Research Article

Yirsaw Hunegnaw*, Getachew Alemayehu, Dereje Ayalew, Mulatu Kassaye

Effects of soil amendments on selected soil chemical properties and productivity of tef (*Eragrostis tef* [Zucc.] Trotter) in the highlands of northwest Ethiopia

https://doi.org/10.1515/opag-2021-0048
received April 29, 2021; accepted September 21, 2021

Abstract: The lack of sustainable soil fertility management is a critical challenge for crop production in the world. The problem is more serious in the East Gojjam Zone highlands. Integrated use of lime, manure, and chemical fertilizers is considered as a good approach for sustainable crop production on acidic soils. In 2016 and 2017, a field experiment was conducted to determine the effect of soil amendments on soil fertility and tef productivity in the Gozamin district. Factorial combinations of two rates of lime (0 and 2 t ha^{-1}), two rates of NP fertilizers (0/0 and 46/20 kg N/P ha^{-1}), and three rates of cattle manure (0, 10, and 15 t ha^{-1}) were laid out in randomized complete block design with three replications. The results showed that applying lime in combination with NP fertilizer and manure significantly improved soil chemical properties. Panicle length, effective tillers, and thousand seeds weight of tef increased from 25.1 to 44.4 cm, 2.8 to 11.3, and 0.23 to 0.37 g, respectively, when 10 t ha^{-1} manure and recommended NP fertilizer were applied together. The highest tef grain yield of 2.31 t ha^{-1} and net benefit of 2,252.91 USD ha^{-1} were obtained from the interaction of 10 t ha^{-1} cattle manure, 46/20 kg ha^{-1} N/P fertilizer, and 2 t ha^{-1} lime. This study recommends the combined application of 2 t ha^{-1} lime, 10 t ha^{-1} cattle manure, and 46/20 kg ha^{-1} N/P fertilizer as an effective amendment to improve soil chemical properties and yield of tef in acidic soils of northwest Ethiopian highlands.

Keywords: fertilizers, lime, manure, yield, soil acidity

*** Corresponding author: Yirsaw Hunegnaw,** Department of Plant Sciences, College of Agriculture and Natural Resources, Debre Markos University, Debre Markos, Ethiopia; Department of Plant Sciences, College of Agriculture and Environmental Sciences, Bahir Dar University, Bahir Dar, Ethiopia, e-mail: yirs2010@gmail.com, tel: +251-911064741
Getachew Alemayehu: Department of Plant Sciences, College of Agriculture and Environmental Sciences, Bahir Dar University, Bahir Dar, Ethiopia, e-mail: getachew.64@gmail.com, tel: +251-918010902
Dereje Ayalew: Department of Plant Sciences, College of Agriculture and Environmental Sciences, Bahir Dar University, Bahir Dar, Ethiopia, e-mail: derejeayal@yahoo.com, tel: +251-913932872
Mulatu Kassaye: Department of Plant Sciences, College of Agriculture and Natural Resources, Debre Markos University, Debre Markos, Ethiopia, e-mail: mulatukassaye12@gmail.com, tel: +251-910007772

1 Introduction

Ethiopia's main stable crop is tef (*Eragrostis tef* [Zucc.] Trotter). Ethiopia is the origin and genetic diversity base for tef [1]. Tef is the most popular cereal grain for making injera, Ethiopia's typical basic diet [2]. During the dry season, tef straw is the primary source of cattle feed [3]. As a result, tef grain and straw have higher retail prices than other cereals. Tef has the highest cultivation area share (24.32%) with about 3 million hectares and ranks second in grain production (17.22%) with 5.44 million tons annually, after maize [4]. Tef was the first cash crop in the study areas, but its productivity (1.4 t ha^{-1}) is low [5] compared to the national average tef yield (1.70 t ha^{-1}) [4], and the highest yields of 3.08 and 2.70 t ha^{-1} were reported by Birhanu et al. [6] and Wato [7].

The main factors limiting tef crop productivity in the Ethiopian highlands are low soil productivity and acidity [8,9]. Due to soil erosion and nutrient leaching caused by frequent rains, this problem is more severe in the highlands of northwest Ethiopia (the current study area) [10]. Because of the poor rate of biomass return to the agricultural fields, most farmed lands in the Ethiopian highlands are prone to soil deterioration [11]. Furthermore, Gebreselassie [12] found that the soils in the Eastern and Central Gojam that are predominantly under cereal cultivation are entisols, which have poor nutrient content due to erosion and lack of nutrient recycling. Most acidic soils have low crop growth as a result of macronutrient deficiencies and high Al and Fe contents, which are the key causes of P fixation [13]. The solubility of Al and Mn in the soil was reduced by liming [14].

Manure is an essential fertilizer in organic and sustainable soil management [15]. Cattle manure increased the pH of acidic soils and decreased Al and Mn toxicity due to its alkalinity and binding effect on toxic elements [16]. Manure contains all plant nutrients including N, P, K and micronutrients necessary for plant growth [17]. Tadesse et al. [18], however, concluded that using only inorganic or organic fertilizers would not result in increased crop production over time. Lime is an outstanding soil amendment for rising soil fertility and improving pH [19]. The addition of lime to manure and industrial fertilizer increased soil physico-chemical properties and nutrient uptake [20]. To ensure adequate nutrient supply and improved soil pH for increased crop yields, determining the optimal dose of integrated soil amendments is critical. However, there has not been enough research done to determine the impact of different rates of cattle manure combined with mineral NP fertilizers and lime on tef production, so it is crucial to investigate the combined effect of manure, NP fertilizers, and lime applications on improving crop productivity in the Ethiopian highlands. Therefore, this study was aimed at assessing the integrated effect of liming, NP fertilizer, and cattle manure applications on soil fertility and productivity of tef in the acidic soils of the East Gojam Zone, northwest Ethiopian highlands.

It was hypothesized that the combined application of cattle manure, lime, and NP fertilizer improves soil physico-chemical properties and tef productivity sustainably.

2 Materials and methods

2.1 Description of the study area

The experiment was conducted in 2016 and 2017 main cropping season at Enerata site in the Gozamin district, East Gojam Zone, northwest Ethiopian highlands. The experimental site is located at the latitude of 10°23′N and the longitude of 37°44′E with an altitude of 2,481 m.a.s.l. The study years map is presented in Figure 1. The weather data source was Debre Markos Metrological Station, and based on 15 years (2003–2017) meteorological data, the average annual rainfall of the study areas was 1,335 mm with the mean minimum and maximum temperatures of 10.7 and 23.2°C, respectively. The monthly average of total rainfall and minimum and maximum temperatures of the study area for 15 years from 2003 to 2017 are presented in Figure 2. The total rainfall of the study years with a range of 0–271 mm per month is shown in Figure 2. The mean

