Optimizing Soil Fertility Gradients in the Enset Systems of the Ethiopian Highlands

Trade-offs and Local Innovations[1]

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Abstract

Ensete ventricosum is a perennial, security crop that feeds about 13 million people in Ethiopia. It is grown in the homesteads, covering about 18% of the farm, in mixture with Coffee, kale, and other vegetables. The recent shift from enset to cereals and continual soil fertility decline in the outfields caused food deficit for at least 3 months in a year. The objective of this work was to evaluate the effect of soil fertility gradients on enset growth, identify the major growth limiting nutrients, and identify farmers' decision making criteria in allocating resources to various enterprises. The research was conducted on farmers fields of resource rich (G1) and poor (G3) for four years (2001-2004). Enset transplants were planted in homestead and outfields. Application of fertilizers by farmers to different units over seasons and years was recorded. Enset growth and nutrient content was measured. The results showed that the G1 group produced about 2xs more organic waste than G3, and purchased chemical fertilizers 5xs more than the G3 farmers. About 80 % of the organic resource produced was allocated for maintaining soil fertility, while 20% being allocated as cooking fuel. Of this 65% is allocated for the enset field in the homestead. There was significantly higher N, P, K and Ca contents in the home stead soils than in the outfield, regardless of farmers' resource endowment. The P content of the outfield was the lowest, less than 25% of the P content of the homestead. Similarly organic matter in the outfield was only about 40% of the homestead. Enset plants grown in the outfields experienced about 90% height reduction and 50% reduction in pseudo stem diameter, regardless of resource categories, while the NPK content of the plant tissues grown in the outfield was significantly higher, in some case up to 150% than those planted in homestead. We thus concluded that growth reduction in the outfield was not directly related to NPK deficiency, but it could have been caused by off-season moisture stress in the outfields, manifested by low soil organic matter. The attempt to attract resources to the outfield using enset as an attractant crop failed, not because of labour shortage but because of unavailability of enough organic resources in the system. Hence on spot management of nutrients was initiated by farmers.

Keywords: Ensete ventricosum, Soil fertility gradient, Nutrients, Growth, Farmer innovation

Introduction

Enset systems is one of the four major agricultural systems in Ethiopia feeding about 13 million people, more than 20% of the population residing in the southern Ethiopian highlands. Enset (*Ensete ventricosum*) is a perennial, banana-like crop, endemic to Ethiopia that produces psuedostem and a starchy belly corm pulped for food, feed and fibre. Although the exact age of Enset domestication is not yet established, it was practiced in Ethiopian highlands between 5000 and 10000 years a go (Brandt et al, 1997). It has probably given rise to better intensification of production systems involving year round cultivation of the land, with emphasis on root crops and close integration between livestock and crop production units (Brandt et al, 1997; Kippe, 2002). One plant of 5 years old could produce up to 21 kg of local food (Kocho, Bulla and Amcho) and 3.6 t/ha dry matter residue (Kippe, 2002). It is commonly grown in the homesteads, in mixture with Coffee, kale, sweet potato seedlings and other high value vegetables, covering about 18% of the farm. Other fillers of the system are maize, wheat, potato and beans, grown mainly in the mid fields and outfields either sole or in intercropping.

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Enset in the sub-system fulfils both production and protective functions (Kippe, 2002). Because of its very high yield it covers the food demand of household covering from 25% where it is a subsidiary crop to 85% where it is the major food crop (Tsegaye, 2002). Its funnel like leaves and spongy root systems form mate-like structure in the root zone that minimizes soil erosion and run-off, which ultimately improve the water and nutrient budget of the sub unit. However, like that of the banana systems in Uganda (Bekunda, 1999), it also attracts most of the organic waste whereby farmers allocate about 80% of the organic manure and crop residue to the enset field, including the nutrients coming from outfield in terms of feed and mulch. As a consequence, the outfields and midfields suffer from very low soil fertility status, aggravated by farmers' preferential management, soil erosion and nutrient mining (Amede & Kirkby 2004). Whole farm nutrient flow analysis by farmers, and yield variability across the farm units in the area indicated that there was a positive N and P balance, while the outfields indicated extremely low N and P balances for all farmers of various social categories (Elias, 2000). The same trend was observed for banana system in Uganda, with the highest deficient being in the outfield of resource-poor farmers (Bekunda, 1999) as their financial capacity to buy chemical fertilizers is very weak (Elias, 2000).

