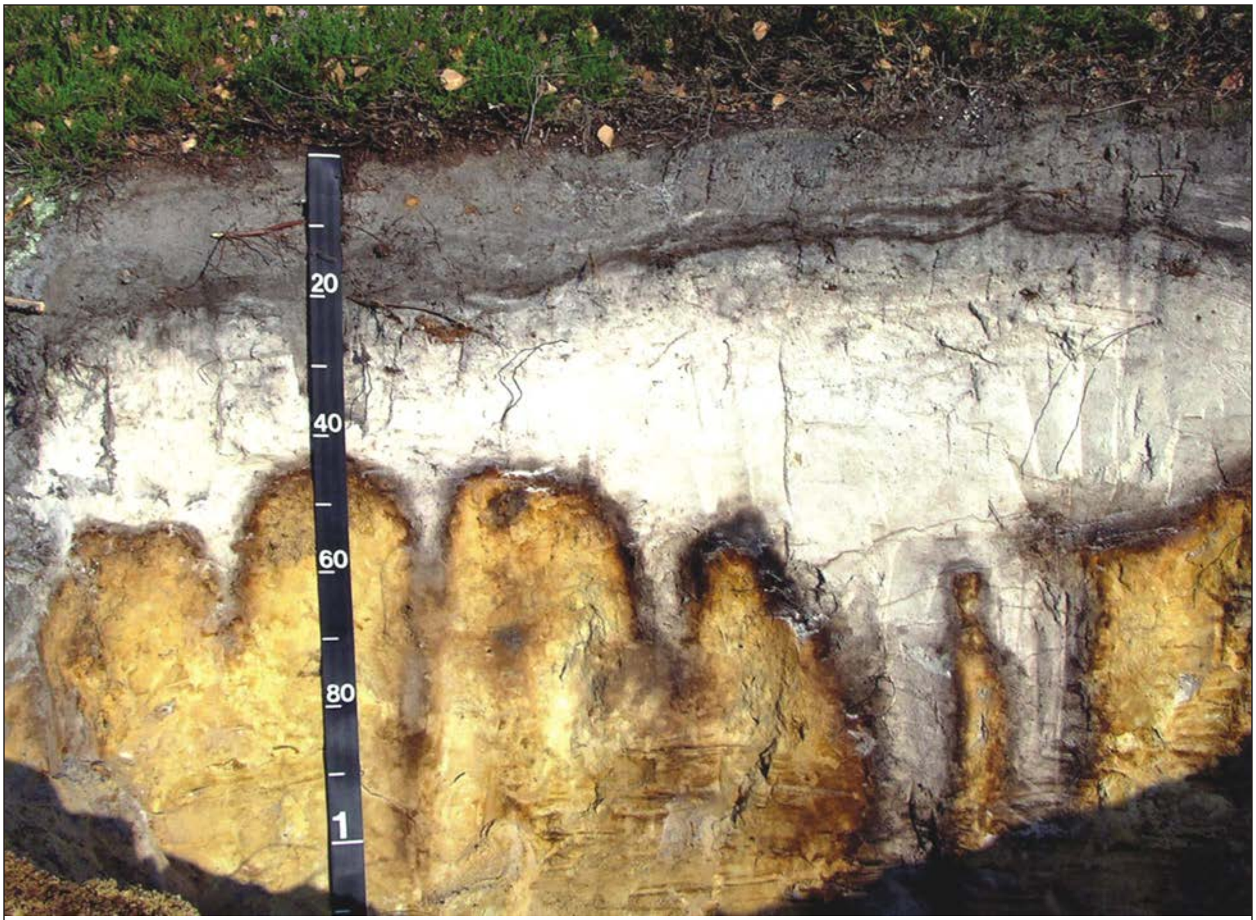

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Comparative Analysis of Soil Nutrient Balance at Farm Level: A Case Study in Jimma Zone, Ethiopia

[1]Abebayehu Aticho, [2]Eyasu Elias and [3]Jan Diels
[1]Department of Natural Resources Management, College of Agriculture and Veterinary Medicine, Jimma University, P.O. Box 307, Jimma, Ethiopia
[2]Gofa Universal College, Addis Ababa, Ethiopia
[3]Department of Earth and Environmental Sciences, Division Soil and Water Management, Ghent University, Belgium

Corresponding Author: Abebayehu Aticho, Department of Natural Resources Management, College of Agriculture and Veterinary Medicine, Jimma University, P.O. Box 307, Jimma, Ethiopia Tel: +251 913 161 824

