Soil Nutrient Balance and Stock on Smallholder Farms at Agew Mariam Watershed in Northern Ethiopia

Tilahun Esubalew (✉ tilahun1215@gmail.com)

Sekota Dryland Agricultural Research Center

Tadele Amare

Adet Agricultural Research Center

Eyayu Molla

Bahir Dar University Department of Natural Resource Management

Research

Keywords: Barley, Inflow, Outflow, Tef, Wheat

Posted Date: January 13th, 2022

DOI: <https://doi.org/10.21203/rs.3.rs-1225228/v1>

License: This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

Abstract

Introduction

Soil nutrient balance is used to evaluate the state of soil fertility, rate of nutrient depletion, sustainability of land productivity, the environmental wellbeing of an area, and to take appropriate management decisions. This study was conducted to quantify soil nutrient balance and stocks on smallholder farms at the Agew Mariam watershed in northern Ethiopia in the 2020/21 main season.

Methods

Inflows and outflows of nitrogen (N), phosphorus (P), and potassium (K) into, and out of barley, tef, and wheat farms were determined through, field measurement, laboratory analysis, and interviews. The balance quantification was done by subtracting nutrient outputs from the inputs.

Results

The N partial balance of barley, tef and wheat was -66, -9.8, and -50.7 kg ha⁻¹ yr⁻¹ respectively. The P balance was also -5.9, 0.9, and -2.6 kg ha⁻¹ yr⁻¹ for barley, tef, and wheat respectively. Whereas, K balance was -12.3, -3.2, and -5.4 kg ha⁻¹ yr⁻¹ from barley, tef, and wheat respectively. The balance results revealed that N, P, and K had negative values except for P in tef. Grain yield and crop residue removal were the major paths of nutrient loss. The stock of N was 1295, 1510, and 1240 from barley, tef, and wheat kg ha⁻¹ respectively. While, the P stock was 63, 18.7, and 27.5, kg ha⁻¹ from barley, tef, and wheat farms respectively. Similarly, K stock was 1092.7, 1059.4, and 1090.6 kg ha⁻¹ from barley, tef, and wheat cropping systems respectively.

Conclusions

Reversing the imbalance between inflows and outflows via adding organic and inorganic fertilizers is critically essential for the study area.

Background

Soil fertility is a limiting factor for agricultural production (Lehmann *et al.* 2003). However, it has been declining as a result of low organic and inorganic fertilizers application (Heerink 2005; Elias 2019), poor land management practice, and soil erosion (Dagnachew *et al.* 2020). Similarly, continual nutrient elimination via crop harvests with inadequate nutrient substitutes depletes the nutrients (Bekunda *et al.* 2002). Soil nutrient depletion negatively affects agricultural productivity (Abera *et al.*, 2009), sustainability (Elias 1998; Gebremedhin and Swinton 2003; Kiros *et al.* 2014), and food security (Nyssen *et al.* 2007; Vlek *et al.* 2010). Hence soil fertility management is a serious issue for farmers and researchers as soil properties vary spatially and temporally (Rosemary *et al.* 2017). This is because crop production and productivity improvement mainly depend on soil nutrient management (Koch *et al.* 2020).

To reverse such nutrient management practice immediate and proper corrective measures should be done on time in place (Oenema and Pietrzak 2002; Ejigu *et al.* 2021).

Soil nutrient balance is the summation difference between nutrient input flows and output flows within a particular framework over a certain period (Stoorvogel and Smaling 1990). On the other hand, it is the difference between the nutrients entering a farming system (mainly livestock manure and fertilizers) and the nutrients leaving the system (the uptake of nutrients for crop and pasture production).

Simultaneously, it is used to identify the present status of agricultural cultivated fields, soil health levels and to take appropriate measures (Haileslassie *et al.* 2006; Lesschen *et al.* 2007). Likewise, it is an indicator of soil whether soil fertility is being maintained, improved, or degraded (Stoorvogel and Smaling 1990). Similarly, it serves as an indicator of management practices and the sustainability of the farm, and the systems (Jiri1 and Mafongoya 2018; Theodora 2018). In Ethiopia, many studies on nutrient balance showed a negative balance (Belete 2014; Kiros *et al.* 2014). This was due to the ineffective use of locally available nutrient resources, and the high cost of synthetic fertilizers (Elias 2002; Aticho *et al.* 2011). Soil nutrient stock is the accumulation of plant nutrients in the soil that can be available to plants from 5 to 10 years (Sanchez and Palm 1996). Therefore, prudent nutrients management strategies for better crop yield and sustainability are indisputable.

In the Waghimera zone of the Amhara national regional state, Ethiopia there is less vegetation cover, poor crop residue management, low organic and inorganic inputs resulted in poor soil fertility. Agricultural production and productivity were low. Regarding this, the productivity of barley, tef, and bread wheat were 2078, 550.5, and 1021 kg ha⁻¹. Consequently, in the study area, there was food insecurity and continuous refuge (BOA 2018). On the other hand, there is a critical research gap on nutrient balance in this part of the country. Therefore, the study was initiated to quantify nitrogen, phosphorous, and potassium nutrient balance and stock of smallholder farms at Agew Mariam watershed in northern, Ethiopia.

