



## Review article

# Cause and cost of onsite nutrient loss replacement in the highlands of Ethiopia and implication of Soil and Water Conservation measures

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## Abstract

Soil erosion and nutrient depletion has been a major national agenda and remains an important issue in the highlands of Ethiopia. In this review it was found that onsite nutrients are lost in agricultural land in the form of soil erosion, crop residue removal, harvested products, gaseous and leaching losses. Most of the essential plant nutrients are found on the top surface soil and hence the top layer of the soil is subjected to soil erosion and most onsite nutrients have been lost. Similarly, crop residue removal is a common activity in the highland of Ethiopia and causes a continuing onsite nutrient loss problem. Hence, soil nutrient depletion is becoming a major challenge for agricultural production. Moreover, nutrient loss from agricultural land became an economic loss to the farmers by both reducing crop yield and increasing the replacement cost of nutrient loss. Practicing proper soil and water conservation measures had a positive impact on the reduction of onsite nutrient losses and consequently increased crop productivity. However, limited studies have been reported on the impact of soil and water conservation practices on nutrient loss in Ethiopia. As a result, further studies need to conduct on the implication of soil and water conservation measures on a nutrient loss management.

## Abbreviations

SWC : Soil and Water Conservation; LUT: Land Utilization Type; SOC: Soil Organic Carbon; OM: Organic Matter; AP: Available Phosphorus; NGO: Non-Governmental Organization; NPK: Nitrogen, Phosphorus and Potassium respectively; NPS: Nitrogen, Phosphorus and Sulfur respectively; PSWC: Physical Soil and Water Conservation Measures

## Introduction

Soil erosion is among the most challenging and continuous environmental problems in highland parts of Ethiopia [1-3]. Particularly, the Blue Nile basin of the country loses fertile soils with a rate of 131 million ton per year [4]. Soil erosion and nutrient depletion have been a major national agenda and remain an important issue in Ethiopia [1,5]. Ethiopia is reported to have the highest rates of soil nutrient depletion through soil erosion in sub-Saharan Africa [6]. At the national

level, full nutrient balance results indicate a depletion rate of 122 kg N ha<sup>-1</sup> yr<sup>-1</sup>, 13 kg P ha<sup>-1</sup> yr<sup>-1</sup> and 82 kg K ha<sup>-1</sup> yr<sup>-1</sup> [7]. Depletion rates were highest in the relative intensive farming systems in mountainous areas located in the central and southern parts of Ethiopia [8]. Soil erosion induced by water had an impact on national food supply [9], deteriorate soil fertility and reduce agricultural productivity [10,11], environmental sustainability [12], downstream flooding and reservoir sedimentation [13,14] and loss of valuable plant nutrients [7,15,16]. As a result, nutrient loss from agricultural land causes an economic loss to the farmers by both reducing crop yield and increasing the replacement cost of nutrient loss [17,18]. Moreover, low intrinsic soil fertility, negative nutrient balance, limited replenishment of removed nutrients, and high erosion rates cause soil fertility decline and become a major threat to current and future food production [19,20].

Various studies at watershed scale in northwestern highlands of Ethiopia have been reported that, the rate of soil

loss from sheet and rill erosion ranged from 50.31 to 237 t ha<sup>-1</sup> y<sup>-1</sup> [21-23] and as high as 127 to 540 t ha<sup>-1</sup> y<sup>-1</sup> for gully erosion [24-26]. This implies that soil erosion status in Ethiopian highlands exceeded the soil loss tolerable limit of Ethiopia 18 t ha<sup>-1</sup> y<sup>-1</sup> [27]. On the other hand, surface runoff leads to onsite nutrient removal and eventual deposition in depressions, or further downstream in valleys, lakes and reservoirs [1,13,15]. In addition, nutrients are temporally lost in agricultural land via crop residue removal, harvested product and leaching, and gaseous [8,28,29]. Particularly, soil erosion is a key determinant of the negative nutrient balances emphasizing the need for improved soil and water conservation measures at farm level and at catchment level [8]. In response to soil degradation challenges, government, NGO and development partners have invested substantial resources in promoting soil and water conservation practices since the mid-1970s and 80s as part of efforts to improve environmental conditions and ensure sustainable agricultural production [30-32]. Combating land degradation and investing in the soil and water conservation for future generations is a major development task promoting sustainable land management [10,33]. For instance, Addis, et al. [34] reported that soil and water conservation measures in Gumara-Maksegnit watershed reduced nutrient depletion and greatly improved crop yield with a net present value of \$477.68 ha<sup>-1</sup>. Thus integrated soil and water conservation measures at the watershed scale have the potential to reduce sediment-associated nutrient loss in the highlands of Ethiopia. Thereby the aim of this review is to document the major cause of nutrient loss, cost of nutrient loss replacement and implication of soil and water conservation on nutrient loss reduction in Ethiopian highlands based on various literature reviews of published articles and other scholarly materials conducted in Ethiopia.