ABSTRACT
Soil nutrient depletion is becoming one of the major challenges of agricultural production for the stallholder farmers in Ethiopia. This study was conducted with the aim of determining N, P and K (kg ha^{-1} $year^{-1}$) balance at farm level and to assess the role of farmers' wealth diversity in maintaining and improving soil nutrients. The balance of nutrient was determined by monitoring N, P and K flow in to the soil with mineral fertilizer (IN1), manure (IN2), biological nitrogen fixation (IN3) and wet deposition (IN4) and out of the soil through crop product (OUT1), crop residue (OUT2), leaching (OUT3), gaseous loss (OUT4) and water erosion (OUT5). Statistically, highly significant ($p = 0.001$) difference was observed between locations, resource rich and poor groups farmers for soil chemical properties and nutrient depletion rates. But, none significant ($p<0.05$) difference was observed between resource rich and medium groups farmers. On the other hand, strongly positive correlation was observed between locations and rate of N ($r = 0.91$) and K ($r = 0.88$). The amount of rainfall, use of fertilizers, land management practices and landscape determine the rate of nutrient depletion. Therefore, to ensure smallholder food security and sustainable agricultural practices landscape based integrated soil fertility management practices should be adopt across wealth groups.

Key words: High and low altitudes, nutrient depletion, nutrient flow, sustainable agriculture, wealth groups

INTRODUCTION
The problem of declining soil fertility is becoming one of the major challenges for sustainable agriculture production in sub Sahara African countries (Stoorvogel and Smaling, 1998). Agricultural productivity per unit area of land is declining through time and food production could not keep pace with population growth (Roy *et al.*, 2003). In order to feed the growing population, agricultural production has to grow at least by 3-4% per annum (Greenland and Nabhan, 2001). This can be achieved either by bringing more land under cultivation (i.e., area expansion) or by increasing productivity per unit area of land (i.e., intensification). The first option has been less feasible due to land shortage. The remaining feasible option to increase productivity per unit area through improved soil fertility management accompanied with the use of improved crop varieties

and better agronomic practices (Sanchez *et al.*, 1997). However, in many place, farmers continue mining soil nutrients without adequate replenishment and soil and water conservation (Ryan and Spencer, 2001).

Ethiopia is one of the countries that are affected by soil nutrient depletion (Elias *et al.*, 1998; Haileslassie *et al.*, 2005). As a result, productivity per hectare has been declining over the past several decades (Elias, 2002). It is less likely that increasing food production without employing integrated soil fertility management practices allied with adoption of improved crop verities (Sanchez *et al.*, 1997; Ayodele and Olusegun, 2008; Ayeni, 2011).

In Jimma Zone, decreasing agricultural productivity per unit area due to soil fertility depletion is becoming a challenge for smallholder farmers. Therefore, this investigation was conducted to determine the effects of current soil fertility management practice on soil nutrients status through nutrient balance analysis via nutrient in and out flow monitoring and to examine the role of farmers' resource endowment in maintaining and improving soil nutrients balance.

MATERIALS AND METHODS

Description of the study area: The study was conducted in two locations (high altitude and low altitude) of Gligel Gibe catchment, Jimma zone, Southwestern Ethiopia. The catchment covers an area of 4225 km², lied between 7°22' 72" to 7° 34' 84" N and 37° 21' 05" to 37° 28' 80" E and has an altitude range of 1609-3018 m above sea level (m.a.s.l) (Aticho, 2011). The dominant soil groups of the region were Nitisols, Ferralsol and Planosol (FAO, 1994). Rainfall of the area is bimodal type. The heavy rainy season (main crop growing) is begin in the mid June and ceased in mid September. The moderate rain (harvesting and planting short cycle crop) is from February to May (USDA, 2003). The mean annual rainfall of high and low altitude is 1592 and 1275 mm, respectively (Aticho, 2011). Hypothetically, an altitude more than 2000 m.a.s.l is taken as high and less than 2000 m.a.s.l low altitude because the land escapes, cropping systems, amount of rainfall, temperature, land and soil fertility management practices are quite different between these altitudes.

Integration of livestock with crops is the common farming system. However, type of crops integrated with livestock is varied with an altitude range. Integrating livestock with Ensete (*Ensete ventricosum*), Wheat (*Triticum* spp.), Oat (*Avena sativa*), Tef (*Eragrostis tef*) and Barley (*Hordeum vulgare*) is common in the high altitude. Whereas in the low altitudes livestock is integrated with Tef (*Eragrostis tef*), maize (*Zea mays*) and sorghum bicolour (Aticho, 2011).

