9. Response of Tef [*Eragrostis tef (Zucc.) Trotter*] to N and P Application Rates in the Highland Vertisols of North Shewa

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Abstract

Blanket application of Nitrogen and Phosphorus could increase crop yield relatively compared to the plots apply

yield to their potential due to soil fertility depletion from time to time. Therefore, impacts of Nitrogen and Phosphorus rates on tef yield and yield componenthave been tested in Moretinajiru, Ensaro and Merhabete districts of North Shewa, Ethiopia in 2019 and 2020. The experiment was comprised of four levels of P (0, 30, 60 and 90 Kgha^{-1} P) and five levels of N (0, 60, 120, 180 and 240 Kgha^{-1} N). The factorial combinations of the factors were laid out in RCBD with three replications. All these treatment combinations were assigned in two soil types (light and heavy Vertisols) and two precursor crops (pulse and cereal). Lentil and wheat at Moretinajiru, chickpea/grasspea, tef and wheat at Ensaro, and tef and chickpea at Merhabete are the most important precursor crops for tef. For this study, plant height, panicle length, total tillers, fertile/productive tillers, biomass yield, grain yield, straw yield, and harvest index were collected for this study. The collected data were subjected to analyses of variance (ANOVA) using R statistical software and linear mixed modeling used for the analysis. The analysis of variance showed that N rate, Precursor crops and soil types significantly influenced most of the measured parameters. Nevertheless, application of different rate of P significantly influenced biomass and grain yield in Ensaro and Merhabete districts. Tef grain yield progressively increased with increasing N rates from zero to 240 Kgha^{-1} N in both locations. In Moretinajiru district, the grain yield increment ranged from 130-229%. Similalry, in Ensaro and Merhabete, grain yield increment ranged from 107-219% and from 122-331%, respectively. Application of P fertilizer increased tef grain yield only in Ensaro and Merhabete districts. Generally, the grain yield obtained from heavy Vertisols and pulse precursor crops was found superior over that obtained from the light Vertisols and cereal precursor. The combined application of N/P at the rate of 180/0, 240/30, and 240/90 on heavy Vertisols with cereal precursor crops resulted in the highest net benefit in Moretina Jiru, Ensaro, and Merhabete areas respectively. For the same type of Vertisols with pulse precursor crops, application of 180/30, 240/90, and 120/60 N/P resulted in the highest net benefit in the respective areas. The combined application of N and P at the rate of 240/60, 180/60, and 180/90 on light Vertisols with cereal precursor crops resulted in the highest net benefit of 105664 ETB, 72697 ETB, and 70419 ETB in Moretina

Jiru, Ensaro, and Merhabete areas respectively. For the same type of Vertisols with pulse precursor crops, application of 240/90, and 240/90 resulted in the highest net benefit of 113429 ETB, and 57863 ETB in Moretina Jiru, and Ensaro areas, respectively. Therefore, applications of those treatment combinations were recommended for the district, soil type and precursor crops.

Keyword*:* *Tef, heavy Vertisols, light Vertisols, Precursor crops*

Introduction

Vertisols, a black cracking clay soil are an important resource in the tropics and subtropics (Syers *et al.,* 2001). Vertisols are montmorillonite-rich clay soils with characteristic shrinking and swelling properties. They have high clay content and when dry they show cracks of at least 1 cm wide and 50 cm deep ((FAO), 2000). They have high calcium and magnesium contents. Considering its high clay content, Vertisols are generally high moisture retention capacity. The pH of Vertisols on Ethiopian highlands varies from slightly acidic to strongly alkaline and depends on different factors (Zewdie, 2001).Therefore, it is an important agricultural soil in Ethiopia covering about 12.7 million ha for production of mainly wheat, tef and chickpea (Mesfin, 1998). Vertisols of the Ethiopian highlands were reported as low in total Nitrogen (TN), available P and organic matter content (OM) (DUDAL, 1963; Hubble, 1984; Mamo and Haque, 1991; Kiflu and Beyene, 2013; Giday *et al.*, 2014; Hailu *et al.*, 2015). Its severe water logging problems limit their productivity. Studies show that N fertilizer application enhanced the productivity of Vertisols with the 55 Kgha^{-1} N for tef (Mamo *et al.*, 1996) and 64 Kgha^{-1} N for durum wheat were determined to be the economic optimal rates (Workneh and Mwangi, 1992).

