Reversing Degradation of Arable Lands in Southern Ethiopia[1]

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Abstract

Degraded soils are a major constraint to agricultural production and food security in the southern Ethiopian Highlands. As their yields and incomes decline, poor farmers have fewer resources to invest in fertilizers or soil conservation measures, while pressure from the growing population forces them to cultivate marginal lands, and discontinue fallow and the use of crop residues to maintain soil fertility. Soil fertility is declining most rapidly in the outer fields, as crop residues from these areas are used on the homestead gardens where enset and coffee crops are grown, which also receive the most manure and organic waste. Farmers need to adapt their soil fertility management strategies to the considerable spatial and temporal variations in soil degradation, focusing on restoring and maintaining the fertility of outfields and degraded land on steep slopes. The African Highlands Initiative (AHI) and Ethiopian Agricultural Research Organization responded to this situation by setting up a participatory research programme on natural resource management. The overall objective of the programme was to increase the capacity for independent innovation within farming communities, while working with farmers to develop appropriate technologies to combat soil degradation. Farmers spent three years testing various methods of restoring soil fertility, introducing legume cover crops into rotation systems, installing measures to control soil erosion, and practicing minimum tillage and more efficient ways of managing crop residues. The results of the research showed that adoption of these technologies depended on factors such as farm size, the availability of labor and soil condition. Research conducted during the programme identified five socio-economic strata within local communities, each with clearly different opportunities and needs. Any attempt to address agricultural problems should take account of this diversity, as blanket recommendations or technology packages are unlikely to provide effective solutions to the range of problems faced by farmers. Their interests will best be served by using a participatory approach to develop technologies that address the needs and specificities of each group, and by ensuring that farmers are fully involved in all stages of the process, from research and implementation to monitoring and evaluation. The AHI team found the participatory approach to research a very positive experience, which helped them identify problems and develop technologies that were specifically tailored to local conditions. The main achievements of the programme were to increase the capacity of farmers to solve their problems through experimentation and encourage various organisations to work together and learn from each other. The next step is to move from discipline-based research towards research and development in integrated natural resource management at watershed level.

Keywords: Participatory research, Land degradation, Resource endowment, Options

Introduction

The Ethiopian highlands, with an altitude of above 1600 Mts. above sea level, occupy only 44% of the area but host about 90% of the total population. The highland includes 95% of the cropped area and 75% of the countries livestock (SCRP, 1996). Ethiopian Highlands have been facing repeated environmental crises associated with mainly drought, deforestation and soil degradation, which in turn caused food shortage and degradation of natural resources.

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The most dominant and widespread problem of natural resources in the region is soil degradation. The degradation and loss of soil resulting from soil erosion in Ethiopia was estimated to be about 20 tons per hectare (Fournier, 1962), which means about 1 mm of soil depth/year across the country. The annual net nutrient depletion is estimated to exceed 30 kg nitrogen, 20 kg potassium and equivalent amount of phosphorus from arable lands of Ethiopia, Kenya, Rwanda and Zimbabwe (Smaling, 1993). On low input soils, losses at this order of magnitude may cause a significant yield decrease within a short period of time. The causes responsible for the nutrient loss from arable lands are multifold, soil erosion being the most important factor. The erosion hazard is aggravated by nutrient mining by crops, extended farming to sloping areas, shortened fallow system, decreased vegetative cover, depletion of soil organic matter and mismanagement of crop lands. The general consensus is that the exhaustive nature of the farming system in Ethiopia accompanied by environmental crisis (erosion, drought and deforestation) caused a sharp decline in soil fertility of arable lands throughout Ethiopia.

Since the 1970s, various attempts have been made by governmental and non-governmental institutions to restore soil fertility of degraded arable lands. During the periods of 1971- 1982, WADU (Wollayta Agricultural Development Unit) launched an extension & credit services for farmers of Wollayta to demonstrate and popularise the use of improved packages (inorganic fertiliser, improved seed and pesticides), and has created the awareness successfully. As an effect, crop yield doubled in that period. However, the use of inorganic fertilisers and pesticides declined sharply because of the end of subsidies and a significant increase in the price of fertilisers. Following the era of WADU, a Swiss-supported soil conservation research program (SCRP) was launched and operated between 1982 and 1993 in Gununo, Wollayta, with the aim of developing and disseminating soil/water conservation technologies. Although the SCRP site is a neighbouring watershed to our research site (only seven kilometres away) there is almost no sign that the technology was adopted and/or disseminated outside the experimental site. Despite the presence of severe soil erosion, especially in the months of July & August, farmers rarely use soil conservation measures.

The African Highland Initiative (AHI) (Box 1) and Areka research centre in partnership with farmers and scientists from Awassa research centre, Awassa College of Agriculture, CIAT and International Livestock Research Institute (ILRI) launched an integrated soil fertility improvement/management project in 1997 to: a) study the factors affected adoption/dissemination of available technologies; b) test baskets of soil fertility amendment options with farmers of different strata and learn their criteria of choice; and c) develop methodologies and processes which could be utilised for soil fertility management beyond the research site.

Box 1. The African Highlands Initiative (AHI) in NRM Research

The African highlands initiative was conceived as a collaborative program of the national agricultural research institutions (NARIs) of the ASARECA countries and the International Agricultural Research Centres (IARC) to facilitate the marriage between better livelihoods for farmers and sustainable use of the resource base in the East African Highlands. AHI is operational in five countries (namely Ethiopia, Kenya, Uganda, Tanzania and Madagascar) in eight benchmark sites, since 1995. It is conducting participatory research in soil resource-based natural resource management to increase farmers capacity to innovate in their own, to develop system compatible technologies, to improve partnerships among all stake holders and to promote scaling-up of technologies, methodologies and processes. Gununo (Areka) is one of the eight benchmark sites of the African highlands ecoregional program, where farmers' participatory research in integrated natural resource management has been conducted.