Data collection: Participatory Rural Appraisal (PRA) exercise was conducted in six villages of the catchment. This activity is used as tool to; select representative study villages, identify major cropping systems, capture local wealth ranking criteria, identify crop production problems (FAO, 1996). Then, the number of villages were minimized in to two based on altitude, cropping system, amount of rainfall, temperature, soil fertility management, vegetation and landscape similarity. Gesheluchine and Kejelo villages were selected to represent the high and low altitude areas, respectively.

Number of livestock and landholding size are the major criteria to classify farmers in to different wealth classes. Accordingly, three (rich, medium and poor) resource group farmers are identified.

Eighteen case study farms were randomly selected (three farms from each wealth classes of both locations i.e., 3×3×2 = 18) and nutrient flow monitoring activity was done for a year. NUTMON (nutrient monitoring) model was used to analyze the N, P and K (kg ha^{-1} $year^{-1}$) balance. It was obtained by subtracting the quantity of N, P and K removed from soil through crop products

(OUT1), crop residues (OUT2), leaching (OUT3), gaseous lose (OUT4) and erosion (OUT5) from the total amount of N, P and K added to the soil with mineral fertilizer (IN1), manures (IN2), biological nitrogen fixation (IN3), wet deposition (IN4) subtracted from the (Stoorvogel and Smaling, 1998).

Nutrient inflow analysis: As reported by the participants of PRA program and survey, currently mineral fertilizer (IN1) application is not practiced in Gesheluchine village because of urea and DAP addition to Wheat (*Triticum* spp.) crop in the last decade caused logging of the crop. Consequently, commercial fertilizer extension was failed and the soil is considered as inherently fertile. Nutrient applied with IN1 was considered to be zero. However, in the Kejelo village urea and DAP fertilizers are used for maize cultivation. The amount of N and P supplied calculated by multiplying the amount of urea and DAP applied with their N and P content.

In both sites fresh manure (IN2) is transported to farm regularly by locally made materials. The amount applied was determined by physically weighing the fresh weight per local material of each wealth groups and then daily record the numbers to four months (November, February, May and August). N, P and K content was determined in laboratory by following standard procedures (AOAC, 1990). The quantity of N, P and K added to farm was obtained by multiplying dry weight of manure with its nutrient content.

N, P and K added to the soil with wet deposition (IN3) were estimated with reassign equation developed by Stoorvogel and Smaling (1998) which is a function of mean annual rainfall (mm year^{-1}). The mean annual rainfall (p) was obtained from eighteen year rainfall data of the nearby meteorological stations.

$$\text{IN3 N} = 0.14p^{1/2}$$

$$\text{IN3 P} = 0.023p^{1/2}$$

$$\text{IN3 K} = 0.092p^{1/2}$$

Studies conducted in different parts of Ethiopia shows that 60% of legume plant N requirement is meet by symbiotic nitrogen fixation (Elias *et al.*, 1998; Haileslassiea *et al.*, 2005). So, in this study the amount of N fixed symbiotically (IN4b) was assumed to be 60%. Similar with IN3, N input from non-symbiotic fixation and N fixing trees that are left on the field was estimated through transfer function (Stoorvogel and Smaling, 1998).

$$\text{IN4b} = 0.5 + 0.1p^{1/2}$$

Nutrient outflow analysis: Crop biomass removal is one of the causes for nutrient flow out of crop land. The amount of crop (grain, tuber and root) products (OUT1) and residues (OUT2) exported from farm section was determined by randomly demarcating ten sample plots per hectare (each plot had 16 m^2 area). At crop maturity, crops in the sample plots were harvested, sun dried, trashed and weighed with hand held balance and composite samples were taken for laboratory analysis.

The amount of N, P and K exported by OUT1 and OUT2 were calculated by multiplying the total amount of crop product and residue exported from farm with their respective N, P and K content (Stoorvogel and Smaling, 1990).

Substantial amounts of N and K are lost with leaching effect but, P is not because, it is highly bind with soil particle (Roy *et al.*, 2003; Ahmed *et al.*, 2006). It is difficult to measure N and K lost (kg ha^{-1} $year^{-1}$) by leaching in field transfer function developed by Stoorvogel and Smaling (1990) was used to estimate lose. Accordingly:

$$OUT3N = 2.3+(0.0021+0.0007 * F) * p+0.3 * IN1+IN2)-0.1 * TNU$$

$$OUT3K = [0.6+(0.0011+0.002\times F) * p+0.5 * (IN1+IN2)-0.1 * TKU]/1.2$$

where, p: mean annual rainfall, F: soil fertility class (1= low; 2 = moderate; 3 = high), IN1+IN2: mineral fertilizer and manure applied (kg ha^{-1} $year^{-1}$) and TNU, TKU: total N and K uptake (kg ha^{-1} $year^{-1}$), respectively.