Tef (*Eragrostis tef* (Zucc.) Trotter) is one of the major cereals grown for thousands of years (D'Andrea, 2008). Tef is adapted to diverse agro-ecological regions of Ethiopia and grows well under stress environments better than wheat, barley and other cereals (Leta, 2012). The crop plays a vital role in the country's overall food security and it is the staple food for most Ethiopian people (Kassaye *et al.*, 2021). Since recently, tef received global attention as a health food because of its gluten-free nature that renders it suitable for people suffering from gluten allergy known as celiac disease (Spaenij-Dekking *et al.*, 2005). Tef plays an important role in supplying the population of the country with protein, carbohydrates and minerals. Moreover, the straw is an important cattle feed source. The national average mean tef grain yield was 1465 Kgha^{-1} for Ethiopia, 1495 for Amhara Region and 1513 Kgha^{-1} for North Shewa (CSA, 2018/19).

Most of the Ethiopian soils contain low nutrients due to erosion and absence of nutrient recycling. Most of the areas used for production of grains especially tef, wheat and barley fall under the low fertility soils (Tefera *et al.*, 2000). Low availability of Nitrogen and Phosphorus were major constraint to cereal production. Fertilizer usage plays a major role in the universal need to increase food production to meet the demands of the growing world population (Melaku, 2008).

Berhe and Zena (2008), recommended 60 Kg N and 26 P_2O_5 Kgha^{-1} for tef production on heavy clay soils (Vertisols) while Ketema (1997) and Achakzai and Taran (2011) recommended 40 Kg N and 26 P ha^{-1} for tef production on sandy clay loam soils (*Andosols*). Recently, Tesfahun (2018) recommend 120 Kg NPS fertilizer (20 Kgha^{-1} P, 22.8 Kgha^{-1} N, 8.4 Kgha^{-1} S) with transplanting method as one effective ways to maximize tef grain yield around Debre Zeit. Nevertheless, in some areas like Moretinajiru, Merhabete and Ensaro farmers use fertilizer beyond the recommended fertilizer rates. In Moretinajiru district, farmers apply 186.5 Kgha^{-1} N and 57.1 Kgha^{-1} P for tef production on Vertisols. Likewise, in Ensaro district farmers also apply 131.8 Kgha^{-1} N and 50 Kgha^{-1} P, which are far above the national recommendation of the crop in Vertisols (preliminary assessment). Farmers in the study areas classify Vertisols as heavy Vertisols called “Mererie” and light Vertisols as “kelal Mererie or bushel). Therefore, the objective of this study was to evaluate the effect of combined application N and P nutrients on yield and yield component of Tef on different soils (having different vertic properties) and precursors.

Materials and Methods

Description of the Study Sites

Merhabete: Merhabete district is situated in Northern Shoa zone of Amhara Regional State. Its altitude ranges from 1050-2650 m.a.s.l. The total area of the district is estimated to be about 121,000 ha. From this area, 27% was covered by cultivated land, (53%) by grassland and fallow, (10%) was covered by bushes and shrubs and (10%) was degraded land. The major proportion of the area lies in Weyna Dega (73%) followed by Kolla (20%), and Dega (6%). The dominant soil type is Vertisols on the plateau of the district. The average annual rainfall is estimated to be 1017.8 mm with unimodal pattern. The mean min and mean max temperature of the district was estimated to be 13.1 and 25.3^{0}C, respectively Rain fed mixed farming is a predominant occupation in the district with average land holdings of less than 2 ha. The major crops grown in the district are sorghum (*Sorghum bicolor* L), tef ([*Eragrostis tef (Zucc.) Trotter*] (30%), barley (*Hordeum vulgare)*, wheat (*Triticum aestivum*), pulse, and horticultural crops (3%).