LOCATION, CLIMATE AND SOIL

The research has been conducted at the Gununo site, Bolosso Sore district (Areka) Wollaita Zone, the Southern Nations, Nationalities and Peoples Region (SNNPR) of Ethiopia. It is situated on 37^o 39' E and 6^o 51' N about 430 km South West of Addis Ababa, at an altitude range between 1880 and 1960 m.a.s.l The topography of the area is characterised by an undulating slope divided by v-shaped valleys of seasonal and intermittent streams, with steep slopes. The mean annual rainfall and temperature is about 1300 mm, and 19.5 ^oC, respectively. The rainfall is bimodal with two growing periods, the small rainy season (belg), which extends from March to June and main rainy season (meher) from July to the end of October. The months of July and August receives the highest amount of rain fall in Gununo and cause a soil loss of 27 to 48 t/ha (SCRP, 1996). The dominant soils in the study area are Eutric Nitosols, acidic in nature, and are characterised by higher concentration of nutrients and organic matter within the top few centimetres of the soil horizon. These soils are originated from kaolinitic minerals which are inherently low in nitrogen and phosphorus (Waigle, 1986).

THE FARMING SYSTEM

Agriculture is the major income source in the area. The farming system is small-scale mixed crop and livestock production, with relatively fewer livestock than elsewhere in Ethiopia. Farmers used to keep 7-8 heads of cattle some 15 years back, but it has declined to 1-2 heads per household due to feed shortage, conversion of grazing land to farm land, forced sale of livestock to pay taxes and debts and disease losses (Farm Africa, 1992). Currently less than 15% of the household own oxen.

Gununo is characterised by very high population density (about 450 persons km^{-2}) which resulted in a very small land holding averaging about 0.24 ha per household. Young male farmers used to inherit land from their parents when they get married. The land holding size per household became so small to the level that some parents are not in a position to inherit land to their children. That is the major reason why the majority of the young from the region migrate to other parts of the country as labourers. Share cropping and renting of land is also common as a significant proportion of the community, especially young farmers, do not have land. Unlike the northern part of Ethiopia, where land redistribution is still in place, there is no more land redistribution in Wollayta zone, as the land use is perennial-based and the land size is already very small to be redistributed. Because of high population pressure sloppy lands which used to be grazing areas or tree plots became under cultivation. In comparison to other AHI benchmark sites, Areka has the poorest infrastructure and the poorest market access for farm products. About 90% of the household experience food shortage at least for two months of the year or more even in relatively good years.

Methods

In 1997, AHI-Areka researchers, composed of agronomists, soil scientists, economists, foresters and extension agents from five different governmental and non-governmental institutions, conducted a participatory rural appraisal to identify the most pressing problems of the system in Gununo. Various PRA tools have been employed. The discussion topics were not specific to soil productivity but treated NRM at a broader scale. Thereafter, farmers in Gununo stated six major problems and set priorities using pair-wise ranking method (PRA report, 1997). The problems of the system according to priorities are as follows:

1. Unpredictability of weather
2. Oxen shortage
3. Soil erosion
4. Progressive fertiliser price increases
5. Soil fertility degradation
6. Shortage/unavailability of improved seeds.

Based on a stratified wealth ranking and social analysis, twenty four farmers were selected as partner farmers of AHI (those who will conduct participatory NRM research with AHI researchers).

About 75% of the households in Gununo lie under the wealth category of III and IV (Table 1). Given the relatively high slope of the catchment area, intensive cropping and high rainfall intensity, Areka site (Gununo) is one where decline in soil fertility is apparent. That was also the reason why three out of five of the major problems listed by farmers are related to decline in soil fertility. The team employed several participatory research techniques (Stroud, 1993, Pretty et al., 1995) to test various soil fertility amendment technologies with farmers.

A Farmers Field School was also established after discussing with farmers to demonstrate the role of legume cover crops in improving soil fertility and also to evaluate the agronomic performance of legume cover crops (LCC) under Areka conditions. Seven LCC species were used, three of which (Trifolium, Stylosanthus and Vetch) are used for fallow improvement besides animal feed in some pockets of Ethiopian Highlands. Four of the LCC (Canavalia, Mucuna, Croletaria and Tefrosia) are included mainly because they found to be effective

Table 1. Description of indicators and categorisation of farmers in different wealth groups, Gegecho zone, 1997 (average of four farmers)

Strata (rich to poor)	**Indicators of Wealth Stratum**
I	They never face food shortage. Have enough money to buy clothes and other necessary commodity. Own more than 2 oxen, 3 milking cows, 4 timed (about 1 ha) of land, 3 sheep, 1 donkey and a number of chickens. They have also many matured (unprocessed) enset plants in their homesteads. They have many coffee plants.
II	They have enough food to eat (not for long time). Have a minimum of one ox, one milking cow, half hectare of farmland, 1-2 sheep, a donkey and chickens. Some of these people are traders. Have few matured enset plants. Have coffee plants (but not as many as the first strata).
III	Have half hectare of land. They share/possess in common (usually two people) an ox, a cow and a donkey. They can have 1-2 sheep. Have immature (few) enset plants and coffee. Keep few chickens. In general they are engaged in buying and selling of maize. They travel to near by towns to buy maize and sell it in their locality.
IV	They have very small plots (usually less than 0.3 hectares) of land, few coffee and enset plants (their enset plants are very young i.e. 1-2 years old). They owe some sweet potato and a few chickens. The major income source of this strata is trade. They obtain money by retail trade of maize flour, ginger, vegetables, salt, tobacco, etc. They buy and sell only within their locality.
V	These are the poorest of the poor. They lost their land because they could not return back the money they borrowed. They grow no crop. They are daily labourers. The women scrap enset, fetch water, cut and carry grass for others. Men collect fuel wood and sell in the nearby small towns, cut and split big trees and sell their labour to get his daily food. These are weak (sick or old) and handless people.

in improving soil fertility in other AHI benchmark sites (e.g Western Kenya and Kabale District, Uganda). Some of the data on soil conservation measures was extract from secondary data collected by the Soil Conservation Research Unit (SCRP) on the same site. We have also monitored the available organic resources of farmers of different strata using resource flow diagrams and recording weekly the production and usage of organic resources of selected households.

