

# Advancing Human Nutrition without Degrading Land Resources through Modeling Cropping Systems in Ethiopian Highlands<sup>1</sup>

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## Abstract

*Food shortage in Sub-Saharan Africa is predominantly taken as a function of limited access to food, with out considering nutritional quality. Analyzing households' production of nutrients on farm across farming systems could be valuable in guiding intensification of those systems. An optimization model was employed to analyze the scenario of human nutrition and cropland allocation in Enset (*Enset ventricosum*)/root crop – based (Areka) or cereal-based (Ginchi) systems of Ethiopian highlands. The type and amount of nutrients produced in each system was analyzed and an optimization model was used to analyse, which cropping strategies may improve the nutritional quality of the household using the existing resources.*

*Both production systems were in food deficit, in terms of quantity and quality, except for iron. Energy supply of resource-poor households in the enset/root crop-based system was only 75% of Recommended Daily Allowance (RDA), while resource-rich farmers covered their energy, protein, zinc, and thiamine demand. Extremely high deficiency was found in zinc, calcium, Vit A and Vit C, which was only 26.5, 34, 1.78 and 12 % of the RDA, respectively. The RDA could be satisfied if they expand the land area of enset, kale and beans by about 20, 10 and 40 %, respectively, at the expense of maize and sweet potato. The critical deficit of the cereal-based system was also calcium, Vit A, and Vit C, which was only 30, 2.5 and 2% of the RDA. In the cereal system, the RDA could be fully satisfied by reducing crop land allocated for barley by about 50% and expand the land area of faba beans, kale and enset. However, Ginchi farmers have better copying options than Areka farmers as they own more land and higher number of livestock that could be used as buffering assets.*

*A shift from the cereal/root crop dominated system to a perennial-enset dominated system would decrease soil erosion by improving the crop factor by about 45 %. It also has a very strong positive implication for soil fertility management. However, any policy suggestion for change in cropland allocation should be done through bottom-up negotiations with households, communities and district stakeholders.*

**Keywords:** Cropping systems, Human nutrition, Modeling, Land allocation, C-factor

## Introduction

The food situation in sub-Saharan Africa (SSA) is continuing to deteriorate as a consequence of multiple calamities such as drought, occasional flooding, decline in soil fertility, increasing pests and diseases, land scarcity and poor market access, coupled with discouraging policy environments. The effect is pronounced as recurring food shortage, malnutrition and poverty. Food shortage in SSA is predominantly taken as a function of limited access to food, with out considering nutritional quality [1]. Malnutrition of the vulnerable groups (children and women) could happen even in good crop harvest years because of non-balanced food intake. Studies in Ethiopia showed that about 45 % of the children are stunted while about 42% are underweight, associated with zinc, iron and Vit A deficiency [2]. The most important documented forms of malnutrition

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country-wide were protein-energy malnutrition and vitamin A, iodine and zinc deficiencies [2,3]. A recent survey showed that 53% of males and 26% of females aged 6-72 months had night blindness and Bitot's spots, with the highest rates in those 36 to 72 months [2].

Analyzing households' production of nutrients on farm across farming systems could be valuable in guiding intensification of those systems, particularly in situations where markets are less important than securing subsistence. For instance, in Papua New Guinea, communities farming in flat wetland area had significantly higher energy and protein intake than those residing in the drier hills [4]. In Uganda, both banana-based and cereal-based system failed to satisfy a range of nutritional needs with calcium and zinc being the most lacking [5]. However, there is scant information on the interaction of Enset/root crop-based and cereal-based systems of Ethiopian Highlands with household nutrition and human health. Enset (*Enset ventricosum*, known also as false banana) is a carbohydrate-rich perennial crop, with a strong pseudostem and edible bulbs and corms [6], which is a staple of millions of households in Ethiopian Highlands.

Food nutritional quality could be improved through different practices such as application of fertilizers and soil amendments, selection of varieties with high micronutrient content, use of indigenous high nutrient value crops and genetic modification of plants to improve micronutrient supplies [1,7]. However the application of these methods to address malnutrition depends upon the availability of technological and policy interventions, that are commonly beyond the accessibility of small-scale farmers. It could have been also possible to supplement with animal products where livestock is an integral part of the system. However, animal products are rarely consumed by rural households as they are scarce sources of cash [3]. Dietary supplements are also rarely available to the rural poor.