Moretina Jiru: Moretina jiru district is situated in Northern Shoa Zone of Amhara Regional State. Its altitude ranges from 1500-2694 m.a.s.l. The total area of the district is estimated to be 66,116 ha of which 87% of the area is cultivated. Vertisols is a dominant soil type especially in the highland plateau of the district. The average annual rainfall is estimated to be 981.8 mm with unimodal pattern. The mean min and mean max temperature of the district was estimated to be 9.4 and 22.1^{0}C, respectively (Table 1). The farming system is characterized by mixed crop-livestock farm. The crops widely grown in the study area include wheat (*Triticum aestivum*), Tef ([*Eragrostis tef (Zucc.) Trotter*], faba bean (*Vicia faba)* and lentil (*Lens culinaris)*, whereas chickpea (*Cicer arietinum)*, grass pea **(***Lathyrus sativus)* and others have low area coverage and mostly grow on residual soil moisture at the end of the rainy season (Chanyalew *et al.*, 2018).

Ensaro District: Ensaro district is situated in Northern Shoa Zone of Amhara Regional State. Geographically, the district is located between 9^{0}35'-9^{0}55'N and 38^{0}50'-39^{0}5'E. Its altitude ranges from 1200 to 2700 m.a.s.l with an average elevation of 2435 m.a.s.l. The total area of the district is estimated to be 44,217.6 ha. Vertisols is a dominant soil type in the districts. The average annual rain fall is estimated to be 1276.4 mm with a unimodal pattern. The average mean min and max temperature of the district was estimated to be 6.9 and 22.2^{0}C, respectively. The farming system is characterized by mixed crop-livestock farm. The crops widely grown in the study area include wheat (*Triticum aestivum*), Tef ([*Eragrostis tef (Zucc.) Trotter*], sorghum (*Sorghum bicolor* L), chickpea (*Cicer arietinum)*, grass pea **(***Lathyrus sativus)*. The growth period average rain fall, maximum and minimum temperature of all districts were presented Figure

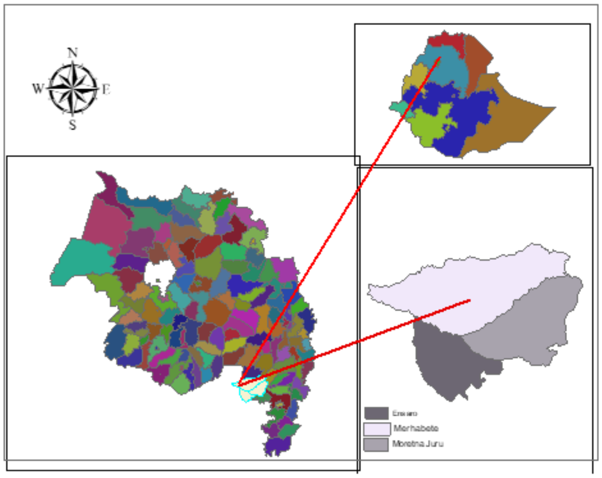

Figure 10. Location map of the study areas

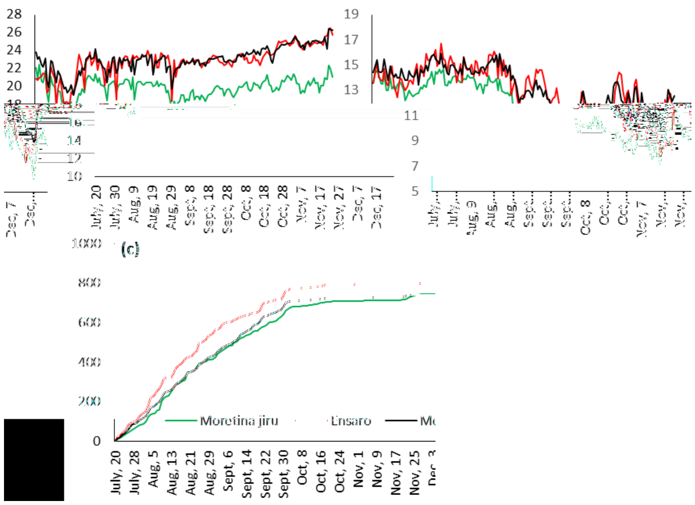

Figure 2. (a) Average daily minimum temperature, (b) daily average maximum temperature and (c) cumulative rainfall during the growth period.