SOIL FERTILITY MANAGEMENT PRACTICES

Land Use and Soil Fertility Management

Unlike the land holdings in the northern parts of Ethiopia which is characterised by land fragmentation, land holding is consolidated in Gununo. Multiple cropping, in the form of intercropping, relay cropping and crop diversity, are commonly practised by farmers thanks to the long growing season with bi-modal pattern of rainfall distribution. The farmers of Wollayta divided their land into several plots for various purposes, namely grazing area, coffee/enset field, maize field, sweet potato field etc. Farmers identify/classify soil types primarily based on crop yield, organic matter status, colour, distance to homesteads, workability, soil texture land use systems/crops grown and locations. These plots have also different soil fertility status, that is soil fertility declines with distance from houses (Eyasu, 1998). The major land use systems in the community include homestead farms, where the most important crops such as enset, coffee, vegetables, planting materials for sweet potato and raise tree seedlings. Homestead soils (Kareta) are characterised by high organic matter content due to the application of manure, compost and house wastes including ashes. Kareta soils are dark brown to black in colour mainly due to high organic matter content. Soils of the neighbouring field except the Kareta types are red in colour. Even the Kareta soils changed their colour due to organic matter application (PRA report, 1997). Red soils are less fertile and since the organic fertiliser sources are limited they require application of inorganic fertilisers. The homestead field is followed by the main field, which is used for planting maize, barley, wheat, tef and haricot beans and potato. Trees are planted on valley bottoms, sloppy area, farm boundaries, in front of house and gully areas. Grazing land (tittering) are found in front of house (Deje). Some plots are left for cut and carry for livestock feeding. The outfield is the most depleted. Detail description of the land use and the fertility gradient of the farm in the area was presented by Eyasu (1998).

Enset (also called False banana) is a carbohydrate rich perennial crop, with strong spurious stem and edible bulbs and corm. It is considered as a security crop in the region. Enset has three major outputs: a) the corm is mainly boiled and consumed at home as Kotcho; b) the pseudostem is shrouded and squeezed to differentiate bulla (starchy part) and Kotcho; and c) the leaf and the midrib are chopped and fed to animals or used as construction material, fuel and for mulching or spread in the fields of enset, taro and maize as organic fertilisers. Enset is harvested in a piecemeal approach all the year round, and most households rely on it mainly in food deficit months.

A CASE STUDY ON RESOURCE POOR FARMERS

Two farmers, Mr. Demeke and Mr. Kassu, were randomly selected for the case study that they own degraded land which may not be enough to feed their family (of wealth groups III & IV). They have almost similar socio-economic strata, similar degree and trend of land degradation but different attitude towards adopting soil fertility management practices.

Mr. Demeke, 25 is a father of two and is responsible to feed 7 members of the family. Most of the income of the household comes from off-farm labour and retail trade. His land holding is less than 0.25 ha, and yet is highly degraded to the level that almost no crop is growing on the land regardless of the amount and distribution of the rainfall. His land has a slope of about 20^0, extremely degraded by severe sheet and rill erosion, and until the arrival of AHI neither biological nor physical control measures were applied to minimise soil degradation. The A horizon of the soil is only 20 cm deep unlike the adjacent neighbouring farms of the same slope having up to 80 cm of A horizon (Sheleme, 2000, unpublished). Demeke doesn’t own any animal except one donkey. Therefore, he did not have access to farm yard manure to be applied to his land. He used to use the donkey for transporting retail goods from one market to the other till 1998. Year 1997/98 was a drought year in Areka and hence he used all his initial investments for buying food. His family was at risk and he was on the verge of migration to sell his labour to one of the nearest gold mines in Shakiso, about 250 km away from his home village. That was the time when AHI has started to operate in Areka and contacted interested farmers to initiate an integrated NRM-related participatory research. AHI researchers contacted him, just like any other farmer, whether he would like to conduct farmers’ participatory research on the crucial problems of his land, i. e. increasing soil productivity. His first reaction was not very optimistic. He said ‘ I don’t think it is possible to convert my exhausted land to a productive one. I have to look for other living options. If you, however, insist that it may get improved I will advice my young brother to collaborate with you’.

AHI-Areka researchers have used participatory varietal trial as entry points to establish partnership with farmers. Researchers brought baskets of options of high yielding varieties from research institutions released for similar agroecologies to be tested by farmers. During the course of the experimentation researchers have been monitoring the selection criteria of farmers of different socio-economic strata and gender, and also monitor how those selected varieties are maintained and disseminated. Mr. Demeke was asked whether he would like to conduct participatory variety trial on his farm and he voted for Sweet potato variety trial. Because of poor soil water holding capacity of his farm to support a long maturing crop, four early maturing sweet potato varieties were proposed and tested in comparison to a locally accepted cultivar ‘Gadissa’. About 100 kg of Urea and 80 kg of DAP was applied. Despite fair rainfall distribution he did not harvest any tuber after four months of waiting. After a year, he planted early maturing maize varieties on the same plot and the crop died even before initiating flowering. That was the time when Demeke became interested to try any intervention that may improve the productivity of his farm.