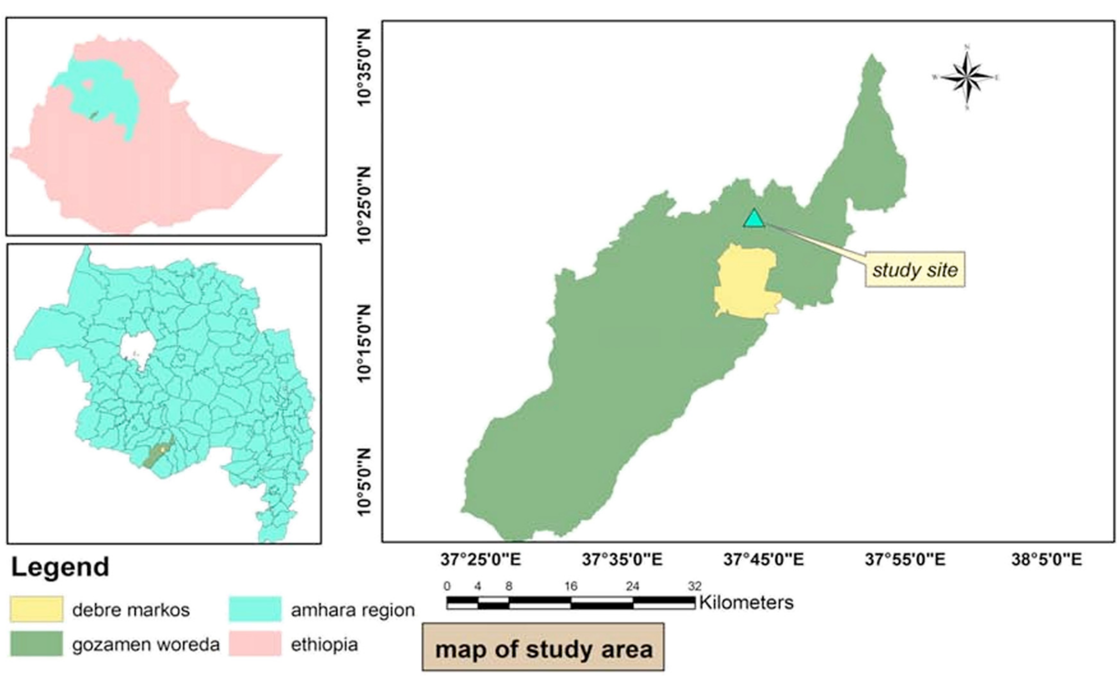

Figure 1: Location map of the study sites in Enerata, East Gojjam Zone, northwest Ethiopia.

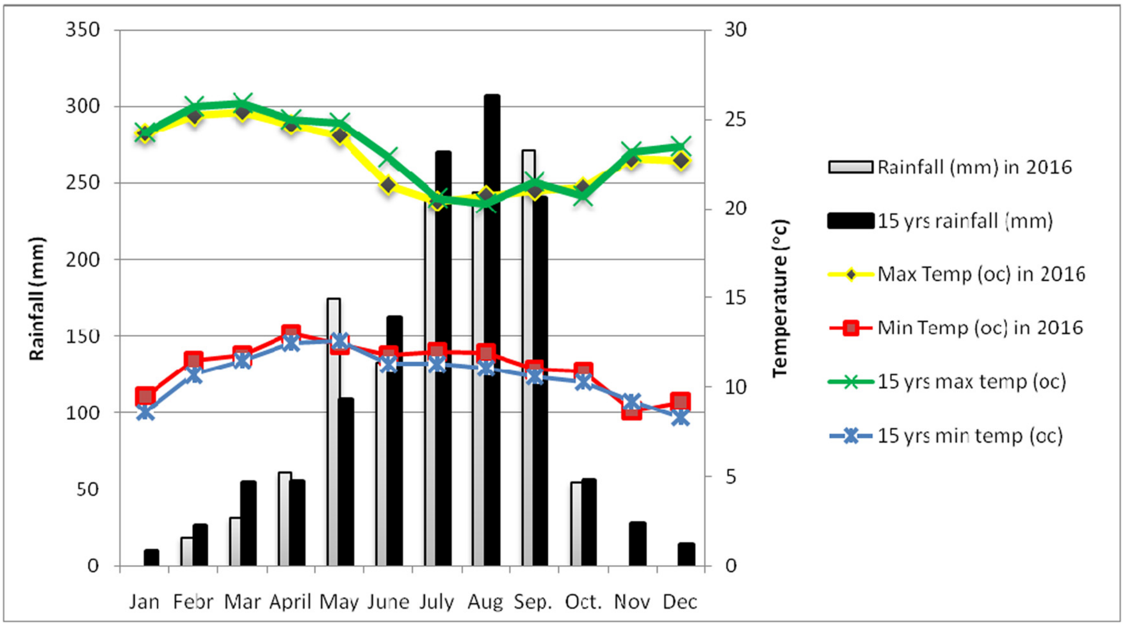

Figure 2: Monthly average rainfall and maximum and minimum temperatures of the study site for 15 years (2003–2017).

minimum and maximum temperatures of the study years were 11.2 and 23.0°C, respectively (Figure 2). The rainfall distribution of the study years is unimodal pattern, and the main rainfall extends from mid of June to October with peak in mid of July to end of August (Figure 2).

To characterize the soils of experimental years, soil sampling and analysis were carried out twice, first before starting the experiment in 2016 and second after the end of the experiment in 2017 by mixing samples collected at eight different spots along the two diagonal lines of the field at 0–30 cm depth with an auger. The composite soil sample was air-dried and crushed to a sieve size of 2 mm before being analyzed for important physico-chemical soil properties.

The Debre Markos soil laboratory analyzed the collected soil samples. The pH of the soil was measured with a pH meter in a 1:2.5 soil–H_2O ratio, as described by Hazelton and Murphy [21]. The Bouyoucos hydrometer method was used to determine the texture of the soil [22]. The Walkley–Black wet digestion process was used to extract soil organic carbon (OC) [23]. Total N was calculated using the Kjeldahl digestion method of Havlin et al. [24]. The Olsen $NaHCO_3$ extraction method was used to extract available soil P [25]. The 1 N ammonium acetate extraction method, as described by Black, was used to determine the cation exchange capacity (CEC) [26], whereas an atomic absorption spectrophotometer was used to assess Ca and Mg [27]. Table 1 shows the findings of the soil laboratory analysis.

Some selected physico-chemical soil properties before soil amendments application are listed as follows: the classification of the experimental soil is nitosol. The experimental soil's textural class was clay, with a pH of 5.1, rated as strongly acidic based on the ratings of Hazelton and Murphy [21]. Total N content was 0.09%, rated low based on the ratings of Havlin et al. [24]. According to Walkley and Black [23], the soil's OC concentration was 1.27%, which is low. The available P content of the experimental soil was 6.85 ppm, which is very low based on the rating of London [25]. Magnesium and Ca were low, while CEC was moderate (Table 1).

A composite animal manure sample was collected for the determination of its moisture content, pH, total N, OC, available P, and exchangeable Ca and Mg. Manure moisture content was determined by oven-drying the samples at 105°C for 24 h. The predetermined rate of manure was adjusted according to the procedure of FAO [28] moisture correction factor. The pH, total N, OC, available P, and exchangeable Ca and Mg were determined by the procedures listed in soil sampling and analysis (Table 1).

2.2 Experimental materials used for the study

The tef variety “Quincho” [(974 × 196)-HT′-387 (RIL355)], Dejen calcium carbonate ($CaCO_3$), cattle manure, urea, and diammonium phosphate (DAP) were used for the experiment.