Fertilizer Use Practice of Farmers: From the two districts, 46 farmers (21 in Moretinajiru and 25 in Ensaro) were interviewed for the amount of N and P they were applying to their farm. Hence, in Moretinajiru, of the interviewed farmers, 4.5%, applied 60-120 Kg N; 59%, applied 120-180 Kg N; 13.6% applied 180-240 Kg N; and 22.7% applied above 240 Kgha^{-1} N. Likewise, 36.4% of the interviewed farmers applied 30-60 Kg P and 63.6% applied 60-90 Kgha^{-1} P. In Ensaro district 54%, applied 60-120 Kg N; 33.3%, applied 120-180Kg N; 8.3% applied 180-240 Kg N and 4.2% applied 240 Kg and above N ha^{-1}. Similarly, 4.2% of the interviewed farmers applied 0-30 Kg P; 66.7% applied 30-60 Kg P; 2.5% applied 60-90 Kg P and 4.2% 90 Kg and above Pha^{-1}. Indicating that farmers are not applying recommended N and P fertilizer for the test crop on Vertisols (60 and 26 Kgha^{-1} P) (Berhe and Zena, 2008). Farmers in the study area use higher fertilizer rate especially N for heavy Vertisols. The most important precursor crop for tef were lentil and wheat in Moretinajiru, chickpea/grass pea, tef and wheat in Ensaro and tef and chickpea in Merhabete

Treatments, Design and Experimental Procedure: The experiment comprised of four levels of P (0, 30, 60 and 90 Kgha^{-1} P), and five levels of N (0, 60, 120, 180 and 240 Kgha^{-1} N). The factorial combinations of the three factors (4x5=20) were laid out in RCBD with three replications. Considering the type of Vertisols and precursor crops, the total number of treatments were 80. All these treatment combinations were assigned in two soil types (light Vertisols and heavy Vertisols) and two precursor crops (pulse and cereal) in each district. Nevertheless, we haven't found light Vertisols with pulse precursor crops in Merhabete district. The test crop, tef variety, Dega (In Moretinajiru and Ensaro) and Kora in Merhabete were broadcasted in the rate of 25.0 Kgha^{-1} in a unit plot size 6.25 m^2. The space between blocks and plots will be 1.5 and 1m respectively. Planting was in the mid of July and all plots were fertilized with equal amount of S, Zn and B with a rate of 10, 2 and 0.1 Kgha^{-1} respectively. The entire Phosphorus, Sulphur, Zinc and Boron fertilizer as per the treatment were applied at planting as triple super phosphate, calcium sulfate, Zinc sulfate and borax. While the recommended N fertilizer as urea indicated in the treatment was applied two times half at planting and the other half at tillering stage of the crop on the presence of soil moisture

Soil Sampling and Analysis: Pre-planting composite surface soil samples (0-20 cm depth) were collected from each farm from 10 sampling spot of the entire experimental site for the determination of soil physico-chemical properties using auger in zigzag pattern. The soil sample were composited in to one for each farmer's field. The soil samples from each farmer's field were composited to one with sample weight of 1 Kg. The samples were then brought to Debre Birhan agricultural research Center soil laboratory where it was analyzed. The samples were air-dried ground and passed through a 2 mm sieve for most parameters except for OC and TN, which passed through 0.5 mm sieve. The processed samples were analyzed for texture following by Bouyoucous hydrometer method (Bouyoucos, 1951). The pH of the soil was measured using pH-water method by making soil to water suspension of 1:2.5 ratio and was measured using a pH meter (Chapman, 1965)). The soil OC (organic carbon) content was also determined by wet digestion method (Walkley, 1934). The total Nitrogen (TN) was determined by using the modified micro Kjeldhal method (Cottenie, 1980), while the available Phosphorus was determined by following Olsen's calorimetric method as described by Olsen (1954).

