracana L., Triticum aestivum L., Zea mays L. and Hordeum vulgare L.

Figure 1:

Study area Farming is traditionally practiced on steep slopes. Degraded land in Hawzen shares 41,197.25 ha (49.04%) of the other land uses. Soil erosion, reduced fertility, gully development, deforestation, scarcity of cultivatable plots, and use of dung for fuel have been pressing environmental issues in the study areas. Since that last two decades there have been positive changes in vegetation cover due to the land rehabilitation interventions introduced in the region.

Sampling and laboratory analysis protocols

The hillside plantation (200 ha) was compared with adjacent disturbed hillsides found in similar landscape (Figure 2). The impact of household level tree planting on soil properties was assessed using soil organic matter, total nitrogen, available phosphorous, available potassium, pH, electrical conductivity, and texture and bulk density as key paramters. From the two land use cover types, soil samples were taken from top soil surface (from the 0–0.3 m depth of the soil) using a soil auger and core sampler. The latter one was used for bulk density analysis. Soil samples were randomly taken from plantation (n=9) and open grazing (n=9) following a transact line passing across hilltops, hillsides, plains and gullies. The slope of the soil sample plots ranges from 5 % to 49 % and the altitudes run from 1950 to 2376 m.a.s.l. Then, the soils were stored in bags and labeled. Soils were then air-dried and passed through a 2 mm sieve to remove stones, roots, and residues before conducting analyses.

The soil samples were then transported to Soil National Laboratory, Addis Ababa, for analyzing organic matter content (Walkey & Black, 1934), total nitrogen (Bremmer and Mulvaney, 1982), available phosphorus (Bray and Kurtz, 1945), available potassium (Morgan, 1941) and soil pH (Okalebo et al., 2002) following standard procedures as described in (Ministry of Natural Resources Development and Environmental Protection), 1990.

Soil Analysis Laboratory Manual Soil Laboratory, Ministry of Natural Resources Development and Environmental Protection, Addis Ababa, Ethiopia.). Soil texture was analyzed using Bouyoucos hydrometer whereas bulk density (as guide to soil compaction and porosity) was analyzed using core sampler method after the soil samples were oven-dried at 105° C (Brady & Weil, 2002). Moreover, 30 farmers were interviewed to assess their reflection on ecological changes observed on the ecological conditions of the hillside plantation before-and-after tree growing and compared to adjacent disturbed hillsides. Intensity of erosion processes; water availability and the physical condition of soils were triangulated using group discussions and transect walks with farmers along the hillside niches.

Statistical analysis

In addressing research question (1), comparative analysis between managed and disturbed hillsides was carried out on total nitrogen, soil organic matter, available phosphorous, available potassium and soil pH using matched pairs test. Moreover, soil texture and bulk density between these land use types were compared to investigate the effect of household tree planting on the soil physical properties. Descriptive statistics was utilized. For research question (2) information obtained from interview, focus group discussions and transects walks were narrated qualitatively. The 5% level was considered in the entire test of significance. The data were analyzed using Statistical Package for Social Sciences (SPSS 17.0) and MINITAB (version 15.1) softwares.

3. RESULTS AND DISCUSSION

Effect of land use change on soil chemical properties

Organic carbon, total nitrogen, available phosphorous, available potassium, soil pH and electrical conductivity are generally higher in managed area than disturbed. Organic carbon in managed area exceeds by more than two-fold than found under disturbed area, the difference being statistically significant. The current content under the managed plantation is good (Table 1). This indicates that the hillside plantation was in a better condition as biological measures were sublimated to the ethno-engineering works. Although organic matter makes up a minor part of the soil, it is powerful indicator for assessing soil productivity under varied land uses.

Table 1: The effect of household tree planting on soil properties (Mean ± S.E), N = 18

Soil characteristics	Managed	Disturbed	t-value	P-value
Organic carbon (%)	3.45 ± 0.32	1.61 ± 0.106	4.52	0.00
Total Nitrogen (%)	0.25 ± 0.01	0.1 ± 0.009	3.98	0.00
Available Phosphorus (ppm)	12.63 ± 1.75	6.08 ± 1.315	2.80	0.02
Available Potassium (ppm)	176.5 ± 18.22	90.455 ± 9	4.64	0.00
Soil pH	6.47 ± 0.09	6.29 ± 0.13	1.10	0.31
Electrical conductivity (ds/m)	0.01±0.00	0.03±0.01	1.09	0.13
Bulk density (g/cm^3)	1.30±0.01	1.39±0.02	3.92	0.02
Sand (%)	31.33 ± 1.31	53.33 ± 1.03	0.80	0.94
Silt (%)	26.33 ± 1.49	26.33 ± 2.00	0.94	0.37
Clay (%)	42.33 ± 1.36	21.16 ± 1.10	1.78	0.10