One option to minimize the risk of malnutrition is through reallocation of cropland in favor of crops with high content of the nutrient in deficit. Once the nutrient budget of these systems is quantified and the type of the nutrient in deficit or excess is identified, the nutritional balance could be improved by reallocation of cropland, and increasing the land area allocated to crops rich in requisite nutrients [5]. Modeling the cropping system, by considering the adaptability of the crop to the environment in question, could offer a better and faster opportunity to reverse malnutrition. However, the possible acceptance or rejection of the model largely depends on the compatibility of the new crop adjustment with cultural values, food habit, labor, input demands and soil fertility management options.

Ethiopia is one of the most severely affected countries in SSA in terms of land degradation, lost about 17% of the countries potential GDP because of physical and biological soil degradation [8,9]. Land degradation could be the major cause of recurrent crop failure, i.e. food insecurity. Hence any attempt to efficiently exploit the potentials of land resources to produce more food should be integrated with strategies to rehabilitate depleted land resources. Altering cropland allocation may have a significant implication on soil and water management [10], as the change in crop type and area would affect interception of rain by the vegetative cover (the erosivity power), which is named as the crop factor (C-factor) in the USLE (Universal Soil Loss Equation) [11]. The relationship between relative erosion and cover is strongly parabolic; a 25% cover would give a 50% reduction in erosion [12]. A shift from cereal-dominated system to a perennial-dominated system may improve the C-factor, while the reverse may cause more erosion and land degradation. Therefore, altering crop allotment to improve human nutrition should take soil fertility, conservation and management into account.

The objective of this work was therefore to, a) estimate the type and amount of nutrients that Enset/root crop based or cereal-based systems furnished, in terms of protein, energy, zinc, calcium, iron, thiamine, Vit A and Vit C, b) model cropping strategies that may improve the nutritional quality of the household using the existing resources, and c) estimate the effect of reallocation of crops on land management and soil erosion.

## Methods

### SITE DESCRIPTION

The research was conducted in two contrasting farming systems of the Ethiopian highlands, Areka and Ginchi. Areka (37° 39' E and 6° 56' N), is characterised by a multiple cropping system, with strong perennial components of Enset and Coffee, accompanied by sweet potato, taro, maize, wheat and many others (Table 1). The population pressure is high (>400 people/Km<sup>2</sup>), with average land holdings of less than 0.5 ha. At between 1880 and 1960 meters above sea level, this area has mean annual rainfall of about 1300 mm, and an average temperature of 19.5 °C. Rainfall is bimodal, with a short rainy season (*belg*) from March to June, and the main rainy season extends from July to October. The dominant soils are eutric nitisols, which are characterised by high water holding capacity, moderately acidic pH, low levels of nitrogen and high phosphorus-fixation.

**Table 1.** Crop yield and nutrient composition of major crops grown at Areka and Ginchi.

Crop	Nutrient Content per kg Edible Yield								
	Yield (qt DM/ha)	Energy (K Cal)	Protein (g/kg)	Zn (mg/kg)	Fe (mg/kg)	Ca (mg/kg)	Thiamine (mg/kg)	Vit A (ug/Kg)	Ascorbic Acid (mg/kg)
Enset (kocho)*	119.08	2111	6	6	37	320	0.3	0.2	0
Taro	29.66	1038	13	1.4	20	550	0.4	0	90
Pumpkin	6.78	249	11	1.9	9	400	0.3	0	40
Kale*	18.75	401	25	8.6	22	50	0.4	112.5	13.2
Sweet potato	39.35	1370	0.7	2	7	130	0.2	0	14.2
Irish Potato*	14.46	840	15	4	36	184	0.1	0.4	2.83
Maize	14.84	2234	41	13.3	20	80	0.2	0	0
Teff	4.09	1620	41	11	115	690	0.3	0.03	0
Wheat*	8.93	2220	68	2	27	270	2.1	0.8	0
Barley*	5.81	2020	44	15.8	35	160	2.1	0	0
Pea	6.97	2071	109	24.6	31	450	2.4	10.5	0
Fababean*	6.77	2759	164	13.8	43	870	1.9	1	0
Common Bean	6.52	1700	91	3	33	560	2.6	0.6	0
Sorghum	8.31	2360	50	4.9	49	150	2.2	1.1	0

\* Indicates crops grown in Ginchi.