In recent years, the Enset system has been in jeopardy in southern Ethiopia partly due to the desire of town dwellers to shift to the 'prestige' foods of cereals thereby affecting the market opportunities to Enset products and partly due to decreased number of animals to produce enough manure to support the enset fields. As a consequence of the shift accompanied by increasing human population, the system has been experiencing food deficit for at least 3 months in a year in recent years (Amede, Stroud, and Aune, 2004). Food deficit was also aggravated by decreasing farm size, currently 0.32 ha per family of 7, and declining productivity of the system to support household needs. Decline in productivity was primarily associated with decline in soil fertility & increased incidence of Enset pests (Amede, Belachew and Geta, 2001). Farmers tend to build hot-spots of fertility knowingly, based on their own priorities to crops and labour and financial investments. The Enset sub-unit became a hotspot to application of organic residues due to social favouritism towards Enset as a security crop for bad years (Brandt et al., 1997; Tsegaye, 2002). Some argue that farmers apply organic waste mainly in the home gardens is due to distance effects to the house, demanding less labour needed to transport household refusal, stall manure and enset by-products (Bekunda, 1999; Elias, 2000).

Although Enset is a high yielding crop whereby only 42 mature plants per year, grown in a small plot of land (Kippe, 2002) could support the food demand of a household of seven, the system became vulnerable to frequent food crisis in the last ten years, and the population became food aid dependent for at least 3 months per year. Hence there is an immediate need to expand the Enset field, which is currently less than 20% in average to about 45% to become food self sufficient with the existing yield and production inputs (Amede, Stroud, and Aune, 2004). Alternatively, there is a need to double the yield of the cereal crops per area to feed the growing population, which may in turn demand an extensive use of inputs and innovations. On the other hand, expansion of enset from the traditional fertile home gardens to the non-fertile outfields will call for an improved soil fertility management strategy that may require more organic inputs and sustainable nutrient flows. Elias (2000) noted the interest of farmers in the region to continually expand the Enset field to the outfield as farm land holding decreases.

We hypothesis that since Enset is a security crop of the system that people rely on in bad days, growing it in the outfield as an attractant would be an incentive for farmers to transport more manure and organic resources to the outfield.

The objective of this work was:

- To evaluate the effect of soil fertility gradient on growth and productivity of Enset
- To quantify the amount of organic matter that farmers would bring to the outfield following Enset as an attractant crop
- To identify the major growth limiting nutrients for possible expansion of Enset to the outfield
- To learn about farmers' decision making criteria in allocating nutrients and organic resources to various farm plots and/or enterprises

Materials and Methods

CHARACTERISTICS OF THE STUDY AREA

The research was conducted in southern Ethiopian highlands, Gununo, Areka. Gununo is situated at 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. Topography is characterised by steep, undulating slopes divided by v-shaped valleys of seasonally intermittent streams. Mean annual rainfall and temperature are about 1300 mm and 19.5^{o}C, respectively, with bimodal rainfall. The small rainy season (*belg*) extends from March to June while the main rainy season (*meher*) extends from July to the end of October. The months of July and August receive the highest rainfall and cause significant soil loss, mainly in the outfields. Eutric Nitosols are the dominant soils, slightly acidic in nature, and are characterised by phosphorus fixation.

The farming system is subsistence, mixed crop and livestock production, with relatively fewer livestock than elsewhere in Ethiopian highlands. Currently less than 15% of households own oxen. Gununo is characterised by very high population density (about 450 people km^{-2}) with only about 0.25 ha for a family of seven, so small that some children are not in a position to inherit land. Hence, the majority of young people migrate to other parts of the country as labourers. Share cropping and renting of land are also common, especially among young farmers who do not own land. For the same reason, hillsides that were formerly used as grazing areas or tree plots came under cultivation.

EXPERIMENTAL METHODS

Farmers have identified soil fertility decline as one of the six major system constraints (Amede, Belachew and Geta, 2001), apparent particularly in the distance fields. Two groups of farms, belonging to resource-poor and -rich farmers with clear soil fertility gradients were selected through participatory negotiation. Those willing farmers planted Enset transplants in May 20, 2001 in both homestead (5 meters away from the house) and outfields (about 60 mts away from the house). Farmers opened pits, watered the holes and planted the transplants. Sixteen plants were planted per treatment with spacing of 2 m^2, in four replications following the contour. Researchers have trained farmers on how to record the amount of organic matter (household refusal, stall manure, mulch, crop by-products) and mineral fertilizers (Urea or DAP) they may apply to the different fields of the farm in general and to the Enset planted in the homestead and outfields in particular. The researchers measured plant height and pseudo stem diameter as growth parameters. We also recorded farmer's perceptions on alternative soil fertility management options and on their decision making criteria to allocate organic/inorganic fertilizers to various fields and enterprises through structured questioners (using pair wise ranking) and various PRA tools (resource flow analysis, resource mapping, key informant and informal discussion).