Crop Data Collection: The following data were collected for this study.

Plant Height (cm): ten randomly selected plants were measured from ground level to the tip of the main shoot panicle using steel tape at the maturity stage of the crop. The average was computed for statistical analysis.

Panicle Length (cm): ten randomly selected plants from each plot were measured from the node where the first panicle starts to the tip of the panicle using steel tape at the maturity stage of the crop. The average was used for statistical analysis.

Total Tillers (plant-1): The numbers of tillers (both effective and non-effective tillers) were determined by counting all the tillers of randomly selected ten plants from each plot at physiological maturity.

Number of fertile tillers plant^{-1}: The numbers of tillers bearing panicle were determined at maturity by counting the tillers from randomly selected ten plants from each plot.

Biomass Yield (Kgha^{-1}*)*: Atharvest maturity, aboveground dry biomass was weighted after sun drying until constant weight obtained from the net plot area. It was expressed in Kgha^{-1}.

Grain Yield (Kgha^{-1}*)*: was weighted after harvesting and threshing the crop from the net plot area and the yield was expressed in Kgha^{-1} then the weight was adjusted to 12.5% moisture content

Straw Yield (Kgha^{-1}*)*: After threshing and measuring the grain yield, the straw yield was determined by subtracting the grain yield from the total aboveground biomass yield.

Harvest Index: Harvest index was calculated by dividing grain yield by the total aboveground dry biomass yield.

Data Analysis: The collected data were subjected to statistical analyses of variance (ANOVA) using R statistical software (Team, 2018). A generalized linear modeling framework was used to determine the variation in plant height, panicle length, total/ferile tiller, biomass yield, grain yield, and harvest index with the different levels of N and P, combining soil type for the first analysis and different levels of N and P combining precursor crops for the second analysis. The general linear model ((in PROC GLM of the SAS system) was selected for different level of analysis because it allows for comparing how several variables affect different continuous variables.

The initial model was of the following form:

(1),

where μ is the grand mean, soil is type of vertisols according to farmers classification, N is N rate, P is P and ε is the error term

(2), where μ is the grand mean, prec is the precursor crops for tef, N is N rate, P is P and ε is the error term. Wherever the treatment effect was significant, mean separation was made using Tukey's HSD. Means were considered to be significantly when $p \leq 0.05$.

Partial Budget Analysis: The partial budget analysis was done following the procedures described by (Program *et al.*, 1988). For partial budget analysis, the variable cost of fertilizer and labor were taken at the time of planting and during other operations. Field price of the grain and straw yield of tef was considered one month from the time of crop harvesting. The average yield was adjusted down ward by 10 % to reflect the farmer's field yield as described by (CIMMYT, 1988). The return was calculated as total gross return minus total variable cost. Field grain price (38 ETBKg^{-1} grain in Moretina Jiru and Ensaro, and 37 ETBKg^{-1} grain in Merhabete area) was considered by average of one month from the time of crop harvesting. Farm gate price of P (52.6 ETB Kg P), Farm gate price of N (32.9 ETBKg N) during planting in all locations was considered for partial budget analysis.

Results and Discussion

Soil Physico-Chemical Properties of the Experimental Site/S: The dominant soil texture of all experimental sites was clay (Table). The CEC of the soils in the experimental plots was high (Hazelton and Murphy, 2016). Similarly, others scholars also reported Vertisols are high CEC content. The results also indicated that soil pH of all the experimental sites was neutral which is ideal for the production of most field crops including tef (Tadesse *et al.,* 1991; Landon, 2014). According to (Mamo and Haque, 1991), the total Nitrogen content and soil organic matter content of the soil were rated as low. Others authors also reported that Vertisols of Ethiopia is deficient in total N (Finck and Venkateswarlu, 1982; Mengel and Kirkby, 1987; Mesfin, 1998; Hailu *et al.*, 2015). While the available P content was rated as medium (Olsen, 1954).