#### Thereby the aim of this review focused:

- The major cause of onsite nutrient loss in the highlands of Ethiopia
- Cost of nutrient loss replacement in highlands of Ethiopia
- Implication of soil and water conservation measures on soil erosion nutrient loss reduction in highlands of Ethiopia

#### Description of the Ethiopian highlands

The highlands are extremely heterogeneous, with steep escarpments (Figure 1). The highland parts of Ethiopian which cover the major portion of the country (40% of the total area of the country), characterized by high human and livestock population pressure, high land fragmentation, rapid expansion of agricultural land, extensive cultivation eventually resulted in high land degradation [36]. The highlands are known as “the roof of Africa” (in Africa the majority of land over 3000m is found in Ethiopia) and reach 4533m at the summit of Ras Dashen in the scenic world heritage Simien Mountains [37]. Most of the sub-Saharan Africa’s Afroalpine ecosystem above 3200 m is found in Ethiopia [38]. Ethiopian highlands have been designated hotspots for large number of rare land plant species [39]. The Ethiopian Highlands are climatically important in trapping moist air that mainly comes from the Indian Ocean, and providing precipitation to the country. Average annual rainfall varies between 600 mm per year in Tigray (the north) and more than 2,000 mm per year in the southwestern highlands [40].

And also in northwestern highlands the mean annual rainfall is 2454 mm (85% during the wet season), and the mean daily temperature ranges from 9.4–25 °C [14].

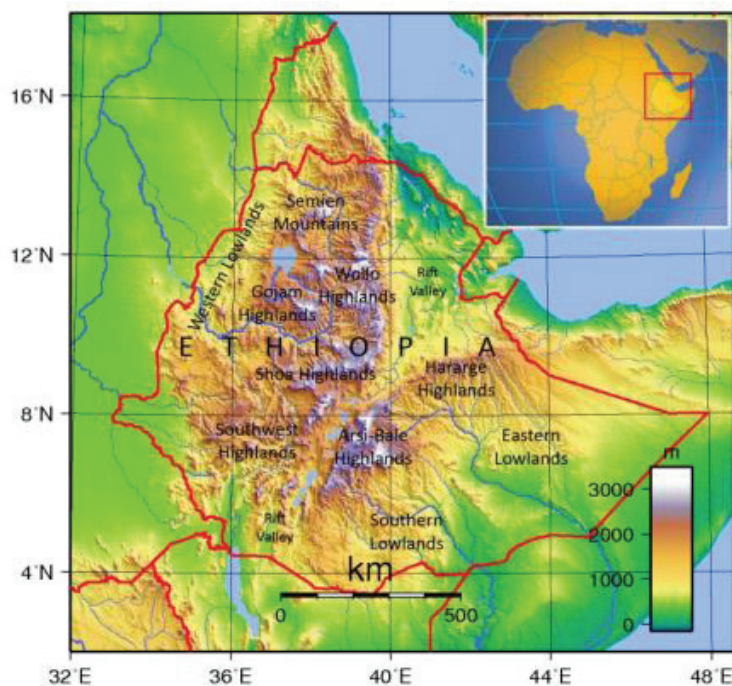


Figure 1: Topographic map of the Ethiopian Highlands and major lowlands including the Great East African Rift Valley, and fractured mountain ranges. Source [35].

## Soil and water conservation practices in highlands of Ethiopia

Soil and water conservation technologies were implemented on cropland in many highland part of Ethiopia since the 1970s and 1980s drought and famine specially, in Wollo and Tigray [30]. Soil conservation is a need to reduce soil fertility depletion and achieve sustainable land management, which is non-negotiable in developing countries where agriculture is the main source food for a growing population [41]. Currently, at watershed scale various recommended PSWC such as soil bund, stone bund, stone faced soil bund, fanya juu, check dam, gabion; hillside terrace, bench terrace, trench, pit, half-moon and indigenous PSWC such as drainage ditches, contour ploughing have been implemented through free community labor mobilization, government and NGO mobilization to prevent and rehabilitate different land use in highland of Ethiopia [9,42-51]. Belay and Eyasu [51] assessed and classified the major SWC measures being employed in Guba-Lafto Woreda of North Wollo as physical SWC measures (stone bund, hillside terrace, micro water ponds, stone faced soil bund, check dam, and fanya-juu terrace); agronomic conservation measures (contour farming, agroforestry, mixed cropping, and crop rotation); and biological conservation measures (afforestation, area enclosure, and grass strip). Haregeweyne, et al. [13] reported the commonly implemented SWC measures in Ethiopia; such as soil bunds combined with trenches in croplands, which are constructed by mobilizing the community through the free-labor day scheme; soil bunds integrated with Sesbania trees in croplands, where the trees are also being used for animal feed through a cut-and-carry system; and exclosures combined with trenches in degraded steep slopes.