Ginchi (38° 11' E and 9° 02' N), represents Ethiopian mountainous plateaus at altitude between 2700 and 3000 mas. The area has a weak bi-modal rainfall of 1200mm per annum and an average temperature of 15 °C. The farming system is dominated by barley-fallow-barely and livestock, which are grazed using a communal management system. Crop diversity is restricted by low mean temperature. Population pressure on the land combines human (100 people per km<sup>2</sup>) and livestock, with an average farm size of 3.0 ha. About 24% of the farmers own more than 4 ha. In the upper side of the watershed the system is predominantly barley-fallow-barley accompanied by wheat, potato, and Enset. The soils in Ginchi plateau are Litisols, which are acidic, low in organic matter, nitrogen and phosphorus. Soil fertility status is so low to the degree that it does not support continuous cropping any more.

### DATA COLLECTION

A household survey was conducted over two years (2000–2001) in the two communities of the Enset/root crop-based and cereal-based systems. Twenty-four and 31 farmers of two wealth categories (relatively rich and poor) were considered for the study in Areka and Ginchi, respectively. A participatory wealth ranking exercise undertaken by the African highlands Initiative program, which grouped the households into three wealth categories based on the size of land holding, number of livestock, perennial crops grown and sources of income was considered [8]. During the household surveys the researchers were able to quantify and observe over the

period of two years. The major parameters considered for the analysis were, farm size /household, household family composition by age and sex, crop land allocation, household food item over seasons, household food allocation/ distribution among family members, crop yield on farm and crop purchase or sell over seasons. Household food consumption was monitored in each household on weekly basis, by interviewing the women. The consumption unit (CU) of each household was calculated using FAO designations [13], by adding the consumption unit of each household member. Secondary data was also collected on average crop yield in the district [14] nutritional composition of each crop [15] (Table 1), and other relevant data was assembled. For crops where reliable data was not available, measurement of yield, moisture content and estimation of edible components was done on farm at harvest.

Since the bimodal rainfall is supporting at least two crops per year at Areka, land size per household was considered as a sum of land used for growing crops in both seasons per year. Hence, the farm size presented here is larger than the actual land size. In the process, intercropping and relay cropping practices complicated establishment of land area and yield per individual crops. However, for the purpose of this exercise, we followed a similar procedure used by McIntyre et al [5], whereby the dominant crop is assumed to occupy the entire area if the companion crops were sparsely populated, and the area occupied by the companion crop was calculated from the current plant population density and optimal population density. If none of the crops were dominating in the mixture, crop area was calculated based on the proportional areas occupied and their ratio within the crop mixture. Nutrient yield of annuals was determined by measuring edible yield per area, and analyzing nutrient contents of their products and by converting it to household nutrient supply as the sum of all consumable crop products of the household in the respective systems. Besides the annuals, the system comprises perennial crops (e.g *Enset ventricosum*) of various age. Nutrient yield of perennial crops *in situ* was determined by estimating crop yield per plant through measuring corm height and circumference of plant of various ages as described earlier [16] supplemented by sample weighing and multiplied by the nutrient content of the product [15] and the number of plants to be harvested per year.

Alteration in crop area and crop species may affect erosion effects through a change in vegetative cover. Therefore, relative farm erosivity index (FEI) was calculated by considering the crop factor, in terms of cover effect on soil erosion (C-factor of the Universal Soil Loss Equation) [12] and by considering the crop land size allocated for each crop at present and after optimisation of the cropping system for optimum human nutrition was done as follows:

$$FEI = \frac{\sum CF * \text{Optimised crop land area}}{\sum CF * \text{Current crop land area}}$$

Whereby:

FEI = Cumulative Farm Erosivity Index  
 CF = Crop factor of respective crop species

## THE MODEL

An optimization model was developed using the Solver in Microsoft Excel and employed to analyze the scenario of human nutrition and cropland allocation. After assembling the land size allocated per crop, yield data, % edible yield, moisture content and the nutrient composition of each crop, a nutrient budget of the year, the household and consumption unit was calculated. Recommended daily nutritional allowance as per world health organization [17] was used to establish nutrient balances.