Table 1. Soil-physico-chemical properties of the experimental sites

Location	Soil physico-chemical properties	Values	Rating	Method
Moretina jiru	Textural Class		Clay	Hydrometer method
	Clay	76.34		
	Silt	14.21		
	Sand	9.45		
	pH	6.9	Neutral	1:2.5 water
	CEC ($CmolKg^{-1}$)	56	Very high	Ammonium acetate
	SOC (%)	0.87	Low	Walkley and Black
	TN (%)	0.08	Low	Kjeldahl method
	Av.P ($mgKg^{-1}$)	14.3	Medium	Olsen
Ensaro	Textural Class		Clay	Hydrometer method
	Clay	68.12		
	Silt	23.4		
	Sand	8.48		
	pH	6.8	Neutral	1:2.5 water
	CEC ($CmolKg^{-1}$)	42	High	Ammonium acetate
	SOC (%)	0.99	Low	Walkley and Black
	TN (%)	0.094	Low	Kjeldahl method
	Av.P ($mgKg^{-1}$)	6.9	Medium	Olsen
Merhabete	Textural Class		Clay	Hydrometer method
	Clay	63.9		
	Silt	22.2		
	Sand	13.9		
	pH	6.8	Neutral	1:2.5 water
	CEC ($CmolKg^{-1}$)	37	High	Ammonium acetate
	SOC (%)	1.041	Low	Walkley and Black
	TN (%)	0.088	Low	Kjeldahl method
	Av.P ($mgKg^{-1}$)	5.3	Medium	Olsen

The three-way interaction of precursor, N and P fertilizer rate were found significant only on harvest index in Moretinajiru district.

In Moretinajiru district, tef having pulse precursor crop was found superior over cereal precursor in all the measured parameters (Table 2). The highest biomass yield, grain yield, plant height, and panicle length, which were observed from pulse precursor crop. This factor increased the respective parameters by 6.6% (427.1 Kgha-1), 7.2% (122.8 Kgha-1), 3.5% (3.5 cm) and 6% (1.7 cm), respectively compared with the lowest value observed from cereal precursor. The present study established a higher response of yield to pulse precursor compared to cereal precursor crop. This was explained by the fact that pulse crop fixes atmospheric N and make portion of the fixed N for the subsequent crop (Ross et al., 2015; Lal, 2017; Liu et al., 2020). Soil fertility through reduction of soil erosion and hence soil depletion is improved by crop rotation that involves legume crops (Azene et al., 2005). Pulse crops also reduce disease, increase availability and uptake of P, K and S nutrient from the soil, improve the structure of soil, and release crop growth promoting substance (Stevenson and Kessel, 1996; Lupwayi and Kennedy, 2007; Arcand et al., 2014; Mazzilli et al., 2016). Similarly, different authors reported the impact of pulse precursor crop on subsequent crop (Anderson, 2008; Kirkegaard et al., 2008; Strydhorst et al., 2008; Bennett et al., 2012; Angus et al., 2015; Ross et al., 2015; Mazzilli et al., 2016; Adamu, 2018).

In Merhabete district, the highest grain yield, harvest index, plant height panicle length which were observed from tef plothaving pulse precursor crop increased the respective parameters by 13.5%% (173.5 Kgha^{-1}), 23.8% (0.05), 4% (4.8 cm) and 5.8% (2 cm), respectively. This was justified by the fact that pulse crop fix Nitrogen from the air and make a portion of the fixed N to the subsequent tef crop. Nevertheless, the highest (6191 Kgha^{-1}) and lowest (5739 Kgha^{-1}) biomass yield was observed from tef plothaving cereal precursor crop. In Ensaro district, the highest grain yield and harvest index were observed from tef plothaving cereal precursor (Table 3). In other hand, the highest biomass yield and plant height were observed from pulse precursor crop.