In February 2004, shortly before the beginning of the short rainy season, soil samples were collected from the enset inter rows of the above 20 cm of the homestead and the outfield, from the four replications. Additional soil samples were collected from the neighboring outfields. Similarly, four upper leaves per plant per replication were harvested for nutrient analysis. Plant and soil samples were oven dried to constant weight, then ground to pass through a 1.0 mm sieve and analyzed for total NPK by Kjeldahl digestion with concentrated sulfuric acid (Anderson and Ingram, 1993). Nitrogen and phosphorus were determined colorimetrically (Parkinson and Allan, 1975) and potassium using atomic absorption spectrophotometer. Similarly, the soil samples were analyzed for N, P, K and Ca using methods given by Anderson and Ingram (1993). Organic C was determined using Wakley-Black method. Treatment differences were tested using ANOVA and treatment means were compared by LSD at $P<0.05$ (Jandel Scientific software).

Results

ORGANIC RESOURCES PRODUCTION AND DISTRIBUTION

The amount of organic resource on farm depended upon the resource endowment category of farmers (Tables 1 & 2) in that resource-rich farmers (G1) produced more organic residue than resource-poor farmers (G3) because of owning more animals and more land to produce higher amount of crop residue and forages. The G1 group produced about 2x more farm yard manure and crop residue than G3. Similarly, the G1 farmers were in a position to purchase inorganic fertilizer, Di Ammonium Phosphate (DAP), about 5 xs more than the resource poor farmers (Table 2).

However, the proportional distribution of resources among various farm sub units was similar across wealth categories. In general, the multi-storey production system with coffee-Enset field around the home garden is favoured to receive high amount of organic matter. Resource flow record of the respected farms showed that about 80 % of the organic resources that farmers are producing are allocated for maintaining soil fertility, the rest 20% being allocated as cooking fuel (Table 1). Of the organic resources allocated for soil fertility maintenance about 65% is allocated for the homestead, where the most important security crops, like Enset and Coffee, are grown the remaining amount being allocated for the nearby midfields. Crops grown in the outfields did not receive any organic manure in farms of both resource endowment categories. However, resource rich farmers applied DAP to the outfield maize and potato crops.

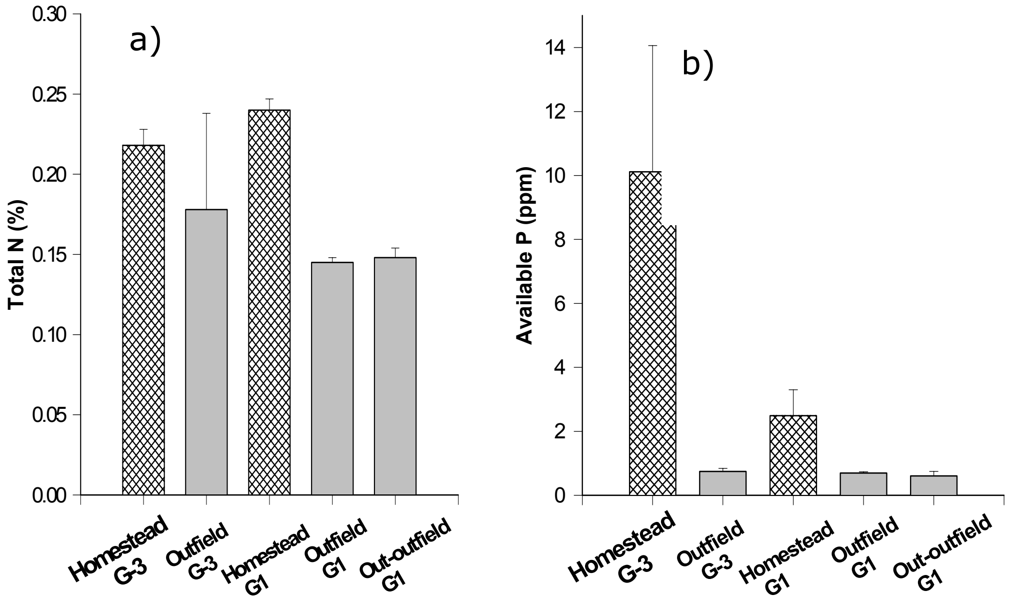

Figure 1. Total nitrogen (a) and available phosphorus (b) content of homestead and outfield soils in farms of resource-rich and resource-poor farmers' fields. Out-out field indicates fields beyond the enset rows of the outfield (n = 4).