### Agricultural practices in the highlands of Ethiopia

Agriculture is the dominant sector and biggest employer of the economically active population in the highlands of Ethiopia (more than 88% of the total population). The livelihood of the community is dependent on mixed farming system i.e. crop production and animal rearing is the main economic activity. Teff, maize, fingermilte, wheat and barley crops and livestock's such as cattle, goats and sheep production were an important source of household consumption and sell [52-54]. In addition, acacia decurrens tree-based farming system is commonly experienced by the larger portion of smallholder farmers in the highland agricultural landscape particularly in northwestern Ethiopia highland as the major source of income from charcoal production and crop production [55]. This farming system is considered as one approach of agroforestry that has a positive effect on restoring soil degradation through the improvement of soil chemical and physical properties and reduces soil erosion with its associated problems [56,57].

Crop rotation is the practice of cultivating different sequences of crops on the same plot of land. It can have a major impact on soil health, due to emerging soil ecological interactions and processes that occur with time [6,58]. Farmers in highlands of Ethiopian practices crop rotation with in the cereal to cereal and legumes to cereal crop each year, of which

mostly teff to maize, bean to fingermilte, maize to teff and fingermilte, barely to fingermilte, wheat to potato are common cropping change system [58,59].

### Landscape characteristics and soil type

The northwestern portion of highlands of Ethiopia which covers the Tigray and Amhara Regions characterized up to 30 % or more in terrain topography. The slopping area of the highland mostly vulnerable to soil erosion due to intensive cultivation and lack proper land management practices [3,14,60]. Information on soil is an essential in sustainable utilization of soil resources and sound land use planning [61]. According to (Food and Agriculture of the United Nations [62] classification system Nitisols, Luvisols, and Vertisols; Cambisols, Regosols and Leptosols are the major soil types in Highland of Ethiopia [61,63-65] The study area soils are characterized with shallow, moderate to very deep in depth and clay loam to clay texture.

### Major cause of onsite nutrient loss

Nutrients are lost in agricultural land in different ways such as; - soil erosion, crop residue removal, harvested products, gaseous and leaching losses. The amount of nutrient loss varied with farming systems, crop type, and soil type, and management. For instance, Hailelassie, et al. (7) reported that high nutrients are lost with runoff and sediment associated in the agricultural land.

### Soil erosion

Most of the essential plant nutrients are found on the top surface soil and hence the top layer of the soil is subjected to soil erosion and most onsite nutrients have been lost. Various studies reported that soil erosion in the form of water resulting in the loss of valuable plant nutrients (NPK and SOM) with the eroded soil [1,16,18,66-68]. For instance, in the past Hailelassie [17] reported that the contribution of soil erosion to NPK loss in teff land use was 70%, 80%, and 63 % respectively. This implies that nitrogen phosphorous and potassium losses in soil erosion are elevated (Figure 2). For example, Grum, et al. [16] obtained 90.6 kg ha<sup>-1</sup> annual average soil losses due to sheet erosion with average annual nutrient losses estimated as 36.4kg ha<sup>-1</sup> total N, 25.9 kg ha<sup>-1</sup> available P in Gule Sub-Watershed, North Ethiopia. Similarly, Erkossa, et al. [1] obtained 5.7 t ha<sup>-1</sup>yr<sup>-1</sup> annual average soil losses due to sheet erosion in Dapo catchment in the Blue Nile basin with average annual nutrient losses estimated as 14.0 kg/ha total N, 6.8 kg/ha available P. Berhane, et al. [68] also observed that 3170 kg ha<sup>-1</sup>yr<sup>-1</sup> annual average soil loss due to rill erosion with average annual OM and total N nutrient losses estimated as 41.4 kg ha<sup>-1</sup> and 2.4 kg ha<sup>-1</sup> respectively in Ruba Gered watershed, North Ethiopia. This implies that the nutrient loss, especially the N and P losses, from the catchment were strongly related to the sediment loss, emphasizes that where there is high soil loss, there is also high onsite nutrient loss from the system. Similarly, sheet and rill erosion mostly remove top fertile soil of which high organic substrate accumulated and source of N and P.