Table *2* The impact of precursor on tef growth, yield related and yield data

Parameters	Moretinajiru		Ensaro		Merhabete	
	Pulse	Cereal	Pulse	Cereal	Pulse	Cereal
Biomass yield	6906^{a*}	6478.9^{b}	4980.4^{a}	4561.4^{b}	5738.7^{b}	6191.1^{a}
Grain Yield	1817.3^{a}	1694.5^{b}	1263.4^{b}	1432.5^{a}	1463.3^{a}	1289.8^{b}
Harvest Index	0.28	0.27	0.27^{b}	0.33^{a}	0.26^{a}	0.21^{b}
Plant height	76.8^{a}	74.2^{b}	71.4^{a}	69.1^{b}	99.4^{a}	95.6^{b}
Panicle length	29.9^{a}	28.2^{b}	27.1	27.5^{b}	36.4^{a}	34.4^{b}
Number of tiller	4.5	4.6	4.4	4.7		

**Means followed by same letter at each location in a row are not significantly influenced at P>0.05 level of probability following DMRT*

The analysis of variance showed grain and biomass yields were increased with increased N rates in all locations (Figure 11). This is attributed the highest loss of applied N from the soil. The mode of application of fertilizer for tef cultivation is broadcasting the fertilizer on the surface of the soil without covering the fertilizer with soil by trampling and compacting the soil using a large number of cattle or donkeys. This will contribute to highest loss of N from the surface of Vertisols (Terman, 1980; Bock, 1984; Patra *et al.*, 1996; Sigunga *et al.*, 2002; Zhou *et al.*, 2003; Solomon *et* *al.*, 2007; Sigunga *et al.*, 2008; Owino and Sigunga, 2012; Somasundaram *et al.*, 2018; Nachimuthu *et al.*, 2019; Singh *et al.*, 2020). This loss includes surface washing of fertilizer with rainfall through erosion especially when highest rainfall comes immediately after fertilizer application. Trampling of the soil before broadcasting the seed and fertilizer also increase surface washing of fertilizer from the soil by decreasing infiltration and hence aggravating soil erosion (Pietola *et al.*, 2005; Lipiec *et al.*, 2006; Muche *et al.*, 2014).

However, the rate at which the yield increased will progressively decreased. From all location, the highest grain and yield of tef were recorded from Moretinajiru district (Figure 2). In Moretinajiru district, application of 60, 120, 180 and 240 Kgha^{-1} N increased tef yield by 130% (907 Kgha^{-1}), 182% (1274 Kgha^{-1}), 217% (1515 Kgha^{-1}) and 229% (1597 Kgha^{-1}) compared with the lowest tef yield observed from the N un-fertilized control plot, respectively. In Ensaro site, the increased in grain yield were found to be 107% (605 Kgha^{-1}), 160% (905 Kgha^{-1}), 198% (1121 Kgha^{-1}) and 219% (1237 Kgha^{-1}) respectively. Likewise, the increased in these parameters in Merhabete district with those rates were found to be 122% (525 Kgha^{-1}), 256% (1106 Kgha^{-1}), 314% (1358 Kgha^{-1}) and 331% (1431 Kgha^{-1}), respectively. Similar trends were also observed on biomass yield too (Figure 11).