Materials And Methods

Description of the Study Area

The study was conducted in the Agew Mariam watershed, Waghimera Administrative zone, Amhara National Regional State, Ethiopia in the 2020/21 main crop season. It is located from 38° 53'14" to 38° 56'15" longitude and 12° 31'40" to 12° 32' 33" latitude with an altitude of 2104 to 2361 meters above sea level. It is located at a distance of 720 km north of Addis Ababa and 20 km south of Sekota town in Sayda kebele of Sekota district (Fig. 1). The watershed was delineated in 2016 by Sekota Dryland Agricultural Research Center as a model watershed for agricultural technology generation, adaptation, and dissemination. It has an area of 147 hectares.

The study area has a uni-modal pattern of rainfall that extends from the beginning of July to early September. The mean annual rainfall was 590 mm, while the mean annual minimum and maximum temperatures were 13 °C and 27 °C respectively from 2000-2020 years (Agew Mariam and Kombolcha

metrological station). The area belongs to dry semi-arid midland (Girmay *et al.*, 2020). The soil types of Sekota district including the Agew Mariam watershed have Nitisols, Vertisols, eutric Regosols, and eutric Cambisols soil types. There are four major land-use types in the Agew Mariam watershed. These are cultivated land (71.4 %), bushland (19.7%), area closure (8.2%), and residence (0.7%) (Reda *et al.* 2018). The farming system is characterized by subsistence mixed crop production and livestock husbandry. The major grown crops are Bread wheat (*Triticum aestivum* L.), sorghum (*Sorghum bicolor* L.), teff (*Eragrostis tef* (Zucc.) Trotter), barley (*Hordeum vulgare* L.), and faba bean (*Vicia faba* L.). The area has a high potential for livestock production including cattle, apiculture, poultry, goat, sheep, and donkey.

Data collection and analysis methods

The sampling crop farms were selected in purposive random sampling techniques. Considering slope class levels (lower, middle, and upper), socio-economic status (poor, medium, rich) wealth categories, soil fertility level, and management activities. Totally 23 representative farms were selected. Among them 10 wheat, 3 barley, and 10 tef farm fields. The inflows of N, P, and K through mineral and organic fertilizers were determined by interviewing the farmers. While the outflows through harvest crop yield and crop residue removal were measured by multiplying the amount of grain and straw by its nutrient contents (FAO 2003) formula. The data of above-ground biomass (grain, and straw) were collected directly from the entire whole field using hanging balance. Moreover, N, P, and K nutrient contents of the crops were analyzed in the laboratory based on their standard procedures. Finally, Partial nutrient balances were quantified by estimating nutrients entering into the farm through organic and inorganic fertilizers and subtracting nutrients lost by harvested crop grain yields and crop residue removal (Stoorvogel and Smaling 1998; Stoorvogel 2007; Zingore *et al.* 2007).

About one kg of composite soil sample was collected by auguring diagonally ten subsamples from each sampled crop farm at a depth of 0.2 m for the analysis of N, P, and K contents, soil SOC, and soil separate particles. Additionally, undisturbed soil samples were collected from the selected crop type using a core sampler for the analysis of bulk density. The input of added N and P content converted from NPSZnB into corresponding total N and P in kg ha⁻¹ by multiplying the amount of P₂O₅ by 0.44. But, the total quantity of applied commercial urea fertilizer was changed into elemental nitrogen amount (Aticho *et al.* 2011). Moreover, soil N, P, and K stocks estimation inputs data of nutrient contents, bulk density, and sampling depth were collected in the field survey. Further, it was analyzed based on the Bond (2010) equation.

The stock of N, P, and K (kg ha⁻¹) = bulk density (kg m⁻³) X soil sampling depth (m) X respective concentration (kg kg⁻¹) X area (10⁴ m²) of N, P, and K. Finally, Field surveyed, laboratory analyzed soil and plant samples data of inputs, outputs, and stored were summarized using Microsoft Excel spreadsheets, and additionally, statistical analysis was done using SAS software version 9.0, and the mean separation was analyzed by using 5% least significance difference (LSD).

Soil sample analysis

The collected composite soil samples were analyzed at Sekota Dryland Agricultural Research Center and Amhara Design and supervision works Enterprise soil laboratory (ADSWE). The soil was air-dried and sieved through a 2 mm sieve for NPK and textural class analysis, but for SOC analysis it was sieved at 0.5 mm. Soil organic carbon was determined following the wet digestion method as described in Walkley and Black (1934). Total nitrogen was determined by the Kjeldahl method (Sertsu and Bekele 2000). Available potassium determined by Morgan's solution and K in the extract was measured by a flame photometer (van Reeuwijk 2002). Available phosphorus was determined following the Olsen method (Dean and Olsen 1965). Soil bulk density is the weight of a dry soil per unit of soil volume and its values were calculated based on the core method. Drying undisturbed soil samples by oven dry at 105⁰ C for 24 hours, then divided the dry soil by its volume (FAO 2020). Soil texture was analyzed through the hydrometer method (Bouyoucos 1962; Beverwijk 1967).

Plant sample analysis

The plants harvested manually on their maturity dates were preferred by the farmers. Crop biomasses were weighed using a hanging balance. Similarly, the grain yield of barley, tef, and wheat was collected and measured. Representative straw samples were taken into oven-dry at 65⁰ C for 72 hours to avoid moisture contents. Then both straw and grain were taken for laboratory analysis (Olson 1963). Plant tissue (grain and straw) was air-dried and grinded to pass through a 0.15 mm mesh (Robinson 1994; Okalebo *et al.* 2002). The concentrations of the total nitrogen in the plant were determined by micro-Kjeldahl digestion, distillation, and titration method (Walkley and Black 1934). Phosphorous and potassium concentration in the plant were measured by spectrophotometer and flame photometry respectively and determined with the procedure described by (Thomas *et al.* 1967).