Nitrogen lost from agricultural soils in the form of dentrification and volatilization is considered as gaseous loss (Stoorvogel and Smaling, 1990). Similar with leaching, direct measurement of N loss in gaseous form is difficult (Stoorvogel and Smaling, 1990) thus it was estimated by regression equation (FAO, 2001).

$$OUT4 = (0.025 + 0.000855 * p + 0.01725 * IN1+IN2+ 0.117) + 0.113 * IN1+IN2$$

where, p= mean annual rainfall; IN1 + IN2: mineral fertilizer and manure applied (kg ha^{-1} $year^{-1}$), respectively.

Soil lost with water erosion (OUT5) was estimated by Revised Universal Soil Loss Equation (RUSLE) for Ethiopia (Hurni, 1985). The quantity of N, P and K lost with erosion was quantified, the amount of soil lost with erosion multiplied with N, P and K enrichment factor (Roy *et al.*, 2003).

Laboratory analysis: Soil samples were air-dried, sieved by 2mm sieve and analyzed by following standard laboratory procedures. pH was determined in 1:2.5 (soil: water suspension) by using glass electrode at 25°C (at room temperature), organic carbon by wet oxidation method (Walkley and Black, 1934) and available P was extracted by Bray method (Bray and Kurtz, 1945) and P in the extract was determined colorimetrically by spectrophotometer. Total N was determined by Kjeldahl method (Houba *et al.*, 1989). Available K was extracted by Morgan's solution and K in the extract measured by flame photometer. Cation Exchange Capacity (CEC) was determined at pH 7 using ammonium acetate as exchanger.

Plant samples were washed with 0.25% detergent solution followed rinsing in distilled water to remove dusts and other contaminants. Then, the samples were dried in oven at 105°C for 24 h, grounded, sieved by 2 mm sieve and again dry at 65°C to obtain a constant weight upon which to base the analysis. Finally, N, P and K compositions of the samples were analyzed in laboratory by wet oxidation.

Plant samples for nitrogen determination were digested in sulphuric acid at a temperature 400°C and determined by Kjeldahl method. K in acid digest was determined colorimetrically by flame photometer and P by spectrophotometer.

Statistical analysis: Laboratory results of soil samples were analyzed by Statistical Analysis Software (SAS version 12) and their means were separated by Least Significant Difference (LSD 0.05 test). Nutrient balance was calculated by employing Nutmon model and means of the depletion rate between wealth groups and nutrients were compared by Duncan multiple test (p = 0.05). Also, 2-tailed t-test correlation analysis was used to determine the relationship between rate of nutrient depletion and locations.

RESULTS AND DISCUSSION

Selected soil chemical properties: Mean comparisons for the selected soil chemical properties attested high value was observed in the high altitude (Table 1). According to Elias *et al*. (1998) vegetation coverage, conservation measure, farming system and soil nutrient management practices determines soil chemical properties.

Farms belong to rich and medium resource classes had similar chemical properties except for CEC and OC. The higher concentration was observed at resource higher classes than the poor. Soil total N and organic carbon has direct relationship, the higher concentration of organic carbon was observed due to organic matter addition to the soil. This is agreed with the findings of Fallahzade and Hajabbasi (2011).

Nutrient balance at farm level: The mean values for nutrient balance at farm scale were negative among wealth groups in both locations (Table 2). This implies that, the subsistence farming systems of smallholder farmers in the area is depleting soil nutrient stock. Due to high P fixation within the study area, P depletion was lower than N and K in both locations for all wealth groups. This, result is agreed with Surendran and Murugappan (2007). According to Stoorvogel *et al*. (1993) soil nutrient depletion rating in sub Sahara African countries; the depletion rate in the high altitude was very high for N, P and K but, high N and very high P and K in the low altitude. None significant difference ($p<0.05$) was observed between wealth classes owing to inadequate nutrient addition via commercial and organic fertilizer at farm scale. Small quantity

Table 1: Mean comparison soil chemical properties between location and wealth groups

	Locations		Wealth groups		
Chemical properties	High altitude	Low altitude	Rich (= 3)	Medium (= 3)	Poor (= 3)
CEC (meq kg^{-1})	31.27^{a}	26.80^{b}	39.22^{a}	27.42^{b}	20.47^{c}
OC (%)	4.32^{a}	3.28^{b}	4.41^{a}	4.37^{a}	2.62^{b}
N (%)	0.22^{a}	0.17^{b}	0.24^{a}	0.22^{a}	0.14^{b}
Ava P (mg kg^{-1})	6.96^{a}	5.48^{b}	7.77^{a}	6.73^{b}	4.15^{c}
Ava K (mg kg^{-1})	2.09^{a}	1.69^{b}	2.16^{a}	2.11^{a}	1.40^{b}
pH (1:2.5)	5.07^{a}	4.13^{b}	5.52^{a}	4.92^{a}	3.35^{b}