Table 1: Some important physico-chemical properties of the experimental soils before plowing and composition of cattle manure used for the experiment

Soil and manure property	Soil analysis		Cattle manure		Rating reference(s)
	Value	Rating	Value	Rating	
Particle distribution					
Sand (%)	32				
Silt (%)	25				
Clay (%)	43				
Soil texture class	Clay				
pH (H_2O)	5.1	Strong acidic	6.87	Neutral	[21]
Total N (%)	0.09	Low	1.52	High	[24]
Organic C (%)	1.27	Low	15	Very high	[23]
Avail. P (ppm)	6.85	Very low	25	High	[25]
Exch. Mg (meq per 100 g)	0.84	Low	20	Very high	[27]
Exch. Ca (meq per 100 g)	2.78	Low	32	Very high	[27]
CEC (meq per 100 g)	20.20	Moderate	23		[26]
Moisture content (%)			19		[28]

2.3 Experimental treatments, design, and procedures

East Gojjam agriculture department and others [5] recommended 46/20 kg ha^{-1} N/P fertilizer to improve soil fertility and enhance grain yield of tef in the Gozamin district. Abewa et al. [29] advised to use 2 t ha^{-1} lime in northwestern Ethiopia for tef fields. According to Assefa et al. [30], the maximum rate of cattle manure (7.5 t ha^{-1}) produced the largest grain yield of tef, and as the rate of manure increased, the grain yield of tef increased. Our treatment combinations are based on these findings. Therefore, two rates of lime (0 and 2 t ha^{-1}), two rates of NP fertilizers (0/0 and 46/20 kg ha^{-1}), and three rates of cattle manure (0, 10, and 15 t ha^{-1}) were factorially combined and tested using randomized complete block design (RCBD) with three replications.

The experimental field was plowed four times using oxen-driven local plowing facility and divided further into blocks and plots as per the treatments and design manually. The gross plot size was 2 m × 3 m (6 m^2) with the net plot area of 1.5 m × 2.4 m (3.6 m^2). Lime was broadcasted and thoroughly mixed into soil 50 days before tef planting. Manure was collected under shade for 40 days and incorporated into soil one month before planting. Tef seeds were drilled in rows, which were spaced apart with 20 cm, in early July 2016 and 2017 at the recommended rate of 5 kg ha^{-1}. The whole phosphorous fertilizer was applied during the sowing of tef seeds, whereas N fertilizer was applied in split in such a way that the first half during sowing and the second half at tillering growth stage. Moreover, all the necessary field-management practices were carried out uniformly on all plots.

2.4 Crop data collection

Data of growth and yield related variables of tef were timely collected following their standard methods and procedures. Plant height, panicle length, and number of fertile tillers were measured on plant basis by taking ten randomly selected plants at physiologically maturity growth stage in the net plot area of each plot, whereas biomass, grain, and straw yields were measured from a net plot area and converted to hectare basis (t ha^{-1}). Above ground biomass yield of tef in each net plot area was weighed with sensitive electrical balance after harvesting and proper drying with sunlight. Grain yield and thousand grain weight were adjusted to 12.5% moisture content before proceeding to statistical analysis. Straw yield was estimated as the difference between biomass and grain yield. Thousand seeds samples were taken from clean tef grain yield of each plot and weighed.

2.5 Data analysis

2.5.1 Statistical analysis

All collected crop data were subjected to analysis of variance (ANOVA) using general linear procedure of SAS software version 9.4 [31]. Results of all crop variables at two years were also subjected to Bartlett homogeneity test and found to be insignificant and hence a combined ANOVA for the considered variables was also conducted over the years. Whenever the ANOVA results showed significant difference among treatments for variable(s), the mean separation between the treatments was further carried out with Tukey test at a probability level of 5% [32].

2.5.2 Economic analysis

In order to decide which treatment to recommend for the study area, it is necessary to know treatments with highest net benefit (NB) and acceptable level of marginal rate of return (MRR). Partial budget analysis was performed following the International Maize and Wheat Improvement Center (CIMMYT) partial budget methodology [33]. It considers the analysis of gross benefit, total variable cost (TVC), NB, and finally the analysis of MRR. The cost of applied lime, cattle manure, and NP fertilizer which varies across each treatment was considered as variable cost considering other costs as constant for each treatment. The value of grain and straw yield was adjusted down by 10% in order to narrow the yield gap between experimental plots and farmers' field. Price of tef grain yield, straw yield, lime, urea, and DAP was 0.84, 0.13, 0.04, 0.51, and 0.55 USD kg^{-1}, respectively. The cost of cattle manure with transportation and incorporation into the soil was estimated as USD 0.47 per 100 kg. The cost of incorporation of lime into the soil was USD 0.73 per 100 kg, whereas the cost of transportation and application of fertilizer into the soil was estimated as USD 5.82 per 100 kg. Labor cost of man per day was USD 2.91.

Table 2: Interaction effects of cattle manure and NP fertilizers on OC, total N, and CEC after tef harvest in main cropping season in northwest Ethiopian highlands

Two-way interaction		OC (%)	Total N (%)	CEC (meq per 100 g)
NP ($kg\ ha^{-1}$)	Manure ($t\ ha^{-1}$)			
0–0	0	1.44^{d}	0.12^{d}	17.5^{d}
	10	1.84^{c}	0.15^{c}	20.2^{c}
	15	1.90^{c}	0.20^{b}	20.9^{bc}
46–20	0	1.93^{c}	0.18^{b}	21.3^{bc}
	10	2.45^{b}	0.21^{ab}	22.1^{b}
	15	2.72^{a}	0.23^{a}	23.4^{a}
P-value		**	**	**
SE±		0.10	0.010	0.56
CV		5.3	8.0	5.2

Means within a column followed by the same letter(s) are not significantly different. **, highly significant at $P < 0.01$; *, significant at $P < 0.05$; SE±, standard error; CV, coefficient of variation.

3 Results

3.1 Soil chemical properties as influenced by lime, NP fertilizers, and manure applications

The interaction of manure and NP fertilizer applications highly significantly ($P < 0.01$) increased the soil OC, total N, and CEC of the experimental site, according to the results of soil chemical properties after tef harvest (Table 2). Similarly, the interaction of lime and cattle manure in combination over the years had a highly significant ($P < 0.01$) effect on pH and OC (Table 3). The highest soil OC content (2.72%) and total N (0.23%) were achieved when 15 t ha^{-1} cattle manure and N/P fertilizers were applied at a rate of 46/20 kg ha^{-1} (Table 2). Furthermore, combining the highest cattle manure with lime resulted in a soil OC of 2.35% (Table 3).

The combined application of cattle manure and lime highly significantly ($P < 0.01$) affected calcium and magnesium. The maximum rate of manure application with lime resulted in the highest 14.5 meq per 100 g Ca and 2.63 meq per 100 g Mg values (Table 3). The combined application of cattle manure and lime had a significant ($P < 0.05$) effect on soil available P. The integrated application of 15 t ha^{-1} cattle manure with lime produced the highest available P (13.3%) after tef harvest (Table 3).