The plantation plots were characterized by dense trees/shrubs with numerous undergrowth herbs (Figure 2). Risks of soil erosion can be reduced by the effects of tree canopies, shrubs and grasses. Plantation also traps transported sediment. All these effects may contribute to the increasing organic carbon content. But organic matter supply varies with type of trees. Consequently, organic matter was positively correlated with tree species density. Mekuria et al. (2009) point out that plant species have a significant impact on nutrient cycling. Acacia etbaica was among the dominant tree species in the study area that produces higher amounts of woody litter with a slow decaying rate. This in turn can increase water infiltration rates into the soil by reducing volume, velocity, and erosive capacity of surface runoff. In line

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with this, Gachane and Kimaru (2003) from Kenya found that soils that are high in organic matter content have water aggregates and sequesters carbon on earth, and are less susceptible to erosion. Disturbed hillsides, however, were exposed to free grazing and population pressure. In this land use, low organic matter content of the soil can limit moisture holding capacity of the soil. According to Carter (2002) and Munro et al. (2008), low soil moisture reduces the ability of plants to utilize the nutrients that are available. This leads to increased nutrient losses through leaching. The aftermath is a viscous cycle of low organic matter, low soil moisture, and poor plant nutrition that contributing to worsening soil erosion.

The presence of dense trees, shrubs and undergrowth herbs in the hillside plantation resulted in higher total nitrogen content compared to disturbed hillside (Table 1). It reaches 0.25% in managed area (plantation) and 0.1% in disturbed area. There is significant difference between the two land use types ($P < 0.01$) due to difference in soil organic matter content, intensity of erosion, leaching and texture. Also changes in total nitrogen content were associated with the influence of tree roots and biomass return in terms of tree litter fall to ground. On the other hand, a decline of total nitrogen content in the disturbed hillsides was resulted from the absence of nitrogen-fixing trees in particular and vegetation covers at large. Analogous to this finding Gachene & Kimaru (2003) showed that low total nitrogen content in the disturbed hillsides occurred due to low nutrient cycle in the disturbed sites.

Figure 2: The status of hillside rehabilitation in Hawzen, Eastern Tigray

Available phosphorous is 12.63 ppm at managed hillside and 6.08 ppm at disturbed hillside, higher in the plantation than the disturbed hillsides (Table 1). The difference is statistically significant attributed to difference in soil organic matter, severity of erosion and leaching and clay content. Irrespective of land use type, the current available phosphorous content is deficient. The higher available P content in the managed hillside than in the disturbed forest suggest that trees contribute phosphorous through litter fall and other plant parts as shown in the higher soil organic matter content, indicating significance of organic source of phosphorus . Therefore the pattern of availability of phosphorous among the land use types suggests the positive effect of household plantation. High sediment deposition on plantation area also enhances the availability of several nutrients such as P. On the other hand, the lower phosphorous content in the disturbed site could be due low supply of organic matter and easily transported of P down slope during runoff (Diress et al., 1999).

The available potassium content varies between 90.5 to 176.5 ppm, higher on plantation hillside and lower on disturbed hillside. The result shows that available potassium in the managed hillside is nearly double that of disturbed and are statistically significant. Disturbed hillsides, on the other hand, had lower available potassium as it could be easily washed away with soil erosion. The buildup of potassium in soils is related to soil texture with the greatest accumulation in clay soils, loam and textured sands (increasing sequence) (Morgan, 1941). Selective removal of the macro-nutrient by erosion also reduces potassium content of soils.

There was no significant difference in soil pH between the two land uses (Table 1). The pH influences plant growth directly and also regulates the availability of nutrients to plants indirectly (Diress et al., 1999). The pH of the studied soils is nearly neutral. This indicates that soil pH is controlled by extent of soil erosion and vegetation cover. Researchers reported that higher soil pH from the managed hillsides was attributed to the ameliorating effect of the high accumulation of organic matter (Brady et al., 2002). Moreover, electrical conductivity was used as indication of total quantities of soluble salts in the soil. There was no significant difference in an electrical conductivity between the two land uses (Table 1).The soils of the study areas possessed a small amount of soluble salts due to the available minerals found in the soil. In summary, chemical soil properties improvement by household level tree planting is extremely encouraging in the fragile economic and ecological context of drylands.