The objective function used in the model was energy availability per consumption unit and day.

$$\frac{\sum_{i=j}^N LS_j * EY_j * DM_j * NC_j}{CU * 365}$$

Whereby:

LS = land allocated for crop *i*

EY = Edible yield of crop *i*

DM = Dry matter yield of crop *i*

NC = Nutrient content of crop *i*

CU = Consumption unit in the house hold (unit of people eating in the house)

Farm land size and daily nutritional requirements for protein, zinc, calcium, iron, thiamine, Vit A and Vit C were used as constraints in the model (see specification). The constraints differ between the locations since the farming systems were different. The constraints were set in such a way that it ensures that the households still will continue to cultivate at least partly their current stable crops. The staple crops for Areka are enset, sweet potato and maize whereas the staple crops for Ginchi are barley, faba beans and kale.

#### Constraints for Areka communities:

Total farm land  $\leq 1659 \text{ m}^2/\text{CU}$

Land size of Enset  $\geq 100 \text{ m}^2/\text{Cu}$

Land size of sweet potato  $\geq 100 \text{ m}^2/\text{CU}$

Land size of maize  $\geq 100 \text{ m}^2/\text{CU}$

Protein  $\geq 35 \text{ g/day/cu}$

Vit C  $\geq 25 \text{ mg/day/cu}$

Zinc  $\geq 15 \text{ mg/day/cu}$

#### Constraints for Ginchi communities:

Total farm land  $\leq 4081 \text{ m}^2/\text{CU}$

Land size of barley  $\geq 1000 \text{ m}^2/\text{Cu}$

Land size of fababean  $\geq 80 \text{ m}^2/\text{CU}$

Land size of kale  $\geq 50 \text{ m}^2/\text{CU}$

Protein  $\geq 35 \text{ g/day/cu}$

Calcium  $\geq 500 \text{ mg/day/cu}$

Vit A  $\geq 25 \text{ }\mu\text{g/day/cu}$

Zinc  $\geq 15 \text{ mg/day/cu}$

The decision variables in the model are land allocation to different crops and the model optimises energy availability per consumption unit and day subjected to the constraints given above.

## Results

Although the average family size is equal, land size per consumption unit is much higher in the cereal-based system (Ginchi) than in root-crop based system (Areka) (Table 2), the difference in land size would be even higher if the fallow land in Ginchi is considered as an arena of expansion. Both systems are considered as food deficit, especially in drought years, although the Ginchi farmers have better coping capacity through selling small ruminants. On the other hand, the areka system has very few animals in the system.

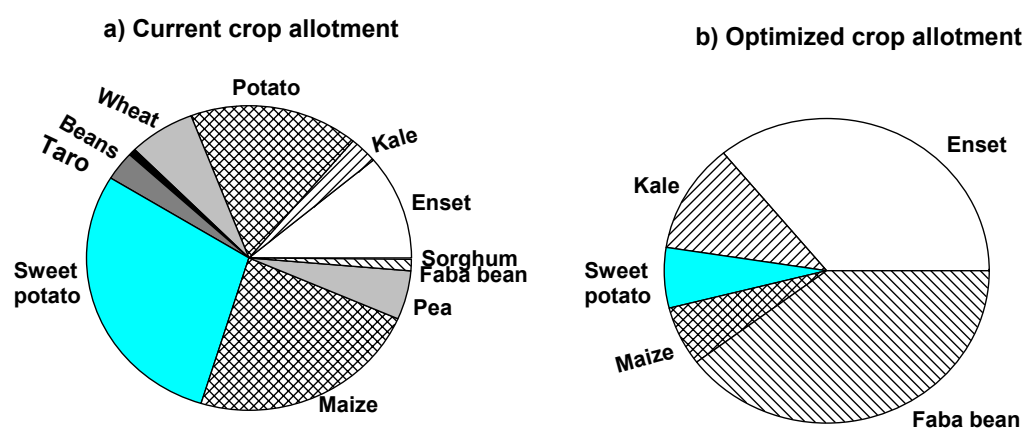
**Table 2.** Characteristics of an average household in Enset/root crop-based (Areka) and cereal-based (Ginchi) systems in Ethiopia