Results And Discussion

Inflow of Nutrients

Cereals barley, tef, and wheat were the major crops in the Agew Mariam watershed. The addition of nutrients into the farms from mineral and organic fertilizers sources was very low. Only a few farmers (30.4%) use inorganic fertilizers for the production of tef, barley, and wheat which was ratified by this research through interviews. The farmers applied only synthetic fertilizers in the form of NPSZnB and urea for the production of field crops. The average used nutrient for the barley was 7.7 kg N ha⁻¹yr⁻¹ but no addition of P fertilizer sources. For tef 5.1 and 2.6 kg ha⁻¹ yr⁻¹ N and P were used respectively. While in wheat farmlands 3.1 and 2.7 kg ha⁻¹ yr⁻¹ N, and P added respectively. Since proper nutrient management is very critical to increase crop production and sustain soil productivity (Demissie and Bekele 2017). Although there was no K fertilizer addition has been done for each study crop farm. The added N, and P amounts could not meet the crops' optimum requirement of nutrients for better production. The recommended amount of nitrogen and phosphorous for tef and wheat to the area were 92 and 10 kg ha⁻¹ N and P respectively (Melak *et al.* 2021). However, the crops in the study area had no responses to K on

crop yields (Esubalew and Sebnie, 2018). But, this statement disagrees with the findings of Haile and Mamo (2013) in Chench and Hagere Selam in Southern Ethiopia K had responses on wheat yield.

The value of nutrient input addition in the study area was low even as compared with other areas (Geze 2019; Haileselassie *et al.* 2005, 2006; Van Beek *et al.* 2016). This might be related to the poor dissemination of mineral fertilizers in the study area. Most of the farmers in the study area could not afford the money to purchase and use mineral fertilizers to their farms. The reasons were high poverty levels, lack of reliable credit services, and the ever-increasing cost of mineral fertilizer affect farmers' fertilizer usage. According to Elias (2002) and Tefera *et al.* (2020), the above-mentioned problems similarly affect the farmers to use low inputs. In Ethiopia, smallholder farms get only 30–40% fertilizer (Spielman *et al.* 2011). As a result, cereal yields and fertilizer use are low in Ethiopia (Zerfu and Larson 2010). Additionally, unreliable, and erratic rainfall is another factor since in dry areas these fertilizers negatively affect crop production (World Bank 2007). The result of this study was similar to the findings of Kiros *et al.* (2014) and Mesfin *et al.* (2020) who reported that poor farmers purchase lower amounts of chemical fertilizers compared with the rich.

According to the results of the interview, farmers did not apply organic fertilizers (farmyard manure and compost) to their barley, tef, and wheat farms. Since the number of animals per household is very low in number for the production of excess farmyard manure. The smaller amount of farmyard manure produced per household is mostly used around the homesteads plots and as fuelwood. So that, there were no input flows of N, P, and K from organic sources to the major cereal field crops. The availability of organic sources' of fertilizers depends on livestock number and family labor size for transporting to the farmlands (Elias 2002). However, currently, in the study area as well as in the rest of the country, farmyard manure is used as a source of energy (Abegaze 2005).

Outflow of nutrients

The amount of nitrogen, phosphorous, and potassium lost via harvested crop yield from barley were 40.1, 3.8, and 3.1, from tef 6.2, 0.6, and 0.6, from wheat 22.5, 2.4, and 1.3 kg ha⁻¹ yr⁻¹ respectively (Table 1). The magnitude differs among crop types due to their production potential, soil type, agronomic practice, and nutrient uptake (Brady 2008; Belete *et al.* 2018; Sarkar *et al.* 2020; Assefa *et al.* 2021). The outflows of N, P, and K by crop residue removal from barley were 33.6, 2.2, and 9.2, from tef 8.7, 1.2, and 2.6, and wheat 31.3, 2.9, and 4.1 kg ha⁻¹ yr⁻¹ respectively. The loss of K through straw residue removal is greater than grain yield since straws had a high K content (Lupwayi *et al.* 2005; Jiang *et al.* 2018; Assefa *et al.* 2021). Whereas, the straw of cereal crops had lower N and P contents than grain (Gezie 2019; Assefa *et al.* 2021).

The outflows of N from barley, tef, and wheat fields were 73.7, 14.9, and 53.8 kg N ha⁻¹ yr⁻¹ respectively as illustrated in (Tables 1). The highest amount of N was lost in the barley farms followed by the wheat farms. However, the lowest loss was recorded from the tef farms. The reasons for this variation could be associated with the variance in grain and straw yield, the amount of mineral fertilizer added, and nutrient

uptake (Stoorvogel and Smaling 1990; Kroeze *et al.* 2003; Tankou *et al.* 2013). The harvested crop products and straw residues removal are mainly the major pathways of NPK losses from agricultural soils (Kiros *et al.* 2014). Similarly, grain yields had better N uptake (Kiros *et al.* 2014; Assefa *et al.* 2021). Thus, the amount of N lost in this study agreed with the findings of Mesfin *et al.* (2020) in Raya-Azebo from the poor farmers' field 48.7 kg N ha⁻¹ yr⁻¹ was lost. However, it disagreed with the findings of Kiros *et al.* (2014) who reported in the May-Leba catchment of northern Ethiopia the loss of N was 101 kg ha⁻¹ yr⁻¹ and Gezie (2019) who reported the loss of 93.1 and 80.1 kg N ha⁻¹ yr⁻¹ from tef and wheat farms in the upland area of Gumara river respectively.