Same latter refers not any difference between the means (p = 0.05)

Table 2: Mean comparison of nutrient depletion rate between wealth groups

		Wealth groups			
Location	Nutrients	Rich (n = 3)	Medium (n = 3)	Poor (n = 3)	p-value
High altitude	N	-58.63^{a}	-54.33^{a}	-53.87^{a}	NS
	P	-10.71^{a}	-10.00^{a}	-8.39^{a}	NS
	K	-48.32^{a}	-48.03^{a}	-53.14^{a}	NS
Low altitude	N	-37.65^{a}	-35.53^{a}	-34.01^{a}	NS
	P	-10.58^{a}	-9.31^{a}	-7.36^{a}	NS
	K	-32.94^{a}	-32.83^{a}	-23.30^{a}	NS

NS: Non significant difference ($p<0.05$), same latter superscript refers not any difference between the means at p = 0.05

Table 3: Mean comparison of nutrient depletion rate within nutrients

Locations	Nutrients	N	P	K	p-value
High altitude	N	-60.61[a]	-56.13[b]	-51.60[c]	***
	P	-14.70[a]	-8.14[b]	-6.26[c]	***
	K	-45.47[b]	-49.20[b]	-54.82[a]	***
Low altitude	N	-41.81[a]	-34.66[b]	-30.72[c]	***
	P	-15.16[a]	-8.01[b]	-4.07[c]	***
	K	-36.60[a]	-29.69[ab]	-22.78[b]	***

*** Highly significant (p = 0.01), same latter superscript refers to none significant (p<0.05) difference between means

Table 4: Correlation of N, P and K (kg ha^{-1} $year^{-1}$) depletion rate with locations

Nutrients depletion	MSE	r	p-value
N	2.54	0.91	***
P	1.04	0.07	NS
K	2.67	0.88	***

NS: Not significant difference (p<0.05), *** highly significant (p = 0.001)

of nutrient added to a portion of large farm by resource rich or medium group had no longer significant contribution to maintain or improve soil nutrient stock at farm scale. In the Jimma Zone soil nutrient depletion caused reduction of agricultural productivity, household food insecurity, unemployment, decreasing household income and overdependence on chat (*Catha edulis*) (mild stimulants) chewing. Recognizing that, Agricultural and Rural Development Bureau of the region attempted different activities (soil and water conservation practices, chemical fertilizers (DAP and urea) use, compost preparation and sustainable land management extension services) to set up the possible solutions.

The measures taken by the government to address the problem were not successfully bring real solutions to the expected level because of the following constraints; farmers inability to afford for chemical fertilizer (due to high price), limited availability of organic fertilizer and its inefficient utilization, absence of experiment based area (soil chemical property, climate, etc..,) and crop specific fertilizer recommendation and farmers' late technology adoption.

Rate of depletion within N, P and K nutrients, there was highly significant (p = 0.001) difference was observed in both locations (Table 3). The mean comparison revealed that; the depletion rate of N weighed against P and K, it was higher than P and K. But, K compared with N and P, none significant difference was observed within N and P. This variation was happened due to, the amounts of N, P and K withdraw from soil by harvest was varied, the quantity of N, P and K added to soil (through fertilizer, wet deposition, biological fixation and other inputs) differ and their susceptibility to remove through leached and erosion.

High degree of correlation was observed for location and N and K depletion but, negligible for P (Table 4). This implies, the quantity of nutrient depletion is positively related with locations.

CONCLUSION AND RECOMMENDATION

This study found that, N, P and K added to crop lands were much more less than nutrients removed out of the system. Poor integrated soil nutrient management practices, ineffective use of locally available nutrient resources, inadequate soil conservation practices and high cost of commercial fertilizers became the cause for unsustainable agricultural production and food insecurity in the study area. To tackle soil nutrient depletion and boost agricultural productivity, adequate nutrient replenishment practices through nutrient addition via chemical and organic fertilizer, nutrient retention or harvesting by soil and water conservation were obligatory. Beside, the existing blanket fertilizer application exercise should be replaced with field experiment based rate for each crop. To achieve this, the government should subsidize the farmers for fertilizers and allocate adequate facility for area and crop specific fertilizers recommendation researches.

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