Effect of land use change on soil physical properties

Land-use systems affect the soil properties. Soil physical properties in turn affect processes that make it suitable for agricultural practices. Soil texture has profound effect upon the water supplying power, rate of water intake, aeration, fertility, ease of tillage and susceptibility to erosion. Mechanical analysis reveals that the soils were composed of sand, clay and silt fractions of the top layer. However, though there was no significant difference between plantation and disturbed hillsides in soil texture (Table 1), clay texture was dominant on managed hillside while sandy soils on disturbed hillsides. More sand content in the disturbed hillsides implies that soils were tended to have low capacity to hold moisture and nutrients. This indicates that the soil cannot retain water against gravity and is usually filled with air in the soil.

There was significant difference between the plantation and disturbed hillsides in bulk density (Table 1). Higher average soil bulk density was observed in the disturbed hillsides compared to hillside plantation. The bulk density difference between the two land use types is attributable to, among other factors, difference in soil organic matter and soil texture. Okalebo et al. (2002) found that the soils with high organic matter accumulation results in lower bulk density whereas the soils with lower organic matter results in higher bulk density. Conversely, the removal of the vegetative cover from the soil increased in bulk density and decreased porosity and reduction in infiltration rate that ultimately reduces land productivity. The results can be used as indicators for moisture and air availability. In a nutshell, the influence of trees in soil physical properties is also important in augmenting the overall capacity of the land to produce.

Farmers' knowledge on the key ecological indicators between the land uses

In the field, farmers determined texture by rubbing the soils between the thumb and the fingers. Older farmers had better knowledge of detecting soil properties changes through their cumulative experience. Most of the farmers (95%) perceived that the soils of disturbed hillsides were characterized by pale color, poor drainage, compaction, stoniness and poor water holding capacity compared to hillside plantation. In addition, farmers well noted that there have been active developments of sheet, rill and gully development in the adjacent disturbed hillsides due to continued clearing of vegetation for household demand. Run-off, low water infiltration, drying up of rivers, declining of water flow and increasing invasive tree species were also observed in the disturbed

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hillsides.

All farmers agreed that tree planting on the hillsides and along the escarpment brought positive change in soil fertility reduce soil erosion, increase animal feed, and water springs development at the foots of the hillsides, in turn improved water availability for their domestic consumption. Observation during transect walks also asserted that farmers were actively trapping silts, planting local fodder grasses and diverting water into riverside terraces which has improved the water availability in the catchment.

Farmers developed local rule on guarding system; maintenance of rehabilitation measures, and production system for hillside plantation. Particularly, maintenance on physical structures were undertaken quite regularly every year to cut run-off and halt soil erosion. Physical structures were engineered into biological measures (grass and multipurpose trees). "Cut-and-carry" conventional system was used to harvest grass after seeds were collected for the next rainy season as described by the local rule. Timber was also harvested after enough substitution. In agreement with Mekoya et al. (2008) local level strategies based mechanisms are pathway to manage natural resources.

4. CONCLUSION AND POLICY IMPLICATION

Soil erosion is a major problem in northern highlands of Ethiopia. Consequently, the degraded hilly areas were poor to offer landscape services for landless farmers. However the finding of this study proved that small-scale tree planting enhanced soil physical and chemical properties in the previously most degraded landscapes. This is sufficiently large to indicate that household level tree planting has paramount effect on stabilizing the natural ecosystem at landscape level. There is a concern about the sustainability of tree planting on such landscape but tree planting by landless people is viable solution for environmental management and means of alternative livelihoods for the poor farmers. This grant to the long-term sustainability of the strategy as the intervention is demand driven and ecologically acceptable approach. To this effect, clear property rights, appropriate institutions, technical support, and clear guidelines are needed to attract the investments and thereby increase vegetation cover and built up of soil nutrients. There is a great opportunity that the efforts made could be scaled-up to other regions with adjustments as one-size-fits-all does not work under the diverse agro-ecological conditions in Ethiopia.