The outflow of phosphorous from barley, tef, and wheat farmlands were 5.9, 1.7, and 5.3 kg P ha⁻¹ yr⁻¹ respectively. The removal of P from tef was the lowest one compared with barley and wheat, this might be related to its smaller above-ground biomass yield. The current research finding is in line with the findings of Elias (1998) and Kiros *et al.* (2014). But, it contrasts with Van Beek *et al.* (2016), Gezie (2019) and Lewoyehu *et al.* (2020). Whereas the outflows of K from barley, tef, and wheat farms were 12.3, 3.2, and 5.4 kg ha⁻¹ yr⁻¹ respectively. The higher outflows of K were recorded by crop residue removal than grain yield. This might be due to the straw having better K content. Moreover, the overall loss of K was low compared with other studies. This might be due to low nutrient uptake by the crops as the N and P were not supplied sufficiently that resulting in low crop yield. The current study showed lower losses of K than the other findings (Hileselassie *et al.* 2005, 2006; Lewoyehu *et al.* 2020).

Table 1. The amount of nutrient outflows from major farmlands (kg ha⁻¹ yr⁻¹)

Crop	OUT1			OUT2		
	N	P	K	N	P	K
Barley	40.1±30	3.8±1.8	3.1±2.1	33.6±22	2.2±0.3	9.2±6.2
Tef	6.2±2.1	0.6±0.2	0.6±0.3	8.7±2.7	1.2±0.2	2.6±1.1
Wheat	22.5±7.7	2.4±0.7	1.3±0.5	31.3±11	2.9±0.9	4.1±1.8

The variabilities of standard deviation among the output and, stock of nutrients were high. In some of them, it exceeds 100% of the data as shown in Table 1. This was caused by the nature of the difference in socio-economic conditions, and farm management activities like nutrient inputs addition. The high grain and straw yield gap between farmlands was among the reasons (Van Beek *et al.* 2016).

Partial soil nutrient balance

The partial nutrient balance is the summation difference between fertilizers (organic, and inorganic) and above-ground biomass yields (grain, and straw). The partial N balance of barley, tef, and wheat were -66.1, -9.9, and -50.7 kg ha⁻¹ yr⁻¹ respectively (Table 2.). Comparatively, tef's partial nutrient balance was

better than barley and wheat, as a result of the outflows through grain yield, and straw was low. This may be due to low above-ground biomass yield. As a whole, the result revealed that N import into the croplands' was highly lower than export out of the soil system. Hence, the balance was negative. It implies that the sustainability of the farmlands was at risk (Jiri1 and Mafongoya 2018; Theodora 2018). Unless reversing the trend of the balance. It may be impossible to increase production, and crop cultivation at all.

Phosphorous partial balance of barley, tef, and wheat were -5.9, 0.9, and -2.6 kg ha⁻¹ yr⁻¹ respectively, as presented in (Table 2.), tef had positive values, even though like N the inputs were very low because of its low outflows by crop yield, and residue removals. Whereas, barley and wheat had negative balances. As a result, the outputs did not counterbalance by the inflows. P was the second most important essential plant nutrient, but farmers' could not add sufficient organic and inorganic P fertilizer sources. Consequently, the yield of crops was low which could lead to low agricultural income and household food insecurity problems in the study area. This study finding is in line with Mesfin *et al.* (2020) 6.3 in Alaje and, 10.6 kg ha⁻¹ in Raya-Azebo. Our study was in line with the finding of Gezie (2019) who reported 11 and -1 kg ha⁻¹ for tef, and wheat respectively. On the contrary, our finding differed from the findings of Haileselassie *et al.* (2005) who reported 6 kg ha⁻¹ yr⁻¹ for Amhara National Regional State. Moreover, Haileselassie (2006) reported a barley-enset farming system with positive P while N and K revealed slightly negative balances. Generally, Phosphorus is an important agricultural input in the world, but it is limited by known phosphate reserves and geological time scales (Cordell *et al.* 2009). Hence it requires a proper management strategy.

Potassium nutrient fluxes (partial balance) of barley, tef, and wheat were -12.3, -3.2, and -5.4 kg ha⁻¹ yr⁻¹ respectively. The result revealed that exported K from the farms was more than the imported into the farms. This was due to the low yield of above-ground biomass. As a result, the loss of K by harvested crop yield and straw removal might not cause severe K depletion in the major cereal crops' farmlands. However, it needs the application of K fertilizer sources. Our finding is in agreement with Haileselassie *et al.* (2005) who reported -2 kg K ha⁻¹ yr⁻¹ for Amhara National Regional State. But it contradicts with the national value of 7 as well as a cereal-pulse system of -87, -11, and -23 kg ha⁻¹ yr⁻¹ for barley, tef, and wheat respectively. Similarly, with the findings of Gelana (2014) K balance for the poor, medium, and rich were -53.98, -54.46, and -56.17 kg ha⁻¹ yr⁻¹ respectively.