Parameter	Areka	Ginchi
Household size Male	3.2	3.1
Female	3.1	3.3
Total	6.3	6.4
Consumption unit, mean	4.59	4.65
Actual crop land (m <sup>2</sup> )/HH	3749.7 (511)	17499.7 (1149)
Used crop land (m <sup>2</sup> )/HH	5218.7 (679)	10402 (709)
Actual crop land/CU	817	3764
Used crop land/CU	1137	2237
Land for cash crop (%)	6	0

## ENSET / ROOT CROP-BASED SYSTEMS

The population density in Areka is relatively high (>400 people/m<sup>2</sup>), and the land holding is relatively small, which is about 816.8 m<sup>2</sup>/CU. More than 50% of the land is allocated for root/corm crops, namely sweet potato, Irish potato, Enset and Taro, with land area of 25.8, 16.2, 10.1 and 2.75%, respectively (Fig 1&2). Most of these crops are grown in the homestead or the mid-field. Another 45% of the land is allocated for cereals, maize being the dominant grain crop in the system. The total land allocated for legumes and vegetable crops in the system is less than 5%.

The current Enset-based system was found to be in deficit of most of the nutritional components, regardless of wealth status of the household. Except for iron, the system failed to cover the demand of macro and micronutrients (Table 3). The daily energy supply of resource-poor households was only 75% of what is recommended. Extremely high deficiency was found in zinc, calcium, Vit A and Vit C, which is only 26.5, 34, 1.78 and 12 % of the required, respectively (Table 3). The scenario was not different even for relatively resource-rich farmers except for energy.



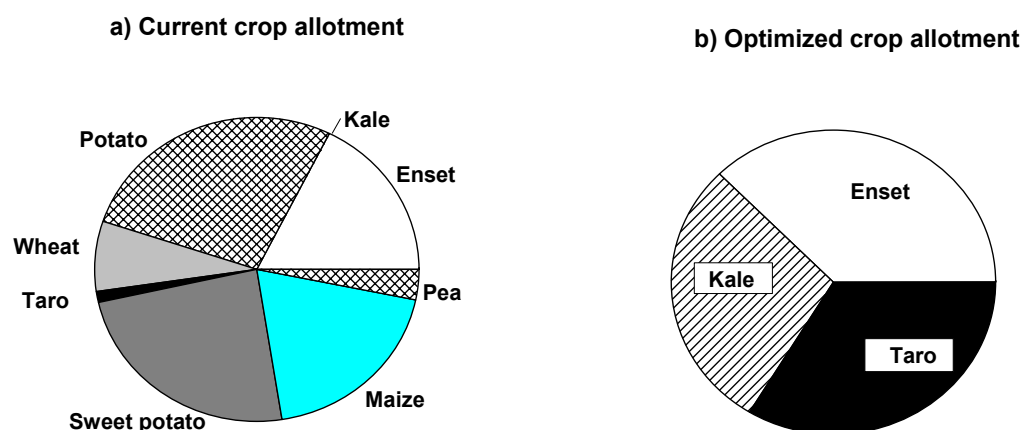
**Figure 1.** land allocation by resource-rich farmers in the Enset/root crop based systems to various food crops, currently (a) and after optimisation for an improved human nutrition (b).

**Table 3.** Nutrient budget of households in an Enset/root crop based or cereal-based systems of Areka and Ginchi under current cropping systems and after the system was optimised for an improved human nutrition