**Table 1:** Impact of SWC measures on soil loss in Ethiopia.

Management practice	Study site	Soil loss (ton ha <sup>-1</sup> yr <sup>-1</sup> )		Effectiveness (%)	Reference
		Treated	Untreated		
Tied ridges + Straw mulch	Gule sub-watershed	8.3	90.6	91	Grum, et al. [16]
Barley cultivated Soil bunds	Galessa micro-watershed	24	46	48	Adimassu, et al. [15]
Minimum tillage with crop residue	Awash River Basin	16	30	47	Adimassu, et al. [19]
Stone bund	Agula watershed	10	28	64	Fenta, et al. [90]
Stone bund	Harfetay watershed	23	119	80	Selassie and Belay [17]
Graded fanya juu	Anjeni watershed	35.6	110.1	68	Mengistu, et al. [71]
Stone-faced soil bund	Welkait district	8	79	90	Abrha, et al. [69]
Trench	May Leiba watershed	4	39	89	Taye, et al. [66]
Soil bund	Debre Mewi watershed	46	71.3	36	Tadele, et al. [70]

### Effectiveness of soil and water conservation measures on soil loss reduction

Human activities associated with soil and water conservation practices such as physical, biological and soil management practices could reduce soil loss in different part of Ethiopia (Table 1). Various studies have conducted on the effect of soil and water conservation measures on soil loss in Ethiopia highlands [14,15,16,69,60,71]. For instance, Admassu et al. (19) observed that zero/minimum tillage with 2 t ha<sup>-1</sup> yr<sup>-1</sup> crop residue was reduced soil loss by 47% compared to control treatment in the Humid Highlands of Ethiopia. Grum, et al. [16] also reported tied ridges with straw mulch reduced soil loss by 91 % compared to non-conserved land Gule sub-watershed. In addition, Abrha et al. [69] observed that stone-faced soil bund reduced soil loss by 90% compared with untreated cultivated field in Welkait district Western Zone of Tigray Ethiopia.

These implying that implementation of soil and water conservation measures are effective to reduce the amount of soil loss through creating surface roughness, convey the erosive surface flow via increasing infiltration rate and minimize the removal of top fertile soil out of the catchment through enhance accumulation of sediment behind it. This argument is line with study made by Jemberu, et al. [72] observed that a farm land treated with soil bund increased porosity, infiltration by 14.2% and 41 % respectively compared to those of untreated farm land in Koga catchment, highlands of Ethiopia. Amdemariam, et al. [73] also reported that a 9-year old soil bund had the highest mean infiltration rate (0.88 cm hr<sup>-1</sup>) whereas the non-conserved land had the lowest mean infiltration rate (0.24cm hr<sup>-1</sup>). Furthermore, Tiki, et al. [74] indicated that averagely 45.74 t/ha/yr sediment was accumulated on soil bunds in Goba District in Bale Zone South East Ethiopia. Likiely, Nyssen, et al. [75] also reported that sediment accumulation rate on stone bund is 57t/ha/year. This implies that implementation of proper SWC of soil and water conservation measures are important for soil erosion control through enhancing infiltration of surface runoff and trapping sediment behind it.

### Crop residue removal

Complete crop residue removal and continuous cultivation without fallowing and inadequate organic fertilization of agricultural field were caused for nutrient loss. Kiros, et al. [28]

stated that removal of crop residue contributed to an onsite nutrient loss in May Leba catchment in Northern Ethiopia, and observed that NPK nutrient losses varied from (5.1 to 13.3, 0.611 to 1.21 and 6.29 to 13.55 kg ha<sup>-1</sup>yr<sup>-1</sup>) along with the landscapes respectively. This implies that the effect of the removal of crop residue at the upper landscape position increased the nutrient loss due to high leaching and low accumulation of organic content. Similarly, Kraaijvanger and Veldkamp [29] reported NPK nutrient loss due to wheat and hanfets residue removal was 8 kg ha<sup>-1</sup>, 2.6 kg ha<sup>-1</sup>, and 40.4 kg ha<sup>-1</sup> respectively in Werie-Leke districts in the tigray region. Negash, et al. [76] also observed that 59, 13.9, and 79 kg ha<sup>-1</sup> yr<sup>-1</sup> of N, PK lost respectively due to consumption of crop residue and dug cake for fuel energy (Figure 2). This implies that most of the smallholder farmers of Ethiopia harvested all crop residues for the purpose of firewood and animal feed consequently, a high amount of essential plant nutrients are lost out of the system. The removal of crop residue is a common activity by smallholder farmers after harvested the product and a continuing onsite nutrient loss problem due to lack of detailed awareness for farmers about the role of leaving >30% crop residue on soil fertility improvement. This is similar which is reported previously in the FAO [77] in most parts of Ethiopia 85% of total residues are removed from cultivated land being used as domestic energy sources. For instance, Admassu, et al. [19] reported that the average soil loss was lower (16 t ha<sup>-1</sup> yr<sup>-1</sup>) in zero tillage with 2 t ha<sup>-1</sup> yr<sup>-1</sup> crop residue and higher (30 t ha<sup>-1</sup> yr<sup>-1</sup>) in conventional tillage without crop residue; and also on average, highest grain (2 t ha<sup>-1</sup>) and biomass (6 t ha<sup>-1</sup>) yields of wheat were recorded in conventional tillage with 2 t ha<sup>-1</sup> yr<sup>-1</sup> crop residue. Thus, the application of optimum organic inputs, proper management of crop residues, crop rotation, and sustainable soil and water conservation measures are very crucial to replace the exported nutrients out of the system via crop residue removal. Moreover, agroforestry practices like alley cropping, intercropping and multipurpose tree plantation might have great impact on reduction of nutrient loss.