3.2 Vegetative growth of tef as influenced by soil amendments

3.2.1 Plant height

In both years and combined over years, cattle manure and NP fertilizer, as well as their interaction, had a highly significant ($P < 0.01$) effect on tef plant height (Table 4). However, neither the lime rate nor the other two- and three-way interaction effects had a significant ($P \geq 0.05$) effect on plant height in both years or over combined years. Plant heights of 118.0 cm were reported in combined over years at the maximum manure rate of 15 t ha^{-1} with

Table 3: Interaction effects of cattle manure and lime on OC, available P, pH, calcium, and magnesium after tef harvest in northwest Ethiopian highlands

Two-way interaction		OC (%)	pH	Available P (%)	Calcium (meq per 100 g)	Magnesium (meq per 100 g)
Lime (t ha^{-1})	Manure (t ha^{-1})					
0	0	1.49^{c}	5.22^{d}	8.2^{c}	5.5^{d}	1.42^{bc}
	10	2.06^{ab}	5.58^{c}	9.8^{bc}	9.4^{bc}	1.97^{b}
	15	2.23^{ab}	5.80^{ab}	10.4^{b}	11.0^{bc}	2.20^{a}
2	0	1.88^{bc}	5.73^{ab}	9.4^{bc}	11.1^{ab}	2.17^{ab}
	10	2.24^{ab}	5.88^{ab}	11.5^{b}	12.4^{ab}	2.52^{a}
	15	2.35^{a}	5.97^{a}	13.3^{a}	14.5^{a}	2.63^{a}
P-value		**	**	*	*	*
SE±		0.22	0.07	0.80	1.81	0.31
CV		6.1	2.2	7.3	8.5	8.5

Means within a column followed by the same letter(s) are not significantly different, **, highly significant at $P < 0.01$; *, significant at $P < 0.05$; SE±, standard error; CV, coefficient of variation.

46/20 kg ha^{-1} N/P fertilizer, whereas the shortest height (72.6 cm) was recorded in the control plot (Table 4).

3.2.2 Panicle length

Cattle manure and NP fertilizer had a highly significant ($P < 0.01$) effect on panicle length.

In both years and combined over years, the interaction effects of cattle manure and NP fertilizer significantly ($P < 0.05$) and highly significantly ($P < 0.01$) affected panicle length of tef, respectively (Table 4), whereas lime and all other interaction effects had no significant impact on panicle length of tef. The combined application of 10 t ha^{-1} manure with NP fertilizer produced the longest panicle length of tef (44.4 cm) compared to the panicle length (40.5 cm) obtained from sole NP fertilizer application (Table 4).

3.2.3 Number of effective tillers

The main effects of cattle manure and NP fertilizer, as well as their interaction, had a highly significant ($P < 0.01$) impact on effective tiller number (Table 4). However, lime, the other two interaction effects, as well as three-way interaction effects, did not have a significant ($P \geq 0.05$) effect on this parameter in both years and averaged over years. The combined application of 46/20 kg ha^{-1} N/P fertilizer and 10 t ha^{-1} manure resulted in a higher number of effective tef tillers (11.3) than the control, which had the lowest effective tillers (2.8; Table 4).

Table 4: Interaction effects of cattle manure and NP fertilizers on vegetative growth and yield parameters of tef in 2016 and 2017 main cropping season in northwest Ethiopian highlands

Two-way interaction		Plant height (cm)			Panicle length (cm)			No. of effective tillers			TSW (g)		
NP (kg ha^{-1})	Manure (t ha^{-1})	2016	2017	COY	2016	2017	COY	2016	2017	COY	2016	2017	COY
0–0	0	73.8^{d}	71.4^{d}	72.6^{e}	23.6^{e}	26.6^{d}	25.1^{e}	2.16^{d}	3.5^{d}	2.8^{d}	0.22^{d}	0.24^{d}	0.23^{e}
	10	89.2^{c}	95.1^{c}	9.2^{d}	29.9^{d}	32.1^{c}	31.1^{d}	4.5^{c}	4.6^{cd}	4.5^{c}	0.25^{c}	0.26^{cd}	0.26^{d}
	15	101.4^{b}	99.3^{c}	100.4^{c}	34.4^{c}	35.8^{b}	35.2^{c}	5.2^{c}	5.3^{c}	5.2^{d}	0.28^{b}	0.27^{c}	0.28^{c}
46–20	0	108.6^{b}	109.2^{b}	108.9^{b}	39.8^{b}	41.3^{a}	40.5^{b}	9.6^{b}	8.6^{b}	9.7^{b}	0.32^{a}	034^{b}	0.34^{b}
	10	116.5^{a}	111.4^{b}	113.9^{ab}	44.6^{a}	43.3^{a}	44.4^{a}	11.3^{a}	11.6^{a}	11.3^{a}	0.38^{a}	0.37^{a}	0.37^{a}
	15	117.3^{a}	118.7^{a}	118.0^{a}	44.8^{a}	43.8^{a}	44.2^{a}	10.8^{ab}	9.2^{b}	9.4^{b}	0.34^{a}	0.33^{b}	0.33^{b}
P-value		**	**	**	*	*	*	**	**	**	*	*	*
SE±		3.67	3.63	2.66	1.65	1.58	1.21	0.67	0.73	0.51	0.009	0.009	0.008
CV%		5.8	5.8	4.5	7.4	7.1	5.4	13.6	14.5	9.2	5.4	5.2	4.2

Means within a column followed by the same letter(s) are not significantly different; *, significant at $P < 0.05$; **, highly significant at $P < 0.01$; COY, combined over years; NP, nitrogen and phosphorus; SE, standard error; CV, coefficient of variation.

3.3 Grain yield and related parameters of tef as affected by soil amendments

3.3.1 Thousand seeds weight (TSW)

The main effects of NP fertilizers and cattle manure highly significantly ($P < 0.01$) influenced TSW. Similarly, the interaction effects of NP fertilizer and cattle manure significantly ($P < 0.05$) affected TSW in both years and combined over years (Table 4). Lime, and its interactions with NP fertilizer and manure, as well as the three-way interaction had no significant ($P \geq 0.05$) influence on tef TSW in both years and combined over years. In comparison to sole NP fertilizer or manure application, application of 46/20 kg ha^{-1} NP with 10 t ha^{-1} manure produced more TSW (0.37 g; Table 4).

3.3.2 Grain yield

Grain yield was highly significantly ($P < 0.01$) influenced by the three main effects and the interaction of NP fertilizer and cattle manure in both years and combined over years. Furthermore, the interaction of lime, NP fertilizer, and cattle manure had a significant ($P < 0.05$) effect on tef yield in both years and combined over years (Table 5). The interaction effects of lime and manure, as well as lime and NP fertilizer, did not show a significant ($P \geq 0.05$) difference on tef yield in both years and combined over years. The combined application of 46/20 kg ha^{-1} N/P fertilizer and 10 t ha^{-1} cattle manure with 2 t ha^{-1} lime produced the highest mean grain yield (2.31 t ha^{-1}) of tef, according to the average results of the two years data (Table 5).

3.3.3 Biomass yield

The main effects of lime, NP fertilizers, and cattle manure highly significantly ($P < 0.01$) influenced biomass yield of tef in both years and combined over years. Similarly, the total biomass yield was significantly affected ($P < 0.05$) by the three-way interaction effects of lime, NP fertilizers, and cattle manure in both years and over years (Table 5). The highest total biomass yield (9.16 t ha^{-1}) was obtained from the highest rate of manure with NP fertilizer and lime when combined over years (Table 5).

3.3.4 Straw yield

ANOVA revealed that straw yield was very highly significantly ($P < 0.01$) affected by the three main effects. The interaction of the three main factors significantly ($P < 0.05$) affected straw yield in 2016 and combined over years (Table 5). The highest straw yield in combined over years (7.05 t ha^{-1}) was obtained from 15 t ha^{-1} manure and 46/20 kg ha^{-1} N/P with 2 t ha^{-1} lime (Table 5).