Table 1. Organic resource production by resource-rich (G1) or resource-poor (G3) farmers and its distribution to different farm sub-units in Areka, Southern Ethiopia (2002)

Farmers' Category	**No. of Animals**		**Organic Manure** (Kg/week)		**Use** (%)		**Distribution in the Field** (%)			
G1	Cattle	Sheep	FYM (Wet)	Others	Soil Fert.	Fire wood	Homestead	Mid field	Mid field	Outfield
A	4	2	101.5	15.0	75	25	70	30	0	Inorganic
B	3	0	72.5	12.3	90	10	50	30	20	Inorganic
C	4	1	116.0	11.5	80	20	70	20	10	Inorganic
Mean	3.67	1.00	96.67	12.93	81.67	18.33	63.33	26.67	10.0	
SE	0.33	0.58	12.80	1.06	4.41	4.41	6.67	3.34	5.78	
G3										
A	2.00	0.00	72.50	8.00	70.00	30.00	40.00	30.00	30.0	-
B	0.00	2.00	29.00	7.50	100.00	0.00	85.00	15.00	0.00	-
C	2.00	0.00	58.00	6.20	60.00	40.00	65.00	25.00	10.0	-
Mean	1.33	0.67	53.17	7.23	76.67	23.33	63.33	23.33	13.3	
SE	0.67		12.80	0.54	12.03	12.03	13.03	4.41	8.83	

When farmers were asked to identify the major five reasons behind to apply most of the organic waste in the homestead year after year, they have identified the following, namely 1) there is no enough organic matter to apply in good amount all over the farm (100%) 2) the most important crops in the homestead field (100%) 3) Enset is traditionally grown in the homestead and the organic matter follows it (100%) 4) there is lack of labour to carry the organic matter in the outfield (33 %) and 5) soil erosion will remove the organic matter if applied in the outfield (33%). Besides, there was a social consensus that the most important security crops (e.g. Coffee, Enset and Taro) be planted around homesteads to protect them from theft, wild animals and manage them better, hence a better care to nearby fields. In some cases, like farmers G1, the heads of the households were willing to transport the organic manure while who are doing the actual work, women and children, were sceptical to implement it due to the traditional favouritism to the homestead fields.

Table 2. Major crops grown in different positions of the farm and crop residues and chemical fertilizers applied to the respective crops by resource-rich

Crop Grown	**Location in the Farm**	**Type of fertilizer**	**Amount of Fertilizer Applied** (kg DAP/ 500 m^2)	
			Farmers G-1	Farmers G-3
Enset-Coffee mixture	Home stead	Organic	80 bundles*	12 bundles*
Sweet potato	Mid field	organic	none	none
Maize	Mid/Out field	Inorganic	29 kg DAP	9 kg DAP
Wheat	Mid/out field	Inorganic	7 »	3 »
Teff	Mid/out field	Inorganic	29 »	3 »
Potato	Out field	Inorganic	7 »	none

(G1) and resource-poor

(G3) farmers in 2002/2003 growing season in Areka.

The organic source is a mix of crop residues from maize stover, wheat stover, Enset residue and other mixtures. *One bundle ≈ 6.5 kg dry matter.

SOIL FERTILITY GRADIENTS

The differential application of different sources of fertilizers within the farm over years created a clear soil fertility gradient from the home stead to the outfield soil nutrient status decreasing from the homestead to the outfields, regardless of resource endowment categories. In this study, there was a significant difference in nitrogen, phosphorus, potassium and calcium contents of the soil between the homesteads and the outfields, regardless of farmers' resource endowment categories (Figs 1, 2&3). However the N concentration of the outfield was adequate, but P was the major nutrient in deficit in the outfield followed by potassium. In contrary to the expectations, the N, K and Ca concentration of the resource poor farmer was as good, and in some cases better than the fields of the resource-rich farmer. Phosphorus content was significantly higher in the homestead units of G1 than G3, though P content of the outfield was less than 25% of the P content of the homestead in both categories. Similarly, there was significant decrease in organic matter with distance from the home whereby the organic matter concentration in the outfield was about 40% of the homestead field regardless of farm categories. Despite differences in organic matter application and nutrient status there was no major change in soil pH between farms neither of the two wealth groups nor within farms (Fig 3). However, in G1 the pH in the outfields was reduced from 6.65 in the homesteads to 5.95 in the outfields.