### Harvested product

Soil fertility decline could be the major factor for the apparent lower crop yield in Ethiopia as a result, soil nutrient loss status evaluation of crops before and after harvesting production is important for sustainable production. This

**Table 2:** Mean Nutrient loss and replacement costs of AN and AP

Land use land cover	AN		AP		Total nutrient replacement cost
	Kg/ha/yr	Birr/ha/yr	Kg/ha/yr	Birr/ha/yr	Birr/ha/yr
Non-conserved croplands	2.36a	45.40a	1.84a	75.82a	121.22a
Conserved croplands	0.82b	15.87b	0.50b	20.54b	36.41b
Forest and scrublands	0.94b	18.10b	0.22c	8.98c	27.09b
Grazing lands	0.82b	15.85b	0.40b	6.36c	32.22b
Plantations	0.30c	5.07b	0.18c	7.40c	13.10c
Weighted mean replacement cost	-	34.01c	-	42.31	98.1
Slope class in non-conserved croplands					
Lower slop class (<15%)	0.88b	16.93b	0.63a	25.95b	42.39c
Middle slope class (15-30%)	2.36a	45.33a	0.75a	36.06a	81.39a
Upper slope class(>30%)	2.16a	41.52a	0.66a	27.12b	68.64b

\*Means in a column for land use type or slope class followed by the same letter are not different at  $p < 0.05$ . Source Selassie and Belay [17].

is because some studies showed that the highest onsite nutrient loss mainly caused by the harvested product. For instance, Hailisalassie, et al. [7] observed that nutrient loss from vegetable and permanent crops was mainly removed via harvested product and crop residue removal. Kiros, et al. [28] also determined nutrient losses of NPK from harvested crops in the May Leba catchment in northern Ethiopia and obtained that the highest NPK nutrient is lost in the range 28.69 to 82.64, 0.12 to 0.32, and 9.37 to 18.02  $\text{kg ha}^{-1} \text{yr}^{-1}$  respectively across all the landscapes. This implies that similar to crop residue removal, harvested product also increased nutrient loss and nutrient withdrawal increased in the monocropping farming system. Similarly, Belete [78] observed averagely 59.1  $\text{kg ha}^{-1}$  NPK nutrient loss due to the harvested product of the cereal in North-Western Ethiopia. Likiely, Van Beek, et al. [8] obtained high total N loss in Bure and Dera districts farmland in North-Western Ethiopia. This implies that though it varies in harvested product type each season a lot of nutrients are lost in cultivated land.

### Gaseous loss and leaching

Gaseous/volatilization can be an important pathway of N fluxes in many agricultural production systems [79]. Nitrogen is easily disappeared through volatilization and leaching from the soil surface due to its very mobile nature. For example, in modern agriculture nitrate is the main source of nitrogen for crops; yet, nitrate is also the most mobile form of N and easily loses from the soil through leaching [80]. And also the conventional furrow irrigated agriculture without management of excess water causes leaching of nitrate-nitrogen and other macronutrients [81]. On the other hand, in high and medium altitude areas where rainfall is high, most of the macronutrient (NPK) is lost through leaching making the nutrient unavailable during the critical stages of crop growth [81]. The loss of nutrients not only troubles the farmer on crop reduction, but it has also hazardous impacts on the environment [34]. As a result, an optimum nitrogen fertilizer application rates for the various growth stages of crops is important to minimize the losses of N and nitrogen use efficiency (NUE) via leaching and volatilization [80]. Nitrogen use efficiency expressed as grain production per unit of N applied [82]. The application of

high cation exchange capacity materials is reduced N leaching and increases plant N uptake in sandy soils [83]. Similarly, Agegnehu, et al. [84] observed that 17–65% fewer fluxes of  $\text{N}_2\text{O}$  produced per unit of peanut produced in the organic amended such as compost and composted biochar-compost than the control treatment.