Table 2. Partial soil nutrient balance of major crop types

Cropland	IN1 + IN2			OUT1 + OUT2			Partial nutrient balance		
	N	P	K	N	P	K	N	P	K
Barley	7.7	0	0	73.7	5.9	12.3	-66	-5.9	-12.3
Tef	5.1	2.6	0	14.9	1.7	3.2	-9.8	0.9	-3.2
Wheat	3.1	2.7	0	53.8	5.3	5.4	-50.7	-2.6	-5.4

Nutrient Stock

Total N, available P, and available K stock for the upper 0.2m depth of the watershed values were low as illustrated in Table 3. The stock of N for barley, tef, and wheat farms were 1295 ± 481.1 , 1510 ± 600 , and $1240 \pm 181 \text{ kg ha}^{-1}$, respectively. Available P stock for barley, tef, and wheat farms were 63 ± 81 , 18.7 ± 4.3 , and $27.5 \pm 11 \text{ kg ha}^{-1}$ respectively. Whereas, the stock of available K on barley, tef, and wheat farms was 1092.7 ± 122 , 1059.4 ± 169.4 , and $1090.6 \pm 168.5 \text{ kg ha}^{-1}$ respectively. The result revealed that the stocks were varied among croplands. The differences were related to bulk densities and nutrient content variation (Aticho and Elias 2011). The stock of N, P, and K had no direct relationship with the current available amount. Because it will be available to the plants gradually in the coming 5-10 years (Sanchez and Palm 1996). The objective of nutrient stock improvement was not to maximize their concentration on soil but to maintain the required optimum amount for sustaining agricultural production. In the tropics and sub-tropics food production usually relies on available soil nutrient stocks (Sheldrick *et al.* 2002). The result indicated that inappropriate soil fertility as well as, land management activities were not effective in maintaining soil nutrient stocks (Tegene 1998; Elias 2002). Removal of crop residue for animal feed, low addition of compost, farmyard manure, and mineral fertilizers cause land degradation (Haileselassie *et al.*, 2005). Soil fertility management practices should be modified continuously in space and time since it is not static (Boesen and Hansen 2001).

Application of combined organic and inorganic fertilizers for a long time improved soil nutrient contents of total N, P, K, Ca, and Mg in the upper 0.1 m depth (Bedada 2015). The current study had lower stock compared to Haileselassie's (2006) who reported 5510, 1200, and 30800 kg ha^{-1} of N, P, and K stock respectively in tef-based cereal-pulse systems, and compared to Gebeyehu and Soromessa (2018) who reported N stock value of 2890 kg ha^{-1} for rain feed and 3180 kg ha^{-1} for irrigation 0 - 0.15 m depth. This might be related to the poor soil fertility management practices of our study area (Girmay *et al.* 2020). Low inputs additions, severe land degradation, and lack of crop residue retention reduce the stock (Zerssa *et al.* 2021). The stocks of N, P, and K had no statistically significant difference ($P \leq 0.05$) among the farmlands (Table 3). However, the farmlands barley, tef, and wheat had a significant effect on nutrient stocks. The stock of $N > K > P$ in all field sites. The results revealed that the amount of N, P, and K throughout the watershed were similar, but there was an amount difference between the N, P, and K amounts.

Table 3. The nutrient stock within farmlands (0.2 m soil depth)

Stock (kg ha ⁻¹)				Stock (kg ha ⁻¹)			
Crop	N	P	K	Nutrient	wheat	tef	Barley
Tef	1510	18.79	1059.4	N	1240.8 ^A	1510 ^A	1295.3 ^A
wheat	1240.8	27.5	1090.6	P	27.5 ^C	18.79 ^C	63 ^B
Barley	1295.3	63	1092.7	K	1090.6 ^B	1059.4 ^B	1092.7 ^A
LSD (0.05)	NS	NS	NS	LSD (0.05)	128.45	239	205
CV	28.37	32.5	14.88	CV	24.76	29.74	35.29

Conclusions And Recommendations

This study result revealed that the habit of using locally available nutrient sources was underprivileged. Thus inflow addition for N, and P were below the recommended level. The partial balance of N, P, and K was negative in all farmlands of barley, tef, and wheat, except the tef P balance. The result implies that the sustainability of the farms' production system being at risk. In general, the study showed a negative nutrient balance with low total nutrient stocks, because of inadequate input additions. To improve the agricultural production capacity of smallholder farms soil fertility should be corrected by adding optimum organic, inorganic fertilizers, and crop residue retention. Similarly, more extension services on the addition of organic and synthetic fertilizers shall be in place. Further studies on integrated soil fertility management activities should be practiced to recover the agricultural productivity of the farms.

Declarations

Acknowledgment: Researchers of this experiment express their deepest gratitude to the Amhara Agricultural Research Institute for funding the research work, and Sekota Dryland Agricultural Research Center for facilitating logistics during the research work.

Author contribution statement

Tilahun Esubalew: Conceived, planned, designed the experiment, and collected the data; wrote the paper. Tadele Amare and Eyayu Molla: supervised and reviewed and edited the paper.

Funding statement

Not applicable to this manuscript.

Data availability statement

We declare that the data used in this manuscript can be made available as per the editorial policy of the journal.

Ethics approval and consent to participate

Not applicable to this manuscript.

Consent for publication

Not applicable to this manuscript.

Competing interests

The authors declared that there is no competing interest.