Mr. Kassu Dand is 33 years old, responsible to feed 6 persons in the household. He owns about 0.30 ha of land but did not manage it himself. Rather he made part of his land available to those who had farm inputs and labour available. At the end they share the produces equally once the price for inorganic fertilisers is reduced. This mode of agreement shows how farmers in Gununo area appreciate the importance of inorganic fertilisers to maintain/increase crop yield and also its associated expenses. His major reason for giving the land for sharing was shortage of inputs and oxen. Therefore, the management of the land was more of exploitation than conservation type.

Both farms are highly degraded. The only difference between the two farms is that the farm of Kassu can still produce some crop while the farm of Demeke was about to be abandoned. The yield difference between the farm of Kassu in comparison to better managed, neighbouring farms is very low and did not panic Kassu to take immediate measures. Factors other than soil fertility may have a greater impact on the yield production of subsistence farms. Besides soil fertility, pests and diseases, availability of high yielding varieties and late planting due to oxen shortage are potential reasons for low productivity in Areka. If other soil fertility amendments are not taken and the trend is reversed, the farm of Kassu will be as much depleted as that of Demeke very soon. Yet, it is questionable whether these level of degradation is crucial enough to influence the behaviour of the farmer. Experiences from Colombian Andes showed that even if all farmers observed soil erosion in their farm and over 95% believe that soil erosion leads to lower yield, only 13% considered decline in soil fertility among major production constraints (Mueller-Samann et al., 1999). Similarly, despite heavy soil losses in Gununo (Tables 5 & 6), decline in soil fertility was mentioned as problem number three in the priority list.

Approaches in Soil Fertility Restoration

INTEGRATION OF SOIL BUILDING SYSTEMS

Legume Cover Crops

In 1999, Demeke conducted farmers participatory research with early maturing maize varieties using up to 100 kg DAP and 100 kg of UREA. Despite high level of fertilisation no yield was obtained from that plot of land. The major constraint of the land was organic matter depletion, as also confirmed by soil analysis. Lack of response to inorganic fertilisers because of low soil organic matter content was also reported elsewhere (Swift and Woomer, 1993). In fact, scientists working in the region argue that decline in soil organic matter is central constraint affecting the sustainability of soil fertility on small holder farms in the tropics (e.g. Swift and Woomer, 1993). Increased organic matter content will increase efficiency of inorganic fertilisers through increased water availability, reduced nutrient loss from leaching and denitrification and increased microbial activity.

To address the deficiency of soil organic matter, AHI researchers have established Farmers Field Schools for legume cover crops (LCC) so as to evaluate the performance of different exotic LCC under Areka conditions and at the same time introduce farmers with the baskets of soil improving legume cover crops. The legume cover crops were grown at three farmers field with different soil fertility status so that AHI farmers may select LCC species that they think may fit in to their farm and improve their land resources. Demeke was willing to try all potential LCC on his farm while Kassu wanted to see the after effect of these legumes first on the farm of others. Demekes’ farm is known by the community as the most degraded, and hence the fate of the LCCs to be accepted or rejected by the community relied on whether the LCC may improve the productivity of Demekes’ farm or not. Seven legume cover crops namely Trifolium, Stylosanthus, Croletaria, Mucuna, Tephrosia, Vetch and Canavalia were tested for their performance on this highly degraded acidic soil of Mr. Demeke. A very high amount of Aluminum is expected in this soil, as Aluminum toxicity symptoms have been observed on the maize crop. The highest biomass yield (about 5t of dry matter/ha in four months) was obtained from Croletaria followed by Canavalia and Mucuna. Although farmers who own livestock considered Stylos and Vetch for integration, those two resource-poor farmers went for Croletaria and Canavalia.

Unlike Demekes' farm Mr. Belays farm is rich in basic nutrients and organic matter (data not shown). Moreover, the species were left to grow for longer periods of time, and hence produced much higher biomass yield than that of Demekes' farm. In the degraded land Croletaria was the highest yielder followed by Mucuna. In the fertile land of Belay Tefrosia out-yielded Croletaria significantly (Table 2). Farmers evaluated the performance of both experiments in the field and voted for Croletaria as it performed well under both fertile and degraded soils. However, the selection criteria of farmers went far beyond biomass production (Table 3).

Table 2. The performance of legume cover crops grown as short-term fallows in relatively fertile plots of Mr. Belay's farm, and their effect on soil water content of the soil at harvest (plants at 6 months of age)

Species	**Fresh yield** (t/ha)	**Dry matter** (t/ha)	**Soil moisture** (%)
Croletaria	23.25	9.17	14.05
Vetch	3.70	1.00	20.78
Mucuna	19.25	5.17	22.72
Canavalia	13.5	3.80	13.98
Tefrosia	32.25	13.51	11.91
Stylos	8.0	2.84	20.22
Undisturbed soil	-	-	17.12

Table 3. Farmers' criteria for selection of legume cover crops (6 being the most pronounced for each criterion)

Species	Firm roots	Early soil cover	Bio-mass	Rate of decom-postion	Moisture conser-vation	Drought resist-ance	Feed value	Sum Total
Croletaria	2	6	6	6	2	2	2	26
Vetch	1	5	5	4	1	1	6	23
Mucuna	6	4	3	3	6	6	4	32
Canavalia	5	3	4	1	4	5	2	24
Tefrosia	3	2	2	2	5	3	2	19
Stylos	4	1	1	5	3	4	5	23