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REFERENCE

Betru, N., Nyborg, I. & Ali, J.(2005). Exploring ecological and socio-economic issues for the improvement of area enclosure management: a case study from Ethiopia. DCG report, vol. No. 38. Ås: The Group. VI, 55 s. pp. | Brady, N. and Weil.(2002). The nature and properties of Soils, 13th Edition. Prentice Hall. Upper Saddle River, New Jersey. 960 p. | Bray, R.H. and Kurtz, L.T.(1945). Determination of total, organic and available phosphorus in soil. Soil Sci. 59:39-45. | Bremmer, J.& Mulvaney, C.(1982). Nitrogen total. Methods of Soil Analysis, Part 2: Chemical and Microbiological Properties. ASA Monograph, vol. 9, pp. 595–624. | Carter, M. (2002). Soil quality for sustainable land management: organic matter and aggregation interactions that maintain soil functions. Agron. J. 94: 38-47. | Diress, T.A; K.O. Farah and D.M. Nyariki.(1999). Influence of Settlements on Land Use and Vegetation in the Rangelands of Northeastern Ethiopia: Application of Aerial Photographic Technique. J. Hum. Ecol., 10(5-6): 349-356. | Feoli E, Vuerich LG, Zerihun W.(2002). Evaluation of environmental degradation in northern Ethiopia using GIS to integrate vegetation, geomorphological, erosion and socio-economic factors. Agriculture Ecosystems & Environment 91: 313-325. | Gachene, C. and Kimaru, G.(2003). Soil fertility and land productivity: A guide for extension workers in eastern Africa. Nairobi, Kenya. | Gebremichael, D., Nyssen, J., Poesen, J., Deckers, J., Haile, M., Govers, G. & Moeyersons, J .(2005). Effectiveness of stone bunds in controlling soil erosion on cropland in the Tigray Highlands, northern Ethiopia. Soil Use and Management, 21 (3): 287-297. | Hooton, N., Hagos, F.(2007). Influences on natural resource management policy in Ethiopia: How a community initiative led to a new regional policy in Tigray. www.pppppc.org. | Hurni, H., Tato, K. & Zeleke, G.(2005). The implications of changes in population, land use, and land management for surface runoff in the upper Nile Basin area of Ethiopia. Mountain Research and Development, 25 (2): 147-154. | Hurni, H.(1986). Guidelines for development agents on soil conservation in Ethiopia. Community Forests and Soil Conservation Development Department, Addis Ababa. | Jagger P, Pender J, Gebremedhin B.(2005). Trading off environmental sustainability for empowerment and income: Woodlot devolution in northern Ethiopia. World Development 33: 1491-1510. | Mekoya, A., Oosting, S., Fernandez, S.,Van der Zijpp, A.(2008). Multipurpose fodder trees in the Ethiopian highlands: Farmers' preference and relationship of indigenous knowledge of feed value with laboratory indicators. Agricultural Systems, 96 (1-3): 184-194. | Mekuria, W., Veldkamp, E., Haile, M., Gebrehiwot, K., Muys, B. & Nyssen, J.(2009). Effectiveness of exclosures to control soil erosion and local community perception on soil erosion in Tigray, Ethiopia. African Journal of Agricultural Research, 4 (4): 365. | Morgan, M. F.(1941). Chemical diagnosis by the Universal Soil Tests System. Conn. Agr. Exp. Sta (New Haven) Bull. 450. | Munro RN, Deckers J, Haile M, Grove AT, Poesen J, Nyssen J.(2008). Soil landscapes, land cover change and erosion features of the Central Plateau region of Tigrai, Ethiopia: Photo-monitoring with an interval of 30 years. Catena 75: 55-64. | Nyssen, J., Haile, M., Naudts, J., Munro, N., Poesen, J., Moeyersons, J., Frankl, A., Deckers, J. & Pankhurst, R. (2009). Desertification? Northern Ethiopia re-photographed after 140 years. Science of the Total Environment, 407 (8): 2749-2755. | Okalebo, J.R, Gathua, K.W, Woomer, P.L.(2002). Laboratory Methods of Soil and Plant Analysis: A Working Manual. TSBF Program UNESCO – ROSTA Soil Science Society of East Africa technical Publication No. 1. Marvel EPZ Ltd.; Nairobi, Kenya. | Walkley, A. and Black, I.(1934). An examination of the degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method soil science 37:29-38. |