References

- Abebe Z, Deressa H (2017) The effect of organic and inorganic fertilizers on the yield of two contrasting soybean varieties and residual nutrient effects on a subsequent finger millet crop. *Agronomy*, 7(2), 42
- Abegaze A (2005) Farm management in mixed crop-livestock systems in the Northern Highlands of Ethiopia. Wageningen University and Research Center, Ph.D. Thesis.
- Abera, T., Feyisa, D., Friesen, D. K., 2009. Effects of crop rotation and NP fertilizer rate on grain yield and related characteristics of maize and soil fertility at Bako, Western Oromia, Ethiopia. *East African Journal of Sciences*, 3(1)
- Assefa S, Haile W, Tena W (2021) Effects of phosphorus and sulfur on yield and nutrient uptake of wheat (*Triticum aestivum* L.) on Vertisols, North Central, Ethiopia. *Heliyon*, 7(3), e06614
- Aticho A, Elias E (2011) Soil nutrient stock evaluation under different land use types in the smallholder farming systems of Jimma zone, Ethiopia. *Int J Agric Res*, 6, 707-713
- Aticho A, Elias E, Diels J (2011) Comparative analysis of soil nutrient balance at farm level: a case study in Jimma Zone, Ethiopia. *International Journal of Soil Science*, 6(4), 259-266
- Bedada W (2015) Compost and fertilizer alternatives or complementary? (Vol. 2015, No. 2015: 123). Doctoral Thesis Swedish University of Agricultural Sciences Uppsala 2015

- Bekunda MA, Nkonya E, Mugendi D, Msaky JJ (2002) Soil fertility status, management, and research in East Africa. *East African Journal of Rural Development*, 20(1), 94-112.
- Belete, A., 2014. Estimating soil nutrient balance of cereal lands of Tigray Region, Northern Ethiopia. MSC thesis, Addis Ababa University, Ethiopia
- Belete F, Dechassa N, Molla A, Tana T (2018) Effect of nitrogen fertilizer rates on grain yield and nitrogen uptake and use efficiency of bread wheat (*Triticum aestivum* L.) varieties on the Vertisols of central highlands of Ethiopia. *Agriculture and Food Security*, 7(1), 1-12
- Beverwijk A (1967) Particle size analysis of soils by means of the hydrometer method. *Sedimentary Geology*, 1, 403-406
- Bindraban PS, Stoorvogel JJ, Jansen DM, Vlaming J, Groot JR (2000) Land quality indicators for sustainable land management: proposed method for yield gap and soil nutrient balance. *Agriculture, Ecosystems and Environment*, 81(2), 103-112
- Boesen J, Friis-Hansen E (2001) Soil fertility management in semi-arid agriculture in Tanzania: farmers' perceptions and management practices (Vol. 1). Center for Development Research
- Bond WJ (2010) Do nutrient-poor soils inhibit development of forests? A nutrient stock analysis. *Plant Soil*, 334: 47-60
- Bouyoucos GJ (1962) Hydrometer method improved for making particle size analyses of soils 1. *Agronomy Journal*, 54 (5), 464-465
- Brady NC, Weil RR, Weil RR (2008) The nature and properties of soils (Vol. 13): Prentice Hall Upper Saddle River, New Jersey
- Bureau of Agriculture (BOA) (2018) Waghimera administration Zone Bureau of Agriculture, Sekota, Ethiopia
- Cordell D, Drangert JO, White S (2009) The story of phosphorus: global food security and food for thought. *Global environmental change*, 19(2), 292-305
- Dagnachew M, Moges A, Kebede A, Abebe A (2020) Effects of soil and water conservation measures on soil quality indicators: The case of Geshy sub-catchment, Gojeb river catchment, Ethiopia. *Applied and Environmental Soil Science*
- Demissie N, Bekele I (2017) Optimizing fertilizer use within an integrated soil fertility management framework in Ethiopia. *Fertilizer Use Optimization in Sub-Saharan Africa*. CABI, Nairobi, Kenya, 52-66
- Elias E (2002) Farmers' perceptions of soil fertility change and management. *ISD and SOSSahel International (UK)*. EDM Printing Press. Addis Ababa, Ethiopia.

- Elias E (2019) Is soil fertility declining? Perspectives on environmental change in southern Ethiopia. *Managing Africa's Soils*, series, (2)
- Elias E, Morse S, Belshaw DGR (1998) Nitrogen and phosphorus balances of Kindo Koisha farms in southern Ethiopia. *Agriculture, Ecosystems, and Environment*. 71: 93-113
- Esubalew T, Sebnie W (2018) Response of sorghum (*Sorghum bicolor* L. Moench) to potassium, zinc, and boron fertilizers in Wag-Lasta northeastern Ethiopia, submitted to the publisher
- Gebeyehu G, Soromessa T (2018) Status of soil organic carbon and nitrogen stocks in Koga Watershed Area, Northwest Ethiopia. *Agriculture and Food Security*, 7(1), 1-10
- Gebremedhin B, Swinton SM (2003) Investment in soil conservation in northern Ethiopia: the role of land tenure security and public programs. *Agricultural economics*, 29(1), 69-84
- Gelena B (2014) *Resource and nutrient flows in smallholders farming systems of Kumbursa village, Ada'a district of central Ethiopia* (Doctoral dissertation, MA thesis paper presented for Addis Ababa University, Ethiopia, Addis Ababa)
- Gezie M (2019) Nutrient balance in small catchments of the upland areas of the Gumara River, northwestern Ethiopia. MSc thesis Bahir Dar University, Ethiopia
- Girmay G, Moges A, Muluneh A (2020) Estimation of soil loss rate using the USLE model for Agewmariyam Watershed, northern Ethiopia. *Agriculture and Food Security*, 9(1), 1-12
- Haile W, Mamo T (2013) The effect of potassium on the yields of potato and wheat are grown on the acidic soils of Chenchu and Hagere Selam in Southern Ethiopia. *International Potash Institute Research Findings*, 35 (2013): 3-8
- Haileselassie A (2006) Soil nutrient stocks and fluxes under smallholders' mixed farming system in the central highlands of Ethiopia: research experiences from the Galessa and Gare areas. *Indigenous tree and shrub species for environmental protection and agricultural productivity*, 62-75
- Haileselassie A, Priess JA, Veldkamp E, Lesschen JP (2006) Smallholders' soil fertility management in the Central Highlands of Ethiopia: implications for nutrient stocks, balances, and sustainability of agroecosystems. *Nutrient Cycling in Agroecosystems*, 75(1-3), 135-146
- Haileselassie A, Priess JA, Veldkamp E, Lesschen JP (2007) Nutrient flows and balances at the field and farm scale: Exploring effects of land-use strategies and access to resources. *Agricultural Systems*, 94(2), 459-470
- Haileselassie A, Priess J, Veldkamp E, Teketay D, Lesschen JP (2005) Assessment of soil nutrient depletion and its spatial variability on smallholders' mixed farming systems in Ethiopia using partial versus full nutrient balances. *Agriculture, ecosystems and environment*, 108(1), 1-16