### Soil nutrient depletion

Nutrient balances are calculated from the difference between inflow and outflow of respective nutrients from the system [7]. Input flows include chemical and organic fertilizer, atmospheric deposition, and sedimentation while output flows from the system include removal of nutrients from the soil by harvests product, crop residue, and soil erosion by water, leaching, and volatilization. Currently, soil nutrient depletion is becoming the major challenge for agricultural production for the stakeholder farmers in Ethiopia [5,8]. This is due to the imbalance between input delivery and output to the system in Ethiopia.

The major causes of soil fertility depletion are inadequate fertilizer use, complete removal of crop residues, continuous cropping systems, and climate and soil types, lack of proper cropping systems and soil erosion and continuous cultivation [85,86]. Agegnehu, et al. [84] also stated that inefficient use of organic fertilizer contributes to the depletion of scarce financial resources, increased unit production costs, and potential environmental risks. For example, a study made by Belete [78] reported that the average negative nutrient balance of NPK in the cereal lands of the Tigray region was -65 N, -27 P, and -45 K  $\text{kg ha}^{-1}$  respectively. Similarly, van Beek, et al. [8] also observed an average negative nutrient balance of  $-23 \pm 73$  and  $-7 \pm 64 \text{ kg ha}^{-1}$  N and K respectively under diverse agro-ecological settings in Ethiopia. Moreover, Hailelassie, et al. [7] also observed a negative full nutrient balance of NPK (-122, -13 and -82  $\text{kg ha}^{-1} \text{yr}^{-1}$ ) respectively on smallholders' mixed farming systems in Ethiopia. The negative nutrient balance implies that net negative losses between inflows and outflows. For instance, Aticho, et al. [5] studied in jimma zone Ethiopia showed that N, P, and K added to cropland were much less than nutrients removed out the system through crop residue removal, soil erosion, and harvesting product.



On the other hand, soil management practices alone or integrated with chemical fertilizer resulting in positive nutrient balance. For instance, Tadesse, et al. [82] observed that combined application of 15 t ha<sup>-1</sup> farmyard manure and 120 kg N ha<sup>-1</sup> resulted in the highest N positive balance (214.8 kg ha<sup>-1</sup>) compared to lonely chemical fertilizer (150.1 kg ha<sup>-1</sup>). The observed highest N balance was just due to the higher amount of N input, coupled with the lower uptake of the nutrient by the plant. Similarly, Kraaijvanger and Veldkamp [29] reported a nutrient balance of NPK under control treatment were -39, -11, and -49, while application of 18 to-1 manure resulted in a positive nutrient balance of NPK, was 0,2, 4 and 4.6 kg ha<sup>-1</sup> respectively. This implies that the application of combined fertilizer particularly farmyard manure and optimum inorganic fertilizers improved the soil characteristics and consequently reduced the loss of nutrients from the system.

### Cost of nutrient loss replacement

Nutrient lost from agricultural land imply an economic loss to the farmers by reducing crop yield and increasing the replacement cost of lost nutrient [1,17,18,66,67]. For example, Erkossa, et al. [1] observed that mean 2024 kg ha<sup>-1</sup> reduced in the maize yield due to loss of major N and P nutrient in Dapo catchment and equivalent onsite weighted mean replacement cost was estimated to be 372 USD ha<sup>-1</sup>yr<sup>-1</sup>. Likely, in Mizewa catchment of the Blue Nile basin study made by Taye, et al. [66] observed that yield reduction of maize due to mean N and P nutrient loss was about 463 kg ha<sup>-1</sup> and equivalent onsite weighted mean replacement cost estimated to be 200 ha<sup>-1</sup>yr<sup>-1</sup>. Selassie and Belay [17] also reported weighted mean replacement cost of N and available P for non-conserved cropland in the Harfeta watershed was estimated to be 6.4USD ha<sup>-1</sup>yr<sup>-1</sup>(Table 2). Moreover, Wudneh, et al. [18] revealed that the net yield of maize reduced by 838.4 kg ha<sup>-1</sup> due to loss of major N and P nutrient in Chekorsa catchment (Table 3). This implies that in addition to the sedimentation effect of exported nutrients on dam /reservoir, it had the highest estimated yield reduction and replacement cost for the total N and available P nutrients lost. Nevertheless, as mineral fertilizers are not affordable for smallholder farmers to replace the nutrients lost from their cultivated land, it is essential that practicing organic fertilizer to ensure the long-term sustainability of agricultural systems and to avoid irreversible losses.