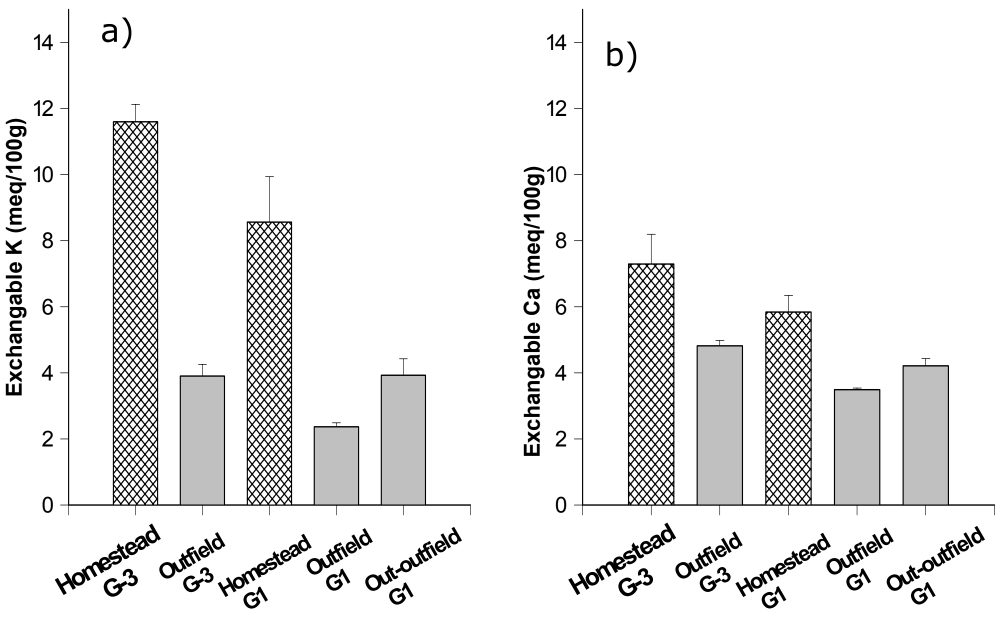

Figure 2 Potassium (a) and calcium (b) content of homestead and outfi.eld soils in farms of resource-rich and resource-poor farmers' fields. Out-out field indicates fields beyond the enset rows of the outfield (n = 4).

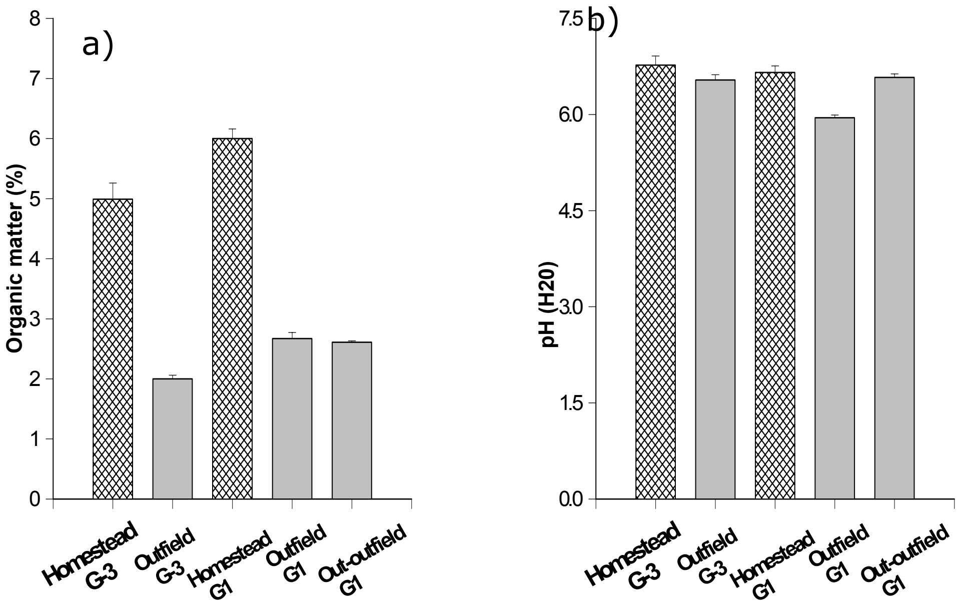

Figure 3. Organic matter content (a) and pH (b) of homestead and outfield soils in farms of resource-rich and resource-poor farmers' fields. Out-out field indicates fields beyond the enset rows of the outfield (n = 4).