- Haregeweyn N, Tsunekawa A, Nyssen J, Poesen J, Tsubo M, Meshesha TD, Tegegne F (2015) Soil erosion and conservation in Ethiopia: a review. *Progress in Physical Geography*, 39(6), 750-774
- Heerink N (2005) Soil fertility decline and economic policy reform in Sub-Saharan Africa. *Land use policy*, 22(1), 67-74
- Jiang W, Liu X, Wang Y, Zhang Y, Qi W (2018) Responses to potassium application and economic optimum K rate of maize under different soil indigenous K supply. *Sustainability*, 10(7), 2267
- Jiri O, Mafongoya P (2017) Partial Nutrient Balances in Tropical Velvet Bean-Maize System in Zimbabwe
- Kiros G, Haile M, Gebresamuel G (2014) Assessing the input and output flows and nutrients balance analysis at catchment level in Northern Ethiopia. *Journal of soil science and environment management*, 5 (1), 1-12
- Koch M, Naumann M, Pawelzik E, Gransee A, Thiel H (2020) The importance of nutrient management for potato production Part I: Plant nutrition and yield. *Potato Research*, 63 (1), 97-119
- Kraaijvanger R, Veldkamp T (2014) Grain productivity, fertilizer response and nutrient balance of farming systems in Tigray, Ethiopia: A multi-perspective view in relation to soil fertility degradation. *Land Degrad Dev*, n/a-n/a. DOI:10.1002/ldr.2330
- Kroeze C, Aerts R, van Breemen N, van Dam D, Hofschreuder P, Hoosbeek M, de Vries W (2003) Uncertainties in the fate of nitrogen I: An overview of sources of uncertainty illustrated with a Dutch case study. *Nutrient Cycling in Agroecosystems*, 66(1), 43-69
- Lemma B, Kebede F, Mesfin S, Fitiwy I, Abraha Z, Norgrove L (2017) Quantifying annual soil and nutrient lost by rill erosion in continuously used semiarid farmlands, North Ethiopia. *Environmental Earth Sciences*, 76(5), 190
- Lesschen JP, Stoorvogel JJ, Smaling EMA, Heuvelink GBM, Veldkamp A (2007) A spatially explicit methodology to quantify soil nutrient balances and their uncertainties at the national level. *Nutrient Cycling in Agroecosystems*, 78(2), 111-131
- Lewoyehu M, Alemu Z, Adgo E (2020) The effects of land management on soil fertility and nutrient balance in Kecha and Laguna micro watersheds, Amhara Region, Northwestern, Ethiopia. *Cogent Food and Agriculture*, 6(1), 1853996
- Lupwayi NZ, Clayton GW, Odonovan JT, Harker KN, Turkington TK, Soon YK (2005) Potassium release during decomposition of crop residues under conventional and zero tillage. *Canadian Journal of soil science*, 86(3), 473-481
- Melak E, Esubalew T, Sebnie W, Abera M, Lamsgen H (2021) Effect of nitrogen and phosphorous fertilizers on yield and yield components of tef in Wag-Lasta areas accepted as completed paper, in

Amhara Regional Agricultural Research Institute annual completed research activates review form, March 2021 Bahir Dar, Ethiopia

Melak E, Esubalew T, Sebnie W, Abera M, Lamsgen H (2021) Effect of nitrogen and phosphorous fertilizers on yield and yield components of wheat in Wag-Lasta areas accepted as completed paper, in Amhara Regional Agricultural Research Institute annual completed research activates review form, March 2021 Bahir Dar, Ethiopia

Mesfin S, Gebresamuel G, Zenebe A, Haile M (2021) Nutrient balances in smallholder farms in northern Ethiopia. *Soil Use and Management*, 37(3), 468-478

Nyssen J, Poesen J, Moeyersons J, Mitiku H, Deckers J (2007) Dynamics of soil erosion rates and controlling factors in the Northern Ethiopian Highlands–towards a sediment budget. *Earth surface processes and landforms*, 33(5), 695-711. *Geography*, 39(6), 750-774

Oenema O, Pietrzak S (2002) Nutrient management in food production: achieving agronomic and environmental targets. *AMBIO: A Journal of the Human Environment*, 31(2), 159-168

Okalebo JR, Gathua KW, Woomer PL (2002) Laboratory methods of soil and plant analysis: a working manual second edition. Sacred Africa, Nairobi, 27

Olsen SR, Dean LA (1965) Phosphorus 1. Methods of Soil Analysis. *Part 2. Chemical and Microbiological Properties*, (methods of soil lab), 1035-1049

Reda Y, Girmay G, Abie Y (2018) Characterization of biophysical and socioeconomic aspects of Agewmariam Watershed. Unpublished paper