Table 5: Interaction effects of lime, cattle manure, and NP fertilizers on grain, biomass, and straw yield of tef in 2016 and 2017 main cropping season in northwest Ethiopian highlands

Three-way interaction			Biomass yield (t ha^{-1})			Grain yield (t ha^{-1})			Straw yield (t ha^{-1})		
Lime (t ha^{-1})	NP (kg ha^{-1})	Manure (t ha^{-1})	2016	2017	COY	2016	2017	COY	2016	2017	COY
0	0–0	0	3.00^{e}	3.39^{i}	3.20^{h}	0.61^{f}	0.66^{f}	0.63^{g}	2.38^{f}	2.76^{i}	2.58^{g}
		10	4.39^{d}	4.67^{h}	4.54^{fg}	1.11^{e}	1.09^{cde}	1.10^{e}	3.28^{e}	3.58^{gh}	3.44^{ef}
		15	4.88^{cd}	5.22^{g}	5.05^{f}	1.32^{cd}	1.32^{c}	1.32^{d}	3.56^{de}	3.90^{fg}	3.73^{e}
	46–20	0	6.88^{b}	6.37^{de}	6.62^{d}	1.72^{b}	1.70^{b}	1.71^{c}	5.15^{b}	4.68^{de}	4.92^{cd}
		10	7.00^{b}	7.38^{c}	7.20^{c}	1.86^{bc}	1.77^{b}	1.81^{bc}	5.14^{b}	5.61^{c}	5.38^{c}
		15	7.60^{b}	8.46^{b}	8.00^{b}	1.89^{bc}	1.87^{b}	1.88^{b}	5.70^{b}	6.53^{b}	6.12^{b}
2	0–0	0	4.01^{d}	4.17^{h}	4.09^{g}	0.98^{e}	0.84^{ef}	0.91^{f}	3.03^{ef}	3.33^{h}	3.18^{f}
		10	4.61^{d}	5.46^{fg}	5.01^{f}	1.14^{de}	1.07^{de}	1.11^{de}	3.46^{de}	4.33^{ef}	3.90^{e}
		15	5.65^{c}	5.87^{ef}	5.76^{e}	1.39^{c}	1.29^{cd}	1.34^{d}	4.26^{cd}	4.58^{de}	4.42^{d}
	46–20	0	6.82^{b}	6.66^{d}	6.74^{cd}	1.88^{bc}	1.72^{b}	1.80^{bc}	4.94^{bc}	4.90^{d}	4.92^{c}
		10	9.01^{a}	8.96^{a}	8.99^{a}	2.36^{a}	2.25^{a}	2.31^{a}	6.64^{a}	6.71^{ab}	6.68^{a}
		15	9.23^{a}	9.20^{a}	9.16^{a}	2.19^{a}	2.13^{a}	2.16^{a}	7.04^{a}	7.06^{a}	7.05^{a}
P-value			*	*	*	*	*	*	*	ns	*
SE±			0.45	0.28	0.30	0.12	0.13	0.07	0.42	0.24	0.27
CV			9.3	6.8	5.0	10.5	10.1	6.1	11.2	7.8	6.1

Means within a column followed by the same letter(s) are not significantly different; *, significant at $P < 0.05$; ns, nonsignificant at $P \geq 0.05$; COY, combined over years; SE, standard error; CV, coefficient of variation.

3.4 Economic analysis

The partial budget analysis method of CIMMYT [33] was used to evaluate the expense and benefit of various treatments. The gross yields of 12 treatments were calculated using the final yield and straw results. The highest NB (2,252.91 USD ha^{-1}) of tef was obtained with 46/20 kg ha^{-1} N/P fertilizer, 10 t ha^{-1} cattle manure, and 2 t ha^{-1} lime, followed by 2,027.64 USD ha^{-1} with 46/20 kg ha^{-1} N/P fertilizer, 15 t ha^{-1} cattle manure, and 2 t ha^{-1} lime, and the lowest (784.91 USD ha^{-1}) was obtained with the control (Table 6).

4 Discussion

4.1 Soil chemical properties as influenced by lime, NP fertilizers, and manure applications

After tef harvest, the rise in OC content of experimental soils was most likely due to increased manure application with NP fertilizers (Table 2), and cattle manure is the source of carbon, which helps to improve soil quality and fertility. Woldesenbet et al. [8] found that when farm yard manure and NP fertilizers were applied to the soil, the organic matter content increased significantly. The maximum OC content was observed due to the application of manure and lime [34]. The addition of NP fertilizer and manure to the soil increased the soil's OC content [35]. The maximum manure application with NP fertilizers in combined over years produced the highest total N content of 0.23% (Table 2). This may be due to manure that increases soil microbial biomass N, the living component of soil organic matter. Microbial biomass N is slowly transformed to inorganic N as organic material decomposes. N fertilization resulted in a considerable increase in total soil N in the first 30 cm of soil depth. Organic fertilizer's residual effect on the physical and chemical properties of the soil increased the total N [36]. The combined application of 15 t ha^{-1} cattle manure and 46–20 kg ha^{-1} N–P resulted in a maximum CEC of 21.67 meq per 100 g in combined over years (Table 2). Tolanur [37] stated that organic and NP fertilizer application significantly increased soil CEC compared to NP fertilizer application alone, which is consistent with the current finding.

The combined application of lime and the maximum cattle manure resulted in a soil pH of 5.97, which was 0.75 pH units higher than the control (Table 3). This could be due to the increased microbial activity that occurs during the breakdown process and the creation of organic matter, which may have resulted in the release of additional exchangeable cations. Bekele et al. [13] found that mixing 7.5 tons of vermicompost with 4 tons of lime raised the pH of the experimental soil from 4.8 to 6.0.

Table 6: Partial budget analysis of combined over years grain and straw yields of tef as influenced by soil amendments in 2016 and 2017 main cropping season in northwest Ethiopian highlands

Three-way interaction			Adjusted grain yield (t ha^{-1})	Adjusted straw yield (t ha^{-1})	Gross field benefit (USD ha^{-1})	TVC (USD)	Net benefit (USD ha^{-1})	MRR (%)
Lime (t ha^{-1})	NP (kg ha^{-1})	Manure (t ha^{-1})						
0	0–0	0	0.59	2.29	784.91	0.00	784.91	
0	0–0	10	0.99	3.1	1,222.55	47.27	1,175.27	825.77
0	0–0	15	1.19	3.36	1,422.91	70.91	1,352.00	747.69
2	0–0	0	1.02	3.06	1,242.55	87.27	1,155.27	D
0	46–20	0	1.44	3.43	1,640.91	120.73	1,520.18	1,090.76
2	0–0	10	1	3.51	1,283.09	134.55	1,148.55	D
0	46–20	10	1.63	4.84	1,979.27	158.18	1,821.09	689.63
2	0–0	15	1.21	3.98	1,518.55	164.36	1,354.18	D
0	46–20	15	1.69	5.51	2,114.73	188.00	1,926.73	354.27
2	46–20	0	1.62	4.45	1,921.27	204.36	1,716.91	D
2	46–20	10	2.08	6.01	2,504.55	251.64	2,252.91	1,100.00
2	46–20	15	1.74	6.66	2,302.91	275.27	2,027.64	D

D, dominated treatment; MRR, marginal rate of return. Price (USD kg^{-1}) of tef grain yield, straw yield, lime, urea, and DAP was 0.84, 0.13, 0.04, 0.51, and 0.55, respectively. The cost of cattle manure with transportation and incorporation into the soil was estimated as USD 0.47 per 100 kg. The cost of incorporation of lime into the soil was USD 0.73 per 100 kg, whereas the cost of transportation and application of fertilizer into the soil was estimated as USD 5.82 per 100 kg. Labor cost of man per day was USD 2.91.