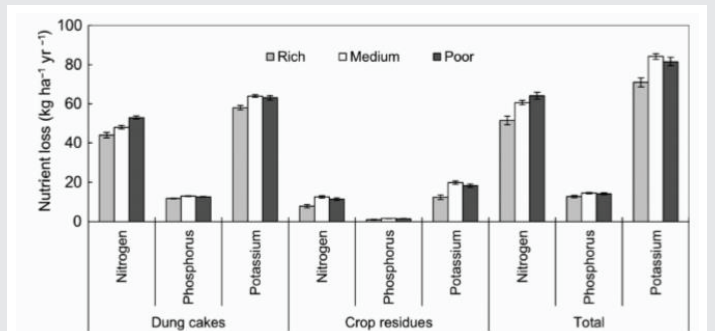
### Impact of SWC measures on onsite nutrient loss

Practicing proper soil and water conservation measures had a positive impact on the reduction of onsite nutrient losses (Figure 3). However, limited studies have been reported on the impact of soil and water conservation practices on nutrient loss in Ethiopia [13,16,17]. For instance, a study made by Grum, et al. [16] showed that tied ridges with straw mulch were reduced total N and available P nutrient loss by 88% and 92% compared to control treatment in the Gule sub-watershed in northern Ethiopia. On the other hand, incorporation of effective microorganisms like bacteria and fungi on straw mulch and tied ridge improved total N and available P (Table 4). Selassie and Belay [17] also observed that stone bund reduced SOC, total N, and available P nutrient loss by 80% 78% and 73%

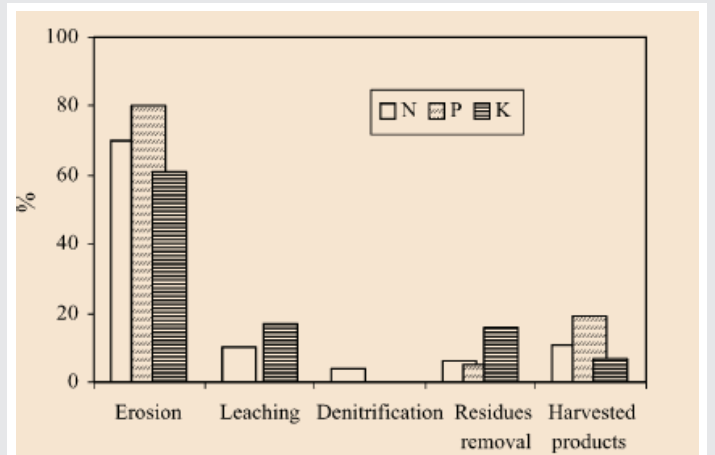
**Table 3:** Estimated monetary value of available nutrient loss by the two sub catchment

Estimated variables	Dapo catchment		Chekorsa catchment	
	N	P	N	P
Total lost /ha	13.6	9.3	14.3	4.1
Potential grain yield response (kg/ha)	3338.1	3905.1	3402.4	3147.6
Mean grain yield with no P and N fertilizer *	2389.3	2483.7	2389.3	2483.7
Net yield(kg/ha)	948.8	1421.4	1013.1	663.9
Total price 9birr/ha)**	3320.8	4974.9	3545.9	2323.7

\*\* Since market price of maize at nekemet is 3.5 birr (1 birr=17.5USD) Source Wudneh [18]



**Figure 2:** Mean loss of nutrients by area of landholding due to use of dung cakes and crop residues separately as well as in combination as fuel. Source [76].



**Figure 3:** Percent share of different out fluxes in total nutrient depletion in Ethiopian smallholders' mixed farming (production year 1999/2000). Source [7].

compared to control treatment in the Harfeta watershed in northwestern Ethiopia.

### Role of integrated soil management practices on land productivity

The application of optimum organic inputs, proper management of crop residues, crop rotation practices are very crucial to soil erosion reduction and replace the exported nutrients out of the system, consequently improving land productivity [59]. Moreover, application of integrated optimum organic and inorganic fertilizer improving soil fertility and crop productivity in highlands of Ethiopia. For example Elka and Laekemariam [87] reported that integrated application of 150 kg ha<sup>-1</sup>



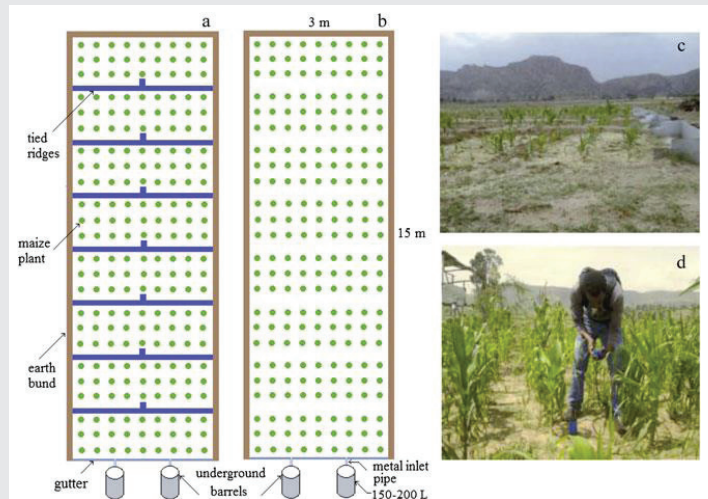
**Table 4:** Impact of SWC practices on nutrient loss in Ethiopia.