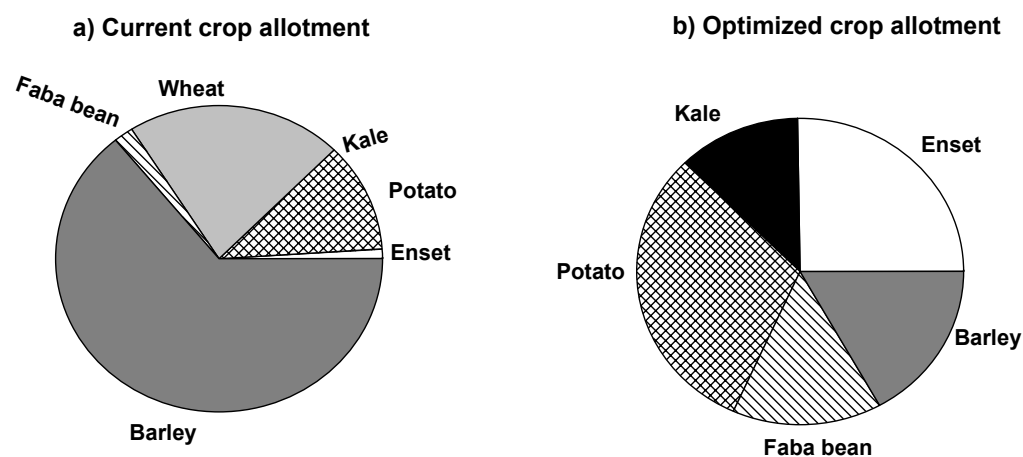
Nutrients	RDA	Areka				Ginchi			
		Resource-Poor		Resource-Rich		Resource-Poor		Resource-Rich	
		Current	Optimised	Current	Optimised	Current	Optimised	Current	Optimised
Energy (kcalorie)	2000.00	1293.66	2000.00	2284.18	4758.4	1397.5	3329.00	2081.50	3695.60
Protein (g)	37.53	7.82	9.31	17.39	35.98	32.39	40.00	42.40	42.75
Zinc (mg)	15.00	3.98	6.09	7.38	15.00	7.39	15.33	19.75	20.80
Iron (mg)	7.61	21.48	36.63	35.68	81.664	26.41	78.00	33.55	68.56
Calcium (mg)	528.00	178.76	362.42	310.00	758.70	163.25	694.00	194.50	547.04
Thiamine (m)	0.92	0.21	0.35	0.41	0.89	1.17	1.08	1.52	1.30
Vit A (ug)	10.00	0.18	10.00	2.54	10.00	0.25	12.51	1.45	20.80
Vit C (mg)	25.42	2.98	14.95	9.08	2.41	0.54	1.62	0.01	2.61

## CEREAL-BASED SYSTEMS

Average land holding is much bigger in the cereal-based system than in the root crop system, with an average land size of 4 ha/hh. However, farmers leave about 40% of their land for fallowing, due to decline in soil fertility and lack of grazing land for livestock keeping. Crop diversification at Ginchi is very low, with only 6 crop species. The largest proportion of land is allocated for barley (63.5%) followed by wheat and potato (Fig 3). Similar to the Areka, the amount of land allocated for legumes and vegetables is relatively small. Hence it is predominantly a barley-fallow-barley system.



**Figure 2.** Land allocation by resource-poor farmers in the Enset/root crop based systems to various food crops, currently (a) and after optimisation for an improved human nutrition (b).



**Figure 3** Land allocation in the cereal-based systems to various food crops, currently (a) and after optimisation for an improved human nutrition (b).

In average, the current production system was also not in a position to satisfy human nutrition in almost all nutrients. However, the resource rich farmers were in a position to cover their energy, protein, zinc, and thiamine demand, while their system is in deficit of calcium, Vit A and Vit C (Table 3). The critical deficit of the system was in calcium, Vit A, and Vit C, which was as low as 30, 2.5 and 2% of the recommended daily allowance (Table 3). However, the system was able to deliver relatively higher amount of iron and thiamine.

## MODELING RESULTS

The modeling was run by considering system constraints into account, including the food habit of the households, the adaptability of the crop, and pests and diseases. In Areka, Enset and sweet potato are major components of the household nutrition, while in Ginchi, barley is currently the major crop used to cook the local staple. Thus, we ran a simulation model that forced the inclusion of barley in Ginchi and enset and sweet potato in Areka.

At Areka, the major constraint affecting the model was extremely low land holding of the majority of the community members, regarded as resource-poor in the analysis. When the whole system was considered in the modeling process, it was not possible to improve the system, except for energy. But when the simulation was run separately for relatively resource rich households, the energy supply became much more than the recommended, while the demand for all other nutrient was fully covered (Table 3). This finding recommends a significant shift from the cereals and root crops to enset-bean dominating system, and the shift was significantly high from about 10% to 36% and from 0.1% to 40 % for enset and common bean, respectively (Fig 1&2).

At Ginchi, there was better possibility for the model to improve the nutritional quality of the household by increasing land area, if it was not constrained by decline in soil fertility and shortage of livestock feed. The existing cropland, 2237 m<sup>2</sup>/CU is enough to furnish balanced nutrition with a moderate change of the cropping system. The suggested shift was to reduce the barley field by about 50% and expand the land area of enset, Ethiopian kale, and faba bean to 25.3, 17.7 and 15.6%, respectively (Fig 3). By doing so, all the need for the considered nutrients was fully and considerably satisfied, except for Vit C. In this case, some Vit C supplement could be needed, or a new vegetable crop should be introduced into the system.