After intensive discussion among themselves, farmers agreed on seven criteria to be considered for selection of LCCs (Table 3). However, the criteria of choice had different weights for farmers of different wealth strata. For poor farmers (who commonly did not own animal or own few) legumes with fast biomass production for green manuring (Croletaria and Mucuna) were the best. For farmers who own sloppy lands with erosion problems Mucuna and canavalia were considered to be the best. During the vegetative period, the soil water content of Mucuna, Stylos and Vetch was much higher than in the other species (Table 2). While for farmers of higher wealth strata (I and II) legumes with feed value and fast growth (Vetch and Stylos) were considered as the best. None of the farmers mentioned labour shortage as a potential constraint. The over all sum of criteria, however, showed that Mucuna followed by Croletaria are the best candidates for the current farming system of Areka. All tested LCC were chopped and incorporated into the plot where they have grown. Mr. Demeke planted Sweet potato in short cropping season of 2000/2001, and witnessed a much vigorous plant stand as an after effect of legumes. The best performance was observed from those planted after Croletaria, Stylos and Mucuna, possibly because of faster decomposition rate of these legumes. He is waiting for better harvest after eight disappointing years. Mr. Belay (Wealth strata II) has planned to grow maize this season following the LCC and evaluate the after-effect of LLCs on soil fertility and crop yield . Given the serious land shortage in Areka, farmers may not allocate full season for LCC. As the Enset and darkua fields are relatively fertile and used for intercropping/relay cropping purposes, growing LCC on that part of the land may not be the choice of farmers. Therefore, the potential niche for integration of LCCs would be the most-out field (Shoka) where small cereals in rotation with maize are grown. AHI-Areka team is conducting participatory research on the possibility of integrating these legume as relay crops and/or short-term fallow in the exhausted outfield of the land.

Crop Residue Management

Mulching, covering soil surface with crop residues, is another potential measure to reduce soil/nutrient loss. Through mulching, the hydraulic force of the raindrop on the soil particle will be reduced, thereby soil detachment is minimised. However, mulch is not applicable in many farming systems because of unavailability of organic residue. In Gunnuno, the availability of organic residue is much better than else where in Ethiopia because of two reasons: 1) there are relatively fewer animals in the system to consume crop residues; and 2) unlike many other parts of Ethiopia, fuel wood is not a problem in Gunnuno.

In the subsistence farming systems of Gununo, where inorganic fertilisers are unaffordable, crop residues play a major role in soil fertility restoration. However, poor management and unwise use of crop residues may have reduced the quality and availability of residues to be used for soil fertility restoration. As mentioned earlier, there is a clear nutrient gradient from the homestead to the outfield of the farming system. Soil fertility decreases with distance from the homestead, which is attributed mainly to crop residue management. One constraint typical of Areka is that farmers are exporting crop residue from the outfield of Maize to the Enset/Coffee field of the home garden every year. The nutrient export from the maize field to the Enset field is practised mainly because Enset is considered as a security crop for the household. Earlier investigations in neighbouring district showed that the Enset field is the most fertile corner of the farm, especially in terms of organic matter and nitrogen (Elias, 1998), and hence there may not be a need to further mining of the outfield. AHI researchers are working with farmers to stop further removal of crop residues from the out field by a) comparing the yield of maize grown in the homestead and in the out field with farmers, using the same variety and same planting dates. b) discussing with farmers the management and distribution of crop residues for the last many years c) inviting them to compare the soils of the two corners using their own soil fertility classification criteria (soil colour, soil depth, types of weeds grown, and crop yield). Moreover, there is a strong competition for crop residues between livestock feed, soil fertility and fuel wood (Table 4). Crop residue from small cereals (wheat, barley and teff) and legumes (haricot beans, pea and faba bean) are either transported from the crop field to the home compound and stored for animal feed during dry spells or sold for those farmers who have shortages in livestock feed.

Table 4. Differential use of crop residues by Gununo farmers of different wealth strata

Wealth Group	**Source of Crop Residue**	**Residue Amount** (kg)	**Use of Crop Residue**
I	Wheat	31.5	60% mulch, 40% feed
	Teff	27.0	60% feed, 40% sale
	Maize stalk	325.0	80% fuel, 20% others
	Sweet potato	240.0	95% planting material
	Enset	Nd	50% dry feed, 30% mulch
I	Wheat	18.0	Same
	Maize stalk	487.5	
	Sweat potato	450.0	
	Enset	nd	
	pea	45.0	
	Barley	9.0	
IV	Wheat	9.0	80% mulch, 20%feed
	Maize stalk	39.0	70% fuel, 30% others
	Sweet potato	120.0	90% planting material
	Haricot bean	9.0	80% animal feed, sale
IV	Wheat	4.5	100% mulch
	Maize stalk	39.0	80% fuel
	Sweet potato	60.0	90% planting material
	Haricot bean	4.5	70% mulch, 30% fuel

As shown in Table 4, the major source of crop residue is maize stalk, followed by sweet potato vines. However, both crops are used for a different purpose than soil fertility restoration. Maize stalk is used mainly as fuel wood while only the leaf and leaf sheath is grazed by animals right in the field. On the other hand, vines of sweet potato fetch a high amount of money as planting materials, and only leaf drops are left in the field. The difference between wealth groups in the utilisation of crop residues originate from the number of animals they have. Wealthier farmers feed the highest proportion of crop residues of wheat, barley, beans, pea, and partly teff to their animals but apply the manure into their enset/coffee fields while poor farmers apply these crop residues to the enset field as a mulch directly.