To correct soil acidity and increase crop yields, soil amendments such as lime and organic materials must be applied [38]. The highest Ca and Mg content of experimental soils was due to the application of manure with lime (Table 3). Repšienė and Skuodienė [39] found that applying manure and lime together substantially increased calcium and magnesium levels. The combined application of lime and manure increased the amount of Mg available in the soil [40].

The overall cattle manure application with lime resulted in the highest available P after harvest (Table 3). The increase in available P with lime may be attributed to a decrease in exchangeable acidity and an increase in organic P mineralization. The release of organic acids during decomposition increased the available P content of the soil, which aided in the release of P. Manure also aids in the formation of intermediate compounds that interact with phosphorus-fixing cations such as Al, iron, and other metal cations, lowering P adsorption capability. Bekele et al. [13] observed that the combined application of fertilizer with lime significantly increased available P. This may be attributed to a large increase in soil pH as a result of the lime effect, which decreased P fixation. Fekadu et al. [41] found that when compost and lime interact, the available P increases due to the desorption effects of the lime and compost.

Before planting tef, the soil pH, total N, OC, available P, and CEC of the study areas were found to be below the optimum requirements for tef production, in general. The soil laboratory results after harvest (2 years) showed that the integrated use of soil amendments resulted in substantial improvement in the overall condition of the soil as well as tef productivity. As a result, the optimal tef production can be achieved using the study area's acidic soil amendments.

4.2 Vegetative growth of tef as influenced by soil amendments

Tef plant height increased as the rate of manure with NP fertilizer increased, indicating that ample supply of balanced essential nutrients from manure and NP fertilizers is responsible for the increase in plant height (Table 4). This could be due to manure's ability to provide multiple plant nutrients as well as create a favorable plant growing environment by enhancing the soil's moisture and nutrient status, all of which improve the plant's development and overall performance. In line with this experiment, Bekele et al. [13] showed that the highest rate of organic manure and P fertilizer resulted in the tallest maize height. Similarly, Dastmozd et al. [42] found that combining organic and synthetic fertilizers increased plant height more than using only synthetic fertilizers. Dinka et al. [43] also found that organic manures and industrial fertilizers had a positive impact on barley mean plant height.

Addition of 10 t ha^{-1} manure with NP fertilizer increased panicle length by 19 cm compared to control treatment (25 cm). Panicle length, which was 40 cm with sole application of NP fertilizer, increased to 44 cm when integrated with 10 t ha^{-1} cattle manure (Table 4). Fertilizer application and effective nutrient use result in high photosynthetic productivity and dry matter accumulation, resulting in panicle length. This is due to the combined application of organic and inorganic fertilizers, which increases synchrony and reduces losses by converting inorganic N into organic forms. Arif et al. [44] found that combining organic and inorganic fertilizers significantly increased rice panicle length over control, which is consistent with our finding.

In comparison to sole application of either cattle manure or inorganic NP fertilizer, the combined application of NP fertilizer and 10 t ha^{-1} manure resulted in a higher number of effective tef tillers (Table 4). This could be due to the synergistic effect of combining organic and mineral fertilizers, which could be attributable to increased macro- and micronutrient availability as well as more fertile spikes per plant. Our results are close to those of Prasad et al. [45], who found that using 10 t ha^{-1} manure in combination with prescribed NP fertilizer resulted in a higher number of effective tillers (8.4) of barley. The combined application of compost and mineral fertilizers significantly increased productive tillers of rice over control and sole application of either inorganic or organic fertilizer [46].

4.3 Grain yield and related parameters of tef as affected by soil amendments

In combined over years, the application of NP fertilizer alone significantly increased TSW (0.34 g) over the control. Furthermore, combining 46/20 kg ha^{-1} NP fertilizer with 10 t ha^{-1} manure resulted in a higher TSW (0.37 g) than sole application either NP fertilizer or manure (Table 4). The possible reason could be the use of manure and inorganic NP fertilizers improved tef's ability to partition dry materials into reproductive seed sinks. Dastmozd et al. [42] showed the application of 80 kg ha^{-1} N and 1.8 t ha^{-1} compost resulted in the highest TSW of wheat (42 g). The application of NP and cattle manure significantly affected barley TSW [4].

The combined application of 46/20 kg ha^{-1} N/P fertilizer and 10 t ha^{-1} of cattle manure with lime increased the combined over years grain yield by 266 and 35% when compared to the control treatment and sole application of NP fertilizer, respectively (Table 5). Thus, the synergistic effect of lime made a significant difference in terms of grain yield increment. In general, combining lime with fertilizer substantially increased tef grain yield in acidic soils as compared to fertilizer alone (Table 5). Increased tef grain yield due to the use of manure in combination with inorganic NP and lime could be related to the gradual release of nutrients into the soil after manure decomposition, resulting in enhanced plant growth and yield components. Furthermore, it could be attributed to the addition of both macro- and micronutrients from the manure, indicating that even a full rate of inorganic NP was insufficient for tef development in the study area. As a result, in acidic soils, lime application could be combined with the optimal amounts of inorganic and organic fertilizers. Golla [19] found that integrated acidic soil management improved yield stability and maximized nutrient use quality, which is in line with our findings. These findings were consistent with those of Demissie et al. [14], which found that using organic and commercial fertilizers in combination with lime improved barley yields more than their main effect. Tesfahun [47] also found that applying combined organic and inorganic nutrient sources alone was insufficient to substantially increase barley grain yield without the addition of lime. Boke and Fekadu [48] concurred that lime is essential but must be supplemented with other nutrients. The increasing effect of grain yield of tef could be mainly due to increasing of effective tillers, panicle length, TSW, and biomass yield in this study.

The combined application of 46/20 kg ha^{-1} N/P fertilizer and 15 t ha^{-1} of cattle manure with lime increased total biomass yield by 36 and 194% compared to the recommended rates of NP fertilizers and the control, respectively (Table 5). The luxuriant vegetative development of tillers, plant height, and panicle length responsible for the highest biomass output is most likely due to the combined impact of lime and NP fertilizer, as well as large manure doses. These findings were consistent with those of Bekele et al. [13], which found that the maximum rates of manure, P fertilizer, and lime produced the highest biomass yield of maize (12.18 t ha^{-1}). According to Fekadu et al. [41], applying 8 t ha^{-1} manure, 30 kg ha^{-1} P, and 3.6 t ha^{-1} lime increased the biological yield of faba bean from 1.91 to 4.43 t ha^{-1}. The combined use of organic and industrial fertilizers resulted in a highly significant difference in bread wheat and rice biomass yield [49]. The interaction effects of lime, manure, and P fertilizer on maize biomass yield were found to be significant [47].

The highest rate of animal manure with lime and NP fertilizer resulted in the highest straw yield (Table 5). This may be because when acidic soils were treated with organic manure and mineral NP combined with lime, the supply of critical nutrients for crop growth and development increased. Similarly, Demissie et al. [14] found that increasing the rate of cattle manure, as well as NP fertilizer and lime, increased barley straw yield. The application of 8 t ha^{-1} farm yard manure, P fertilizer, and lime substantially increased the yield of faba bean straw from 1,037 to 2,904 kg ha^{-1} [41].