Enset Nutrient Contents

Nutrient content in the leaves and young stems of the Enset plant showed a completely reversed trend to the soil nutrient concentration in that enset plants grown in the outfield contained a higher concentration of major nutrients, NPK (Fig 4), and in some case, like K the concentration was 150% or higher in plants grown in the outfield compared to plants grown in the homestead. There was no difference in trend between resource endowment categories (Fig 4).

Enset Growth and Yield

Enset growth was significantly affected by soil fertility gradients. Differences in major nutrient content between the homestead field and the outfield was strongly correlated to enset growth (data not presented). Enset productivity parameters, height, psuedostem diameter and pseudostem height were severely reduced (Fig 5). Plant height was the most affected by soil fertility gradients, experienced about 90% height reduction, regardless of household resource endowment categories. Similarly pseudo stem diameter was reduced by about 50%. However, enset growth in G1 farm in the homestead was by about 0.8 meters higher than that of plant height in G-3 farm. Enset growth in the out field of farm G1 was also higher than that of Farm G3.

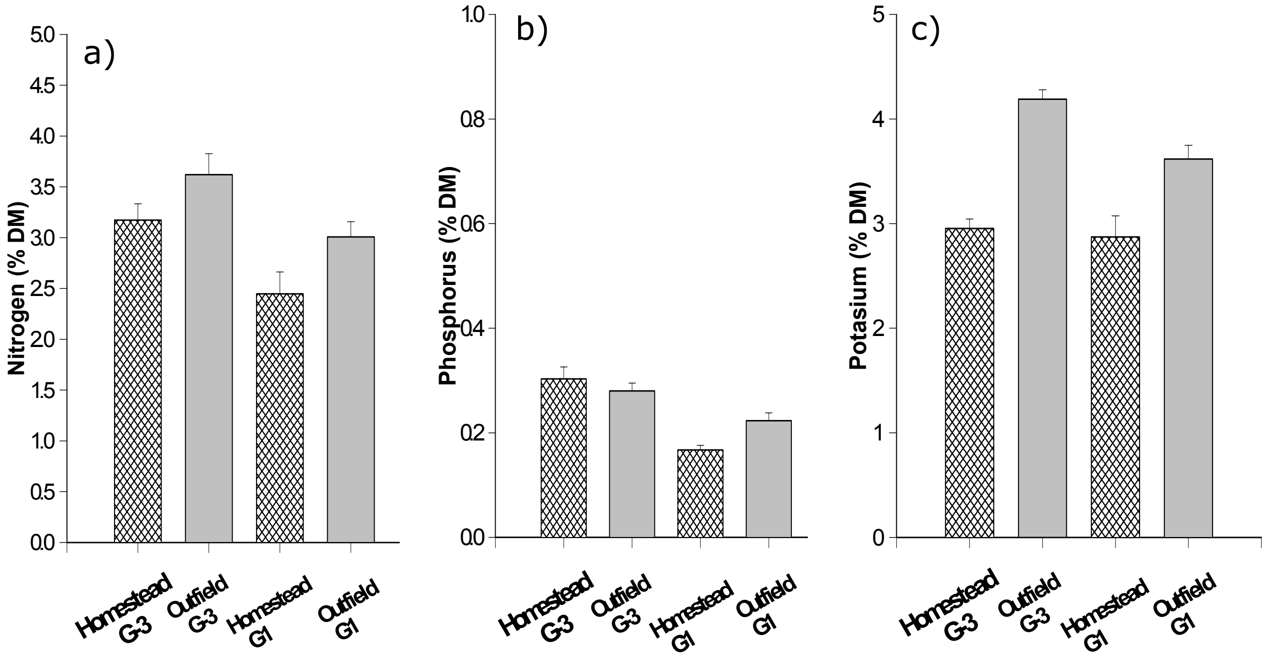

Figure 4. Nitrogen (a), Phosphorus (b) and Potassium (c) content (% of dry matter) of Enset plant tissues grown under homestead and outfield soils in farms of resource-rich and resource-poor farmers' fields (n = 4).