Legumes as Soil Fertility Promoters

Crop sequence affects the entire soil-plant ecosystem through altering the quantity and quality of organic residues returned to the soil, soil water reserve, soil erodibility and availability of nutrients. Some crops have a negative effect on the proceeding crop via exhaustion of nutrient and water reserve of the land (e.g. sorghum) while others show a positive effect on the soil and the proceeding crop (e.g. faba beans). Farmers in Areka acknowledge that a cereal-legume rotation scheme is commonly profitable, as the legume may add fixed nitrogen and some amount of organic matter to the soil. There is a consensus among farmers that a maize crop following pea or faba bean require less amount of nitrogen than a maize monocrop. Traditionally, the major cereals like teff (*Eragrostis abyssinica*), wheat or barley is grown in rotation with pulse crops. Faba beans and haricot bean are grown following wheat or teff, or intercropped with maize. It is not uncommon to find up to 6 different crops grown in mixtures. Areka farmers rotate cereals with pulse crops for three objectives. Firstly, legumes can restore soil fertility through N-fixation and residual organic effects. Secondly, the effect of host-specific pests and diseases of legumes (e.g. stem maggot of beans) will be controlled. Thirdly, legumes are the most important components of their dish. Jung et al. 1989 compared the after-effect of faba bean, red clover and alfalfa on the yield and nitrogen budget of the succeeding wheat in central Ethiopia. They found out that winter wheat grown after legumes took up 18, 47 and 65 Kg N/ha after faba beans, red clover and alfalfa, respectively. The amount of nitrogen recovered by wheat was only 24-44% of the potentially available nitrogen. The rest N was lost by leaching, which could have been recovered if a crop was grown in association with or immediately after the legumes are harvested. Getnet et al, 1991 compared the effect of different non-legume and legume preceding crops on the yield of subsequent barley crop on red soils of Holleta, another benchmark site of AHI, for more than three seasons. Their results showed that barley following forage legumes in crop sequence produced significantly higher grain yield than when grown after fallow or barley, regardless of the amount of nitrogen and phosphorus applied. Barley after clovers and vetch gave the highest grain yield possibly because, in addition to N-fixation, higher amount of crop residue could have been delivered and incorporated into the soil.

EVALUATION OF SOIL PROTECTING SYSTEMS

The major objective of this measure is to reduce soil loss through erosion. Soil erosion by water occurs simultaneously in two steps: the detachment, which is caused mainly by falling raindrops; and the transport of detached particles. The transport of detached soil particles is mainly the function of run-off, and any measure to reduce the amount and velocity of the runoff will reduce the possible effect of soil erosion. The AHI-Areka team is using the following interventions to combat run-off effects:

Soil Bunds along Contour Lines

Experiences from the indigenous terracing practices of Konso, Ethiopia and the Philippines shows that mechanical soil conservation practices play a vital role in developing sustainable agriculture in the highlands through preventing soil and water loss, especially if augmented by biological measures. The soil conservation research program (SCRP) have tested the effect of different conservation measures on run-off and soil loss in Gununo at 14% slope (Table 5).

Table 5. The effect of different soil conservation measures on run-off (% control) and soil loss (% control) under crop covers across years in Gununo (data extracted from SCRP, 1996)

Year	Crop	**Runoff** (% control plot)				Precepitation (mm)
		Control plot	Grass strip	Graded Bund	Leveled bund	
1987	barley	100	59.8	63.4	39.0	1244.3
1988	sorghum	100	51.8	59.1	6.41	1446.0
1989	barley	100	40.5	38.4	13.6	1257.9
1990	maize/ sorghum	100	17.8	29.5	6.8	992.3
1991	barley	100	46.28	46.7	18.0	1455.8
Mean			49.24	45.32	16.76	1279.3
SD			15.9	13.3	13.34	169.1
		Soil Loss (% control plot)				
1987	barley	100	25.0	0.0	0.0	1244.3
1988	sorghum	100	12.07	8.6	0.0	1446.0
1989	barley	100	11.2	9.6	1.5	1258.9
1990	maize / sorghum	100	0.0	2.3	0.0	992.3
1991	barley	100	28.2	18.6	6.3	1445.8
Mean			15.29	7.82	1.56	1279.3
SD			11.42	7.27	2.73	169.1

As presented in Table 5, the degree of run off and the amount of soil lost due to erosion depends mainly on the amount of precepitation, the type of crop grown and the type of soil conservation measure applied to control erosion. Both physical and biological measures reduced runoff and soil loss significantly regard less of the species of conservation measures. Runoff was the smallest in crop lands treated with levelled bunds followed by plots treated with grass strips. Soil loss was the smallest in plots covered by narrow spaced cereals (barley) than wide spaced cereals (maize and sorghum). However, the amount of annual precipitation and its distribution dominated all the other factors.

Although farmers in Gununo had the opportunity to witness the considerable potential of physical measures in reducing erosion, they did not adopt the technology for mainly two reasons: a) farmers of wealth groups III and IV have very small land holdings (<0.25 ha/ household) and were not willing to allocate a strip of their plots to construct soil and water measures; and b) farmers of wealth group I failed to accept the technology mainly because the design of the physical measure did not allow oxen plough.

In July 1998, AHI-Areka scientists discussed with farmers on how to overcome the causes of non-adoption of soil conservation measures in the catchment and asked for suggestion to modify the technology. The researchers trained farmers on how to construct physical and biological soil conservation measures, adding up on the indigenous knowledge. Then after, researchers of AHI-Areka together with farmers have initiated outward bench soil bunds on arable lands. Accordingly, farmers who own degraded lands, took the initiative to construct soil conservation bunds and planted elephant grass and/or multi-purpose trees to stabilise the bund. The objective of constructing the bund, for example on Demekes´ farm, was not only to decrease the velocity of the runoff but also to reduce the existing steep slope of 20% to milder slopes.