## IMPLICATION OF CROP REALLOCATION ON SOIL EROSION

A shift from one cropping system to another may have a considerable effect on soil loss and nutrient management [10]. In the Enset-based system, a shift from the Enset-root crop mix to more Enset/beans system improved the crop factor at farm level (farm erosivity index) by 42 %, indicating that soil erosion could be significantly minimized. The same applies for the cereal-based system where by farm erosivity index was improved by 45 % (Table 4). This also has a very strong implication for soil fertility management, as the enset system is traditionally privileged to attract more organic matter into the system [6,8,18].

**Table 4.** The effect of crop reallocation on soil erosion at Areka and Ginchi. Data shows effects of current and suggested (optimised) cropping on C-factor as a component of USLE.

Crops	C-factor	Cumulative C-factors			
		Areka		Ginchi	
		<i>Current</i>	<i>Optimized</i>	<i>Current</i>	<i>Optimized</i>
Enset	0.04	6.48	24.20	0.88	24.56
Taro	0.35	16.17	np*	np	np
Kale	0.26	11.17	48.47	0.73	80.32
Sweet potato	0.23	99.45	23.00	Np	np
Potato	0.22	59.73	np	59.21	159.98
Maize	0.35	127.67	35.00	np	np
Sorghum	0.4	0.94	np	np	np
Teff	0.4	58.84	np	np	np
Wheat	0.42	43.39	np	228.89	np
Barley	0.42	Np	np	648.48	167.96
Faba beans	0.24	4.16	np	11.61	91.00
Common beans	0.19	2.132	126.83	np	np
Pea	0.15	11.21	np	np	np
Erosivity Index (%)		100	58.3	100	55.1

\* np = not planted.



## Discussion

### INTEGRATING HUMAN NUTRITION WITH SUSTAINABLE LAND MANAGEMENT

An attempt to address food security cannot be complete without a thorough consideration of the relationship between land degradation and nutritional availability. Initiatives and policies towards food security should integrate strategies to turn the negative chain reactions between productivity and land use into positive balances.

Crop reallocation, considering human nutrition as sole criteria, could affect land management at least in two different ways. Firstly, the system may demand an intensified soil fertility management because of the expansion of perennials. Traditionally, farmers divide their farm into three major categories, namely homestead, mid field and outfield based on the fertility status, type of soil fertility management and type of crops grown. In the homestead, where enset is traditionally grown, about 80% of the whole organic fertilizer is applied [6,8]. Hence, it is the most fertile corner of the farm because of addition of manure, crop residues and household wastes [6,8]. Farmers even export crop residues from the outfield to the enset field as the local wisdom considers it as a mulch-loving crop. The expansion of enset at the expense of cereals may, therefore, improve the nutrient budget of the system by encouraging farmers to intensify soil fertility management options, such as composting, better manure management and fair distribution of resources across soil fertility gradients. It may have a strong effect on labor and availability of organic resources to fertilize the expanding enset fields. In this case farmers would be encouraged to practice better organic resource production and management. Secondly, a shift from cereal dominating system to an enset-dominating system may minimize erosion effects through improved vegetative cover, by reducing the erosivity power by about 45%.

### IMPLICATIONS FOR HUMAN NUTRITION

Malnutrition is a common phenomenon in the farming communities of Ethiopian highlands [2,3]. This work suggested that one affordable remedy could be reallocation of cropland in favor of perennial crops with high content of the nutrient in deficit, by considering the food habit of the community, adaptability of the crop to the respective environment and its potential effect on agro-ecosystem health.