4.4 Economic analysis

The highest MRR of 1,100% was achieved by combining the application of 2 t ha^{-1} lime with 10 t ha^{-1} cattle manure and 46/20 kg ha^{-1} N/P fertilizer (Table 6), implying that for every Birr invested in tef production, the producers will receive 11.00 Birr after recovering their investment CIMMYT [33]. Using manure rates more than 10 t ha^{-1} in combination with 2 t ha^{-1} lime and 46/20 kg ha^{-1} N/P fertilizer will result in higher variable costs with no compensatory advantage. This represents an increase in net return of at least 1 Birr for every Birr invested. Therefore, the manure rate of 10 t ha^{-1} in combination with 2 t ha^{-1} lime and 46/20 kg ha^{-1} N/P fertilizer application, which had the highest grain yield (Table 5) and, thus, had higher NB (2,252.91 USD ha^{-1}) and acceptable MRR (1,100%), can be recommended for farmers in the area. In line with this finding, Ryan et al. [50] found similar results. Thus, for increased grain yield of tef in strongly acidic soils, a combination of 2 t ha^{-1} lime, 10 t ha^{-1} cattle manure, and 46/20 kg ha^{-1} N/P fertilizer is ideal and could be recommended.

5 Conclusion

The results showed that applying cattle manure in combination with NP fertilizer and lime significantly improved soil chemical properties compared to the control. Growth parameters and yield components of tef were significantly affected by the interaction effects of cattle manure and NP fertilizers. The combined application of lime, NP fertilizer, and cattle manure significantly affected grain, straw, and biomass yield of tef. The combined application of 46/20 kg ha^{-1} NP fertilizers and 15 t ha^{-1} cattle manure increased OC, total N, and CEC by 89, 109, and 34%, respectively, relative to the control. Similarly, the combined application of 15 t ha^{-1} cattle manure and 2 t ha^{-1} lime increased OC, soil pH, and available P by 58, 14, and 62%, respectively, relative to the control. Furthermore, the combined application of 46/20 kg ha^{-1} NP fertilizers and 10 t ha^{-1} cattle manure increased panicle length, effective tillers, and TSW of tef by 10, 15, and 9%, respectively, relative to the sole application of NP fertilizers. The combined application of 10 t ha^{-1} cattle manure, 46/20 kg ha^{-1} NP fertilizers, and 2 t ha^{-1} lime resulted in the highest grain yield of tef (2.31 t ha^{-1}), net return (2,252.91 USD ha^{-1}), and MRR (1,100%). This treatment increased the tef grain yield by 35 and 266% compared to the recommended rates of NP fertilizers and the control, respectively. In northwest Ethiopian highlands, a combination of 10 t ha^{-1} cattle manure, 46/20 kg ha^{-1} NP fertilizers, and 2 t ha^{-1} lime is recommended as an effective soil amendment to improve soil fertility and tef productivity. The field experiment was conducted only for two years. Thus, a more long-term experiment should be established to obtain concrete information on the effects of soil amendments on crop yield and soil properties.

Acknowledgments: Our special gratitude to all persons involved during data collection, data analysis, writing, and improvement of this article. Furthermore, I express our thank to Ministry of Science and Higher Education and Debre Markos University for giving me an opportunity to pursue PhD studies.

Funding information: The authors state no funding involved.

Author contributions: Y.H. performed all the research activities such as collecting data, analyzing data, and writing the manuscript. All authors contributed to the manuscript enhancement and finalization, read, and approved the submitted version.

Conflict of interest: The authors state no conflict of interest.

Data availability statement: The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

References

[1] Vavilov NI. The origin, variation, immunity and breeding of cultivated plants. New York: Roland Press; 1951. (Translated from the Russian by K. Starrchester).

[2] Baye K, Mouquet-Rivier C, Icard-Vernière C, Rochette I, Guyot J-P. Influence of flour blend composition on fermentation kinetics and phytate hydrolysis of sourdough used to make injera. Food Chem. 2013;138(1):430–6.

[3] Ketema S. Tef. (Eragrostis tef (Zucc.) Trotter). Promoting the conservation and use of underutilized and neglected crops. 12. Institute of Plant Genetics and Crop Plant Research. Rome, Italy: Gatersleben/International Plant Genetic Resources Institute; 1997.

[4] CSA (Central Statistics Agency). Agricultural Sample survey: Report on area and production of crops (private peasant holdings, meher season). Addis Ababa, Ethiopia: Statistical Bulletin 590; 2019.

[5] East Gojjam Zone Agriculture Office. Annual crop performance report for 2016/2017 cropping season. Agricultural Office; 2017. p. 35.

[6] Birhanu A, Degenet Y, Tahir Z. Yield and agronomic performance of released Tef [*Eragrostistef* (Zucc.) Trotter] varieties under irrigation at Dembia, Northweastrn, Ethiopia. Cogent Food Agricul. 2020;6:1762979.

[7] Wato T. Effects of nitrogen fertilizer rate and inter-row spacing on yield and yield components of teff [Eragrostis teff (Zucc.) Trotter] in Limo district, southern Ethiopia. Int J Plant Soil Sci. 2019;31(3):1–12.

[8] Woldesenbet M, Tana T, TN S, Mekonnen T. Effect of integrated nutrient management on yield and yield components of food barley (Hordeum vulgare L.) in Kaffa zone, Southwestern Ethiopia. Sci Technol Arts Res J. 2014;3(2):34–42.

[9] Kidanemariam A, Gebrekidan H, Mamo T, Tesfaye K. Wheat crop response to liming materials and N and P fertilizers in acidic soils of Tsegede highlands, northern Ethiopia. Agric For Fish. 2013;2(3):126–35.

[10] Asrat M, Gebrekidan H, Yli-Halla M, Bedadi B, Negassa W. Effect of integrated use of lime, manure and mineral P fertilizer on bread wheat (Triticum aestivum) yield, uptake and status of residual soil P on acidic soils of Gozamin District, north-western Ethiopia. Agric For Fish. 2014;3(2):76–85.

[11] Zelleke G, Agegnehu G, Abera D, Rashid S. Fertilizer and soil fertility potential in Ethiopia: constraints and opportunities for enhancing the system. Addis Ababa: International Food Policy Research Institute; 2010.

[12] Gebreselassie Y. Selected chemical and physical characteristics of soils of Adet research center and its testing sites in North Western Ethiopia. Ethiop J Nat Resour. 2002;4(2):199–215.

[13] Bekele A, Kibret K, Bedadi B, Yli-Halla M, Balemi T. Effects of lime, vermicompost and chemical P fertilizer on selected properties of acid soils of Ebantu District, Western Highlands of Ethiopia. Appl Environ Soil Sci. 2018;2018:8178305.

[14] Demissie W, Kidanu S, Raghavaiah CV. Effect of integrated use of lime, blended fertilizer and compost on productivity, nutrient removal and economics of barley (Hordeum vulgare L.) on acid soils of high lands in West Showa Zone of Ethiopia. Int J Life Sci. 2017;5(3):311–22.

[15] Agegnehu G. Ameliorating effects of organic and inorganic fertilizers on crop productivity and soil properties on reddishbrown soils. In: Proceedings of the 10th Conference of the Ethiopian Society of Soil Science; 2010. p. 127–40.