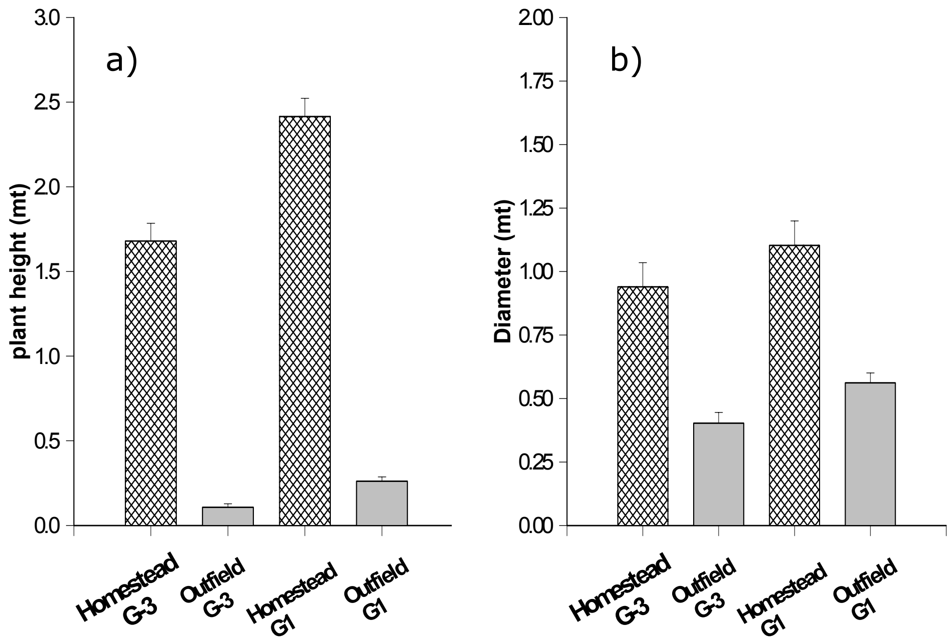

Figure 5. Plant height (a) and Pseudo stem diameter (b) of Enset grown under homestead and outfield soils in farms of resource-rich and resource-poor farmers' fields (n = 4).

Discussion

The desire of the town dwellers to shift towards cereals, and the related high market demand for cereal products has been forcing farmers to allocate more land to cereals at the expense of Enset and other perennial crops. On the other hand, as the available land per capita becomes more limited it became a necessity to intensify the systems to produce more food per unit area. Enset is one crop that could enable to feed a household of 7 with only about 45 Enset plants per year (Kippe, 2002). Hence, the expansion of enset from the current number, which is in average 10 mature enset per household per year to about 30 Enset plants, i.e. a total of about 250 enset plants of different age per household, would address food security, supplemented by pulses, cereals and other root crops (Amede, Stroud, and Aune, 2004). This ultimately needs for an expansion of the enset field to the middle and outfields.

Enset as a major sub-unit has been positively contributing to nutrient cycling (Brandt et al., 1997; Kippe, 2002), as an erosion barrier particularly when it is planted on the top of the farm, and as an incentive to farmers to invest labour and manure. Farmers favour mulching crops like banana and enset because they know that it suppresses weed growth, maintains soil fertility and conserves moisture for these shallow rooted crops (Bekunda, 1999). On the other hand, the concentration of enset in the homesteads encouraged a continual nutrient mining of the outfield via crop residues transported as mulch and feed to be used for fertilizing the homestead fields.

The soil nutrient analysis across the gradient showed that soil fertility decline is not global; rather there is a very high difference in nutrient accumulation within the farms, the homestead fields being rich in major plant nutrients (Figs 1, 2&3). The attempt to attract more organic and inorganic fertilizer by planting the most favoured security crop, Enset, in the outfield was not successful as little organic matter was transported to the outfield over time (Table 2). In contrary to the observations of Bekunda (1999), where farmers applied most of the manure for banana in the home fields to reduce the time and effort needed to transport the organic waste to the outfield, the limited transfer of manure to the outfield in the Enset systems of Areka could not be explained by labour shortage, as farmers' did not transport manure to the outfield even in off-season months when labour is abundant (data not presented). Rather, they were investing their family labour to transport crop residues of maize, wheat, and other crops from the out and mid fields to the homestead for mulch and feed (Table 2). The preferential application of the organic waste to the home garden was partly because of the limited manure available due to reduced number of animals and partly as a result of decline in farm size which resulted in fewer opportunities to produce and apply cattle manure and crop residue, as also observed in Uganda (Bekunda, 1999). Households, with no/few animals, lack access to manure as it is becoming an increasingly valuable resource, and not even keen ship or local market can guarantee a supply of it (Eyasu, 2000). But farmers, regardless of wealth groups, initiated three innovation schemes to enhance the management of the outfield. Firstly they have minimized the transportation of crop residues that was taken as mulch (e.g. maize and wheat stover) - with limited feed value- and compost it on the spot to recycle back to the field. Secondly they have been growing N-fixing, fast growing legumes (mainly vetches and stylosanthes) that they have identified earlier (Amede & Kirkby, 2004) as short term fallows and intercrops in the outfields. Thirdly, they have started to construct soil bunds to minimize run-off.