Robinson JBD (1994) Tropical Soil Biology and Fertility: A Handbook of Methods. Edited By: JM Anderson and JSI Ingram, with 13 appendices by various authors. Wallingford, Oxfordshire: CAB International (1993), pp. 221, £ 19.95. ISBN 0-85198-821-0. *Experimental Agriculture*, 30(4), 487-487

Rosemary F, Indraratne SP, Weerasooriya R, Mishra U (2017) Exploring the spatial variability of soil properties in an Alfisol soil catena. *Catena*, 150, 53-61

Roy RN, Misra RV, Lesschen JP, Smaling EMA (2003) Assessment of soil nutrient balance. Approaches and methodologies. FAO Fertilizer and plant nutrition bulletin 14. FAO, Rome, Italy

Sanchez PA, Palm CA (1996) Nutrient cycling and agroforestry in Africa. *UNASYLVA-FAO*, 24-28

Sarkar S, Skalicky M, Hossain A, Brestic M, Saha S, Garai S, Brahmachari K (2020) Management of Crop Residues for Improving Input Use Efficiency and Agricultural Sustainability. *Sustainability*, 12(23), 9808

Sertsu S, Bekele T (2000) Procedures for soil and plant analysis: Technical P. 74. National Soil Research Center. Ethiopian Agricultural Research Organization

- Sheldrick WF, Syers JK, Lingard J (2002) A conceptual model for conducting nutrient audits at national, regional, and global scales. *Nutrient Cycling in Agroecosystems* 62, 61-72
- Spielman DJ, Dawit K, Dawit A (2011) Seed, fertilizer, and agricultural extension in Ethiopia. *Food and agriculture in Ethiopia: Progress and policy challenges*, 74, 84
- Stoorvogel JJ (2007) From nutrient balances towards soil organic matter dynamics. In: Van de Zijp M et al (eds) *Fishponds in farming systems*. Wageningen Academic Press, Wageningen, pp 107–124
- Stoorvogel JJ, Smaling EMA (1990) Assessment of soil nutrient depletion in Sub-Saharan Africa: 1983-2000. Vol. 1: Main report (0924-3062)
- Stoorvogel JJ, Smaling EMA (1998) Research on soil fertility decline in tropical environments: integration of spatial scales. In *Soil and water quality at different scales* (pp. 151-158). Springer, Dordrecht
- Tamene L, Vlek PL (2008) Soil erosion studies in northern Ethiopia. In *land use and soil resources* (pp. 73-100). Springer, Dordrecht
- Tankou CM, de Snoo GR, de longh HH, Persoon GA (2013) Soil quality assessment of cropping systems in the Western Highlands of Cameroon. *International Journal of Agricultural Research*, 8(1), 1-16
- Tefera T, Elias E, van Beek C (2020) Determinants of smallholder farmers' decisions on fertilizer use for cereal crops in the Ethiopian highlands. *Experimental Agriculture*, 56(5), 677-687
- Tegene B (1998) Indigenous soil knowledge and fertility management practices of the South Wällo Highlands. *Journal of Ethiopian Studies*, 31(1), 123-158.
- Theodora WM (2018) Partial nutrient balance in cropping systems: The case of Ganspan settlement, Northern Cape Province. *Agrotechnology 2018*, Volume 7 DOI: 10.4172/2168-9881-C3-036
- Thomas RL, Sheard RW, Moyer JR (1967) Comparison of conventional and automated procedures for nitrogen, phosphorus, and potassium analysis of plant material using a single digestion 1. *Agronomy Journal*, 59(3), 240-243
- Van Beek CL, Elias E, G.selassie Yihenew, Heesmans H, Asrat T, Feyisa H, Marlin T, Melmuye M, Yemane G, Seyoum M (2016) Soil nutrient balances under diverse agro-ecological settings in Ethiopia. *Nutrient Cycling in Agroecosystems*, 106(3), 257-274.
- Van Reeuwijk LP (2002) Procedures for soil analysis: Wageningen. *International Soil Reference and Information Centre, Technical Paper*, 9
- Vlek PL, Le QB, Luelseged T (2010) Assessment of land degradation, its possible causes, and threat to food security in Sub-Saharan Africa. *Food Security and Soil Quality*. CRC Press, Boca Raton, Florida, 57-86

- Walkley A, Black IA (1934) An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. *Soil science*, 37(1), 29-38
- Wang Lv Y, Wang YL, Zhu P (2019) Straw return with reduced nitrogen fertilizer maintained maize high yield in Northeast China. *Agronomy*, 9(5), 229
- Wato T (2019) Improvements of crop production through integrated soil fertility management in Ethiopia. *Asian journal of environment and ecology*, 1-11
- World Bank (2007) Ethiopia: Accelerating equitable growth country economic memorandum. Part II Thematic Chapters - Report No. 38662-ET. World Bank Africa Region Poverty Reduction and Economic Management Unit, Washington DC
- Yirga C (2007) The dynamics of soil degradation and incentives for optimal management in the Central Highlands of Ethiopia (Doctoral dissertation, University of Pretoria)
- Zerfu D, Larson DF (2010) Incomplete markets and fertilizer use: evidence from Ethiopia. *World Bank Policy Research Working Paper*, (5235)
- Zingore S, Murwira HK, Delve RJ, Giller KE (2007) Influence of nutrient management strategies on variability of soil fertility, crop yields and nutrient balances on smallholder farms in Zimbabwe. *Agriculture, ecosystems and environment*, 119(1-2), 112-126

Figures

Figure 1

Location map of Agew Mariam watershed