The conventional wisdom was that enset/root-crop based systems may have sufficient amount of carbohydrate and vitamins suffice to cover the RDA of the household, but may be in deficit of protein and micronutrients. The results, however, showed that the system was deficit in most of the required micronutrients nutrients, especially malnourished in VitA, Vit C, Zinc and Calcium (Table 3). Even the available energy and protein for the resource-poor families was only 75% of the recommended amount. This was confirmed by the fact that the system heavily relied on food aid at least for three months in a year for the last decade. It was partly the consequence of small land size, 817 m<sup>2</sup>/CU cropland, and very low crop yield caused by low soil fertility status, use of low yielding varieties and occasional drought. Malnutrition was severe in the resource poor households (Table 3) as resource-poor farmers concentrate on annual crops while the resource-rich farmers allocate large plot for enset [6,8] in agreement with our findings. It would be important for resource-poor farmers to allocate about 38% of their land, an increase by 20% to the current system, and increase crop yield by about 20% to cover the nutritional demand of the household (Fig 2). As it stands now unless external supplement is considered, the resource-poor household would remain in deficit of the most of the micronutrients even after optimization and crop allocation is practiced (Table 3).

The constraints of the cereal-based systems were similar to the Enset-root crop systems except for the severe deficiency of vitamins. Malnutrition in Ginchi could be even severe than presented for the resource-poor families as the crop yield is much lower in Ginchi than in Areka because of low temperature in the mountains. And yet, there is more opportunity to expand cropland and increase productivity by intensifying the existing fallow-barley system through integration of soil fertility management options and high yielding forages. Malnutrition was aggravated by limited diversification of crops, and even reallocation of the existing crops was not enough to fulfill the demand for Vit C. Introduction of frost resistant vegetable crops to be grown under the story of the would-be expanded enset field may satisfy the vitamin demand (Fig 3). To date, the household used to buy green papers and fruits (high Vit C crops) from the nearby market in the valley bottoms occasionally.

Earlier reports also showed that the lowest Vit A deficiency rates in Ethiopia were documented in predominantly Enset systems [3].

Nutrient deficiencies (e.g. protein and calcium) in the two systems could have been satisfied by livestock products. However, 93% of the interviewed households in both systems sold their produce to cover the household cash demand. Hence there was limited direct contribution to household nutrition.

The results indicated that if food security and environmental health is to be achieved in Ethiopian highlands in the short term, there is an alarming need to shift from cereal-dominated to an Enset/legume dominated system. Land area expansion of beans in Areka and faba bean in Ginchi is vital to alleviate protein malnutrition. Enset is already supporting 7-10 million people as a staple, or co-staple with cereals and root crops [8,18], and increasing its land area is expected to be an acceptable proposal. The shift would have a positive implication on food security not only because of its high-energy yield, but also because of its land protective functions, its availability for food at any time of the year and its drought resistance potential.

This approach differs from biofortification in that it does not demand to introduce nutrient-loving crops/varieties with possibly higher nutrient concentration that could be expressed by new colour, new taste, and/or cooking quality. Biofortified varieties could also be aggressive nutrient users because of their specific demand for micronutrients, and may lead towards unsustainable production unless the system is continuously supplemented by external inputs.

## IMPLICATIONS FOR POLICY

The current policy of the Ethiopian Government is giving utmost attention to food security, with limited emphasis on natural resource management. On the other hand, the continual quest for food, pasture and fuel for mere survival and meet basic community needs forced the increased cultivation of marginal lands regardless of ecological soundness. The current model favours the expansion of perennial crops to address household food security and environmental degradation while the current land tenure, in situation where the government owns land, may not encourage farmers to expand their perennial crops from their homesteads to the middle and outfields, and to practice sustainable land use systems.

Integration of the suggested cropping system may need a strong policy support in many ways. Firstly, an expansion of enset field would have strong implications on labor use, mainly for women, who are commonly responsible for managing Enset fields. The most labor demanding operation is processing Enset to Kocho and Bulla, which is currently estimated to take about seven hours per plant. Hence, integration of more Enset into the system should be accompanied by integration of processing implements at affordable prices so as to minimize pressure on household labor. Secondly, the expansion of perennials calls for an urgent policy decision on land tenure and guarantee. Thirdly, initial policy support, in terms of credit, would be needed as expansion of enset may demand more organic and mineral fertilizer inputs to into the system to establish and grow in the less fertile outfields. However, farmers' choice of livelihood strategies substantially influences cropping choice decisions and welfare and resource outcomes. Hence, any policy suggestion for change in cropland allocation should be done through bottom-up negotiations at individual farmer, community and district levels. Increasing awareness of the communities on nutritional disorders of the current system and its implication on health, and the would-be benefits of modifying the current production system may lead to an early adoption.

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