Although the nutrient status of the outfield was significantly lower than the nutrient status of the homestead, which was also reflected by Enset growth, plant analysis showed that there was a very strong accumulation of NPK in the plant tissue of the stressed plants. Accumulation of nutrients under stress conditions could be explained by two possible reasons (Amede & Schubert, 2003). Firstly Enset plants grown in the degraded corners of the farm could be exposed to repeated water stress over the course of the year as the soil water holding capacity, expressed by the low soil organic matter content (Fig 3) is relatively low. In this case, the domination of external atmospheric deficit over water uptake may lead to a reduction in the expansion rate of the tissue (reduced cell volume), and thereby to an accumulation of cations in the plant cell. Secondly, under moderate levels of stress, roots may still actively absorb nutrients, but they may not be utilized by the plant owing to growth inhibition. Instead translocated ions may accumulate in the cell and induce substantial role in maintaining the turgidity of the plant. Crop growth inhibition, despite sufficient amount of available in the rhizospher, has been reported (Marschner, 1995). Although Enset is considered as a drought resistant crop that could survive short term dry spells better than annuals (Bayush, 1991) it has got little additional weight beyond survival when planted in outfields. Increased use of chemical fertilizers for Enset in the outfield may not compensate for the manure loss because of the multiple roles the organic waste plays (Brandt *et al*, 1997), but it could be possible to increase yield in the far out fields by increasing the soil water holding capacity of the soil through increasing the soil organic matter content and reducing the evaporation through mulching low quality crop residues, tree litters and other conservation measures. Although the hypothesis of a U-form relation between population pressure and soil fertility management is not yet observed in the Enset systems, a U-form response is needed to feed the ever growing population.

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References

Amede, Tilahun and Kirkby R (2004) Guidelines for Integration of Legume Cover Crops into the Farming Systems of East African Highlands. Pp 43-64. In: Bationo A. (2004) Managing nutrient cycles to sustain soil fertility in Sub-Saharan Africa. Academic science publishers. 608 p.

Amede, Tilahun, Takele Belachew and Endrias Geta (2001) Reversing the degradation of arable land in Ethiopian Highlands. Managing African Soils: No. 23. IIED- London.

Amede, Tilahun and Schubert S (2003) Mechanisms of drought resistance in grain legumes: I. Osmotic adjustment. SINET: Ethiopian Journal of Science 26 (1): 37-46.

Amede, Tilahun, A. Stroud and J. Aune, 2004. Advancing Human Nutrition without Degrading Land Resources through Modeling Cropping Systems in Ethiopian Highlands. Food and Nutrition Bulletin of the UN- Boston. Accepted for publication.

Anderson, JM, Ingram JSL (1993) Tropical Soil biology and Fertility: A hand book of methods. CAB International, Willingford, U.K.

Bayush T (1991) Community management of crop genetic resources in the Enset complex farming systems of Southern Ethiopia. A case study from Sidama region. MSc thesis. Agricultural University of Norway.

Bekunda, M (1999) Farmers' response to soil fertility decline in banana-based cropping systems of Uganda. Managing African Soils no. 4. IIED-London. 17 p.

Brandt S, Spring A, Hiebsch C, McCabe T, Taboge E, Diro M, WMicheal G, Ynitso G, Shigeta M, Tesfaye S (1997) The 'Tree Against Hunger': Enset-based Agricultural systems in Ethiopia. American Association for the Advancement of Science. 66p.

Elias, Eyasu (2000) Soil enrichment and deletion in Southern Ethiopia. Pp 65-82. In: Hillhorst, T. and Muchena, F. (editors). Nutrients on the move: Soil fertility dynamics in African farming systems. 146p.

Kippe Tadesse (2002) Five thousand years of sustainability? A case stud of Gedeo land use, Southern Ethiopia. Tree book 5, Treemial publishers, Heelsum, The Netherlands.

Marschner H (1995) Mineral nutrition of higher plants. Second edition. Academic press, U.K, 889 p.

Parkinson JA and Allen SE (1975) A wet oxidation procedure suitable for the determination of nitrogen and mineral nutrients in biological materials. Communications in Soil Science and Plant Analysis 6:1-11.

Tsgaye, Admasu (2002) On indigeneous production, genetic diversity and crop ecology of Enset (Ensete ventricosum). PhD Dissertation, Wageningen University.198p.

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