[16] Nada WM, van Rensburg L, Claassens S, Blumenstein O. Effect of vermicompost on soil and plant properties of coal spoil in

the Lusatian region (Eastern Germany). Commun Soil Sci Plant Anal. 2011;42(16):1945–57.
[17] Balemi T. Composition of different composts and vermicompost and effects of their application rates on growth parameters of pot grown tomato. Afr J Agric Res. 2017;12(18):1514–25.
[18] Tadesse T, Dechassa N, Bayu W, Gebeyehu S. Effect of farmyard manure and inorganic fertilizers on the growth, yield and moisture stress tolerance of rain-fed lowland rice. Am J Res Commun. 2013;1(4):275–301.
[19] Golla AS. Soil acidity and its management options in Ethiopia: a review. Int J Sci Res Manag. 2019;7(11):1429–40.
[20] Verde B, Danga B, Mugwe J. Influence of manure, phosphate fertilizer and lime on soil available NPK and uptake of NP by soybean in Embu county, Kenya. Discovery. 2018;54(265):13–22.
[21] Hazelton P, Murphy B. Interpreting soil test results: what do all the numbers mean. Collingwood, Australia: CSIRO Publishing; 2007. p. 152.
[22] Bouyoucos GJ. A recalibration of the hydrometer method for making mechanical analysis of soils. Agron J. 1951;43(9):434–8.
[23] Walkley A, Black IA. An examination of the degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. Soil Sci. 1934;37(1):29–38.
[24] Havlin JL, Beaton JD, Tisdale SL, Nelson WL. Function and forms of N in plants. Soil Fertility and Fertilizers. 6th edn. New Jersey: Prentice Hall; 1999. p. 345.
[25] Tadesse T, Haque I, Aduayi EA. Soil, plant, water, fertilizer, animal manure and compost analysis manual. Plant division working document 13, Addis Ababa, Ethiopia: ILCA; 1991.
[26] Landon JR. Booker tropical soil manual: a handbook for soil survey and agricultural land evaluation in the tropics and subtropics. Essex, New York: Longman Scientific and Technical; 1991. p. 474.
[27] Metson AJ. Methods of chemical analysis for soil survey samples. Soil Bureau Bulletin No. 12, New Zealand Department of Scientific and Industrial Research. Wellington, New Zealand: Government Printer; 1961. p. 168–75.
[28] FAO. Fertilizer development in support of the comprehensive Africa agriculture. In: Twenty-third regional conference for Africa; 2004 Mar 1-5; Johannesburg, South Africa; 2007.
[29] Abewa A, Yitaferu B, Selassie YG, Amare T. The role of biochar on acid soil reclamation and yield of teff (*Eragrostis tef* [Zucc] Trotter) in northwestern Ethiopia. J Agric Sci. 2014;6(1):1–12.
[30] Assefa A, Tana T, Abdulahi J. Effects of compost and inorganic NP rates on growth, yield and yield components of teff (Eragrotis teff (Zucc.) Trotter) in Girar Jarso district, central highland of Ethiopia. J Fertil Pestic. 2016;7:1–8.
[31] SAS-Institute SAS 9.4. Cary, NC, USA: SAS Institute Inc. 2014.
[32] Gomez KA, Gomez AA. Statistical procedures for agricultural research. New York (NY): John Wiley and Son; 1984.
[33] CIMMYT (International Maize and Wheat Improvement Center). An economic training manual: from agronomic data to farmers recommendations. Mexico: CIMMYT; 1988. p. 79.
[34] Laxminarayana K, John KS, Ravindran CS, Naskar SK. Effect of lime, inorganic, and organic sources on soil fertility, yield, quality, and nutrient uptake of sweet potato in alfisols. Commun Soil Sci Plant Anal. 2011;42(20):2515–25.
[35] Amba AA, Agbo EB, Voncir N, Oyawoye MO. Effect of phosphorus fertilizer on some soil chemical properties and nitrogen fixation of legumes at Bauchi. Continent J Agric Sci. 2011;5(1):39–44.
[36] Singh S, Singh RN, Prasad J, Binod K. Effect of green manuring, FYM and biofertilizer in relation to fertilizer nitrogen on yield and major nutrient uptake by upland rice. J Indian Soc Soil Sci. 2002;50(3):313–4.
[37] Tolanur ST. Integrated nutrient management on physical conditions, soil fertility and productivity of crops in dry land vertisol. Karnataka J Agric Sci. 2002;14(3):186–7.
[38] Abebe Z, Tolera A. Yield response of faba bean to fertilizer rate, rhizobium inoculation and lime rate at Gedo highland, western Ethiopia. Glob J Crop Soil Sci Plant Breed. 2014;2:134–9.
[39] Repšienė R, Skuodienė R. The influence of liming and organic fertilization on the changes of some agrochemical indicators and their relationship with crop weed incidence. Žemdirbystė (Agriculture). 2010;97(4):3–14.
[40] Ortiz Escobar ME, Hue NV. Temporal changes of selected chemical properties in three manure - amended soils of Hawaii. Bioresour Technol. 2008;99(18):8649–54.
[41] Fekadu E, Kibret K, Melese A, Bedadi B. Yield of faba bean (Vicia faba L.) as affected by lime, mineral P, farmyard manure, compost and rhizobium in acid soil of Lay Gayint District, northwestern highlands of Ethiopia. Agric Food Secur. 2018;7:16.
[42] Dastmozd GR, Ebrahimi HR, Haghighi BJ. Combined application of vermicompost and NPK fertilizers on wheat production in Marvdasht. Res J Fish Hydrobiol. 2015;10(10):153–6.
[43] Dinka TB, Goshu TA, Haile EH. Effect of integrated nutrient management on growth and yield of food barley (Hordeum vulgare) variety in Toke Kutaye district, West Showa Zone, Ethiopia. Adv Crop Sci Tech. 2018;6(3):365.
[44] Arif M, Tasneem M, Bashir F, Yaseen G, Iqbal RM. Effect of integrated use of organic manures and inorganic fertilizers on yield and yield components of rice. J Agric Res. 2014;52(2):197–206.
[45] Prasad J, Thomas T, Bharosre R, Mir AZ. Effect of organic and inorganic source of nutrients on growth and yield of barley (Hordeum vulgare L.). J Pharmacogn Phytochem. 2019;8(2):521–3.
[46] Sahu P, Chandrakar T, Paikra M, Josh KK. Effect of organic and inorganic sources of nutrients on yield attributing characteristics and yield of direct seeded rice in inceptisols of Bastar Plateau zone. Int J Curr Microbiol Appl Sci. 2018;7(3):3757–61.
[47] Tesfahun W. Tef yield response to NPS fertilizer and methods of sowing in East Shewa, Ethiopia. J Agric Sci. 2018;13(2):162–73.
[48] Boke S, Fekadu A. Lime and NPK effect on soil acidity and yield of barley in different acid soils of southern region, Ethiopia. Int J Nat Sci Res. 2014;2(7):113–22.
[49] Admasu A, Tadesse K. Response of organic and inorganic fertilizers on growth and yield of wheat at Kulumsa in Arsi Highlands of Ethiopia. J Agric Res (Lahore). 2018;3(6):1–6.
[50] Ryan J, Monem MA, Amri A. Nitrogen fertilizer response of some barley varieties in semi-arid conditions in Morocco. J Agric Sci Technol. 2009;11:227–36.