SWC measures	Study site	Average Nutrient loss with Sediments (kg ha <sup>-1</sup> yr <sup>-1</sup> )						Effectiveness (%)			References
		SOC		TN		Available P		SOC	TN	AP	
		with	without	with	without	with	without				
Stone bund (Cultivated land)	Harfeta watershed	196.11	973.25	34.53	154.7	0.5	1.8	80	78	73	Selassie and Belay [17]
Soil bunds	Galessa micro-watershed	0.45	0.93	25.0	47.8	0.27	0.59	51	48	54	Adimassu, et al. [15]
Tied ridges + Straw mulch	Gule sub-watershed	-	-	4.26	36.41	2.0	25.9	-	88	92	Grum, et al. [16]
Tied ridge Straw mulch + Effective Microbes	Gule sub-watershed	-	-	9.8	36.41	6.28	25.9	-	73	76	

NPS fertilizer and 2.5 kg ha<sup>-1</sup> compost resulted in faster decomposition and the highest yield component, and grain yield over unfertilized crop. Similarly, Sigaye, et al. [88] reported that the highest maize grain yield (7494.3 kg ha<sup>-1</sup>) and above-ground biomass yield (18718.0 kg ha<sup>-1</sup>) was obtained from the applications of 50% recommended NP fertilizer plus 50% vermicompost which is based on the recommended N equivalent respectively. Degu, et al. [6] reported that maize-fababean-pepper improve soil organic matter by 11% compared to maize-maize-maize crop rotation in Dembecha District, Northwestern Ethiopia This implies that crop rotations between legume and cereal showed relatively better improved soil properties status compared to rotations where only cereal crops were involved. Moreover, Madalcho, et al. [89] indicated that agroforestry practice could be one option to address the problems of deforestation and related resource degradations in Gununo watershed, Wolaita Zone, Ethiopia. Geremew [90] also reported that cash tree plantation bear out a positive impact on food crop productivity. This, in turn, empowered farm households to acquire and employ better farm technologies since cash tree plantation could enable rural Ethiopia farmers to fill the gap of rural financial market failures. Farmers cultivate indigenous trees for a variety of benefits, including livelihoods, ecosystem services and the existence of scenic and economically valued birds [91].

## Conclusion and policy implication

Soil erosion and nutrient depletion has been a major national agenda and remains an important issue in the highland of Ethiopia. The rate of soil loss from sheet and rill erosion in northwestern highlands of Ethiopia raise up to 237 t ha<sup>-1</sup> y<sup>-1</sup> and in gully erosion raise up to 540 t ha<sup>-1</sup> y<sup>-1</sup>. The impact of soil erosion and crop residue removal is the main triggering factor for onsite nutrient loss in agricultural land in highland Ethiopia. Hence, soil nutrient depletion is becoming the major challenge for agricultural production for the stakeholder farmers in Ethiopia due to the imbalance between input delivery and output to the system. Soil erosion is a key determinant of the negative nutrient balances emphasizing the need for improved soil and water conservation measures at farm level and at catchment level. Consequently, nutrient loss from agricultural land had an economic loss due to reducing crop yield and increasing the replacement cost of lost nutrients. However, limited studies have been reported on the impact of soil and water conservation measures on nutrient loss management. Hence, lonely or integrated SWC measures are effective in reducing soil erosion and nutrient loss in Ethiopia due to enhancing soil aggregation, infiltration,



**Figure 4:** Layout of the experimental runoff plots with and without treatment respectively (a&b); Experiment plots with tied ridges + straw mulch and effective microorganisms (c); Soil-moisture measurement by using Trime-PICO64 soil-moisture sensor (d). Source Grum, et al. [16].

and accumulation of sediment behind the SWC measures. As a result, further studies need to conduct on the implication of soil and water conservation measures on a nutrient loss management. Thereby to minimize the nutrient depletion and economic loss, sustainable integrated land management approach like agroforestry practice, application of organic fertilizer, stone-faced soil bund with vegetative measures are a best alternative new approach. Obviously, agroforestry practices like multipurpose tree plantation, alley cropping, intercropping, and organic fertilizer such as compost, locally available animal manures are pillar to minimize nutrient depletion and economic loss via lonely inorganic fertilizer.

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