In 1998, Demeke planted wheat on the lower side of the slope. He used about 3 kgs of wheat as a planting material, and harvested only 4 kg of wheat despite an application of about 25 kg DAP/ha. One year after the soil bund was constructed, he planted again wheat in 1999 on the same plot of land, with the same amount of fertiliser applied and harvested 45 kg of wheat. The farmer reasoned out that this tremendous yield gain could be attributed to the soil conservation measures as it protected both planting materials (seeds) and fertiliser from being washed away.

The spacing of the contour bund, which refers to vertical distance between the channels of successive bunds, was determined by the farmers them selves. The major criteria of farmers to determine the vertical interval was land size, slope and its' convenience to oxen plough. The farmers criteria shows that vertical interval increases with increasing land size. Vertical interval is also wider when oxen plough is used than hoe plough. About 10 to 15 m vertical interval was selected by Mr. Demeke, whose land has about 20% slope, while 20m interval was used by Mr Birhanu (wealth group I) whose land has about 5% slope. The outlets for the run-off during heavy storms are natural draws and permanent pastures. However, we have witnessed potential conflicts in water way as the farmer at the lower side of the sub-catchement was affected by the water management of the farmer on the upper side of the catchement. Therefore, AHI-partner farmers have called for collective action to agree on common water ways and exploit the potential of water harvesting to be used in dry spells.

Different biological soil bund stabilisers were tested by farmers according to their own choice, namely Enset/bananna, Gravillie alone, Gravillie in combination with Elephant grass and Elephant grass alone. The growth of Enset and banana during the first two seasons was very slow to protect the bund from being washed away by run off. Moreover, farmers fear the risk of root expansion of these crops to the farm land. Gravillie was not performing well partly due to the extended drought and partly the low fertility status of the soil. Among the tested species, Elephant grass was the most successful biological stabiliser of the bund. Elephant grass became also attractive for its side benefits. For example Mr. Demeke has taken care of the Elephant grass planted on the soil bunds so well and managed to get an additional income of up to 40 birr/month by feeding Bulls for the community to be slaughtered a holy day 'Meskel' (finding of the true cross).

Minimum Tillage

Tillage in Ethiopia is practised by oxen plough using the local 'Maresha' to prepare the seed bed and also control weeds. The traditional belief is that well tilled soils produce higher yield than less tilled soils, hence excessive tillage is preferred whenever possible regardless of slope and crop type. In Gununo, fields are cultivated and hacked throughout the year for maximum utilisation of the small land holdings and the rain fall to produce short season crops (beans, sweet potato, etc.) following the aftermath of long season crops (maize). On the other hand, excessive tillage is known to aggravate erosion. AHI researchers have conducted experiments to determine the frequency of tillage needed to produce a full crop, and the preliminary results showed that for large seeded cereals (maize) reduced tillage gave higher yield than excessive tillage. If this recommendation is adopted, the farmers may benefit not only through conservation of soil/water but also through reduced costs that may have been paid for hiring oxen.

Growing Soil-Protecting Crops

Crops vary in their rooting and mulching behaviour, in that the root system of some annual crops is effective enough to reduce soil loss from the rhizosphere. Other crops could be effective in mulching the soil by their canopy thereby reduce the kinetic energy of the rain fall and also reduce the velocity of the runoff (e.g. melons, sweet potato). Table 6 shows that the soil loss from grass lands is almost nill despite higher slopes, and higher rainfall intensity. On the other hand, frequently hacked plots are extremely vulnerable to erosion even under low rainfall intensity, followed by plots covered by wide spaced crops. Narrow spaced, mulching type crops (e.g. beans and sweet potato) could minimise soil loss mainly through decreasing the detachment power of the rain drops. The results showed that short-term fallow did not reduce neither run-off nor soil loss much. Therefore, Gununo farmers have started to grow such crops on the part of their land that is vulnerable to soil erosion. Demeke has planted sweet potato on the steeply corner of his land continually for the last three seasons, but is planning to rotate it with beans in the coming season.

The soil and water conservation technologies, which were introduced by AHI-Areka researchers and evaluated by AHI partner farmers, are well appreciated by the community. However, the technology was well taken and disseminated to the other part of the watershed (non-participating farmers) than those within the watershed. Those farmers interested in the technology (11 non-member farmers are working on it) are those who own sloppy lands (>20% slope), with extreme erosion problems. The technology was well taken when it is accompanied by bund stabilising Elephant grasses than soil bunds *per se*. The advantage of the grass is two

Table 6. The effect of land management type on run-off (mm) and soil loss (t/ha) in Gununo (1987-1991) (SCRP, 1996)[1]

Year	**Type of Land Management**						
	Hacked (16% slope)		Cropland (16% slope)			Grassland (40% slope)	
	Runoff	soil loss	Crop type	Runoff	Soil loss	Runoff	Soil loss
1987	224.40	332.70	maize beans	80.20 100.20	21.90 8.90	14.40	0.00
1988	410.80	398.60	sorghum / beans fallow	219.60 261.80	37.70 23.00	17.00	0.00
1989	231.90	176.40	fallow barely/ sweet potato	139.70 149.90	30.60 38.50	26.80 26.80	0.00 0.00
1990	94.60	143.90	beans/ barley fallow/ teff	55.20 39.94	15.50 12.80	5.30 -	0.00 -
1991	180.30	298.40	fallow	155.3	129.80	5.20	0.00
Mean	***228.40***	***270.00***		***138.03***	***35.41***	***15.92***	
SD	*115.66*	*107.16*		*71.84*	*36.90*	*9.67*	

[1] In some cases two crops were listed as a single crop type as they were planted in combination as intercrops or relay crops.

Table 7. Advantages and disadvantages of soil building and soil-protecting interventions, as perceived by farmers of different socio-economic strata

Technology	**Wealth group I**		**Wealth group III &IV**	
	Advantage	*Disadvantage*	*Advantage*	*Disadvantage*
Legume cover crops	Enhance fertility; feed Moisture content	Compete for land; immediate benefit minimal	Protects soil from sunlight and run-off	Occupies space; no food value
Crop rotation	Enhance fertility; controls pests	None	Enhances soil fertility; better yield	None
Crop stubble management	Enhance soil fertility Increases yield	Shortage of animal feed	Enhance soil fertility	Shortage of fuel and animal feed
Soil bunds	Runoff cnt; Niche to grow feeds	Labour demanding; did not allow oxen plough	Erosion control	Labour demanding; occupies land
Increased vegetation cover	Controls run-off; provides feed & fuel; soil fertility amendment	Perennial weeds grow together	More feed available; controls surface run-off	Competes for land and moisture
Mulch	Moisture conservation; soil fertility	Fuel wood and feed shortage	Moisture; soil fertility	Brings termites

fold, not only it stabilises soil bunds but also became a very important feed source during the dry periods of the year. In 1999/2000 the dry spell was extended by about three months in Areka, and Elephant grass was the only green feed available on the ground. In fact, AHI was praised for introducing it.

SCALING-UP

AHI is a partnership among different stakeholders, which includes farmers, research institutions, Buro of ministry of Agriculture, Agricultural Colleges and NGOs. These stakeholders are the major players not only in developing/testing technology but also in disseminating technologies and knowledge. The farmer research group, established in 1999, have been playing the major role, not only in demanding for more technologies but also in disseminating knowledge through local organisations (like *debo*, a local organisation of people with similar age coming together to work in group when even there is a critical labour shortage in the farm of one or more of the members.) There has been also an effort going on to institutionalise participatory research into the Ethiopian Agricultural Research Organisation (EARO). Moreover, AHI being an eco-regional programme, technologies and knowledge obtained from one benchmark site have been tested in other benchmark sites and presented in regional and international forums, and these channels facilitated dissemination. Policy makers via Burro of Agriculture, have been also participated in AHI field days and planning meetings and are watching the AHI approach closely.

The potential reasons for non-adoption of NRM technologies, despite problems of soil degradation and food insecurity in the Areka benchmark site, include:

- Labour shortage for constructing bunds. In normal cases there is enough labour to construct soil bunds during the off-season. However, the time of labour availability coincides with food deficit period. This may have affected the adoption of the technology in two ways. Firstly farmers became physically weak to carry out hard works like digging and transporting construction materials. Secondly, they go for off-farm jobs at any wage to feed their family. These could be jobs that they may not go for if they had enough reserve to feed their family.
- Lack of knowledge in assessing principal causes of soil degradation and trends on-farm. Factors other than soil fertility (e.g. drought, pest) determine yield productivity in most years. Therefore, farmers may produce as much yield as the neighbouring fields except under extremely degraded soils.
- Current ownership of the farm (whether the farmer ploughs the farm or give it for shareholding during the year of the intervention). For example Kassu shared his farm with another farmer, so that he makes his land available while the other farmer brings the inputs (labour, oxen for ploughing, seed and fertiliser) and at harvest they share the produce equally once the cost of the fertiliser is reduced. Therefore, he can not decide on what to do and what to grow on his farm land for that specific year.
- Reductions in farmland and cost. In Areka, where land holding is so small every inch of land matters. Therefore, reduction of farm land should be accompanied by intensification of the system.
- The associated benefits of the soil bunds, beside soil conservation, should be attractive (e.g. elephant grass became attractive for feed in Areka). Getting additional income from the conservation component may sharply increase adoption rates of conservation measures.
- Level of attraction by entry points, implemented prior to complex NRM research agenda. In some cases, where the entry points were not successful, the probability of farmers testing other NRM interventions became minimal.
- Specific to Kassu, his experience with large and high input but poorly managed and unprofitable farms gave him the impression that yield increment is a difficult task even for high input agriculture.

Conclusions and Recommendations

Soil degradation became one of the major environmental constraint affecting agricultural production, thereby caused food insecurity in the Ethiopian Highlands. The ever increasing population pressure has aggravated soil degradation via extended farming to sloppy areas, shortened fallow system, and unchecked depletion of the inherent soil nutrients. Therefore, there is an urgent need to conserve and restore the fertility status of arable lands so as to be able to grow enough food that may cover the demand of the present and coming generations. Since farmers of different socio-economic strata may have different opportunities and needs, agricultural packages and blanket recommendations may not address the actual problem of the user. The technology in question should, there fore, consider the interest of farmers and other stakeholders. The degree of soil degradation of arable lands could also vary in space and time that may require stratified but integrated type of soil fertility management. We propose six integrated steps to restore soil fertility of degraded arable lands, which may require full participation of farmers at all research and implementations stages:

1. Minimisation/control of soil loss due to water and/or soil erosion using physical and biological measures;
2. Analysis of the soil to identify the limiting soil-related factor (nutrients, pH and alike);
3. Increasing the organic matter content of the soil through legume cover crops, application of manure, crop residues and the like;
4. Improving the water holding capacity of the soil through contour ploughing, minimum tillage, enriched organic matter and the like;
5. Increasing the nutrient status of the soil (mainly the nutrient in question) through application of inorganic/organic fertilisers, N-fixing legumes and the like; and
6. Designing an effective crop rotation scheme that may rotate deep-rooted with shallow rooted, soil-depleting with soil-enriching crops.

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