The N rate at which highest grain yield recorded from with current finding were found higher from previously recommended N rate for the same soil type (Mamo *et al.*, 2000; Liben, 2004; Berhe and Zena, 2008; Tulema *et al.*, 2008; Assefa *et al.*, 2016; Asfaw *et al.*, 2020). The fertilization recommendation of the former research conducted in Vertisols of Ethiopia ranged from 41 to 80 Kgha^{-1}. This might be probably because of the depletion of this nutrient from the soil through time. For instance, Haileslassie *et al.*, (2005) reported that N nutrient depletion of -147 Kgha^{-1} was recorded from Amhara region. This rate is the highest compared with other regions of Ethiopia. The same authors also reported that, the main determinants of nutrient depletion are with nutrient removal through harvested product, residual removal, leaching, denitrification and erosion. Van Beek *et al*., (2016) also noted that diverse Ethiopian agro-ecologies experience accelerated soil nutrient depletion that is severe in N, with average annual depletions of 0.2% of the entire stock, or 4.2% of the accessible soil N pool. Others authors also reported nutrient depletion especially N in Ethiopia (Hurni, 1988; Beek *et al*., 2018; Haileslassie *et al*., 2005; Elka and Laekemariam, 2020; Adimassu *et al*., 2017).

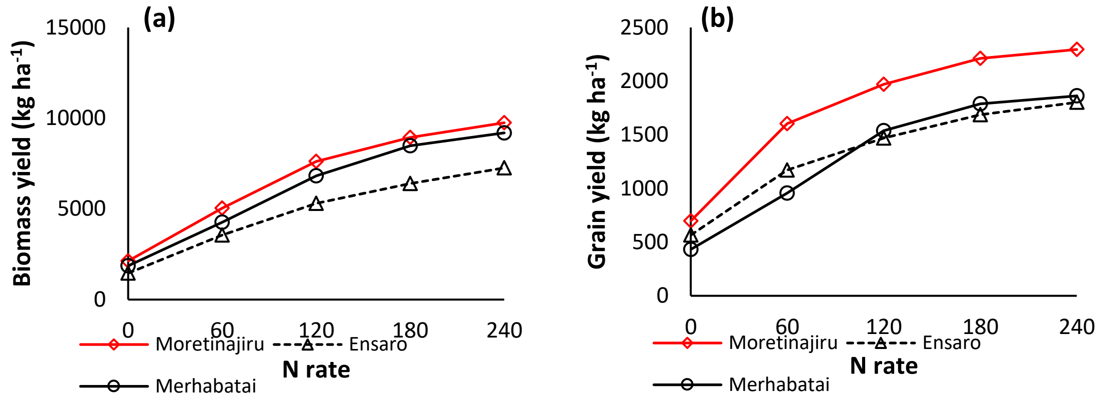

Figure 11. a= effect of N fertilizer rate in biomass yield; b = effect of N fertilizer in grain yield

Application of P fertilizer significantly increase yield of tef in Ensaro and Merhabete district. The yield increase ranged from 14% (164 Kgha^{-1}) to 24% (276 Kgha^{-1}) in Ensaro and from 33% (335 Kgha^{-1}) to 50% (499 Kgha^{-1}) in Merhabete district compared with the lowest grain yield observed from the P un-fertilized control plot (Table 3). This could be justified by the fact that those districts are low in their available P content and application of P containing fertilizer can have increased grain yield of tef. In Moretinajiru district, application of different rate of P fertilizer could not brought any significant yield change. This might be due to the continuous application of highest rate of P fertilizer could be gradually increased soil P level.

In Merhabete areas, combined application of N and P resulted in significant yield difference (Table 3 and 4). The lowest (1735 Kgha^{-1}) and highest (10385 Kgha^{-1}) biomass yield of tef was recorded from application of 0/0 and 240/90 Kgha^{-1} N/P, respectively. The respective increase in yield due to combined application of N/P ranged from 3% (49 Kgha^{-1}) to 499% (8650 Kgha^{-1}). In Ensaro and Merhabete area combined application of N and P significantly influenced biomass yield

Table 3. Effect of P rate on biomass and grain yield of tef

P rate	Biomass yield (Kgha^{-1})			Grain yield (Kgha^{-1})		
	Moretinajiru*	Ensaro	Merhabete	Moretinajiru	Ensaro	Merhabete
0	6528	3941.8^{c}	4833.9^{c}	1746.2	1168.6^{b}	999.6^{c}
30	6735.8	4767.1^{b}	6140^{b}	1783.9	1332.9^{ab}	1334.1^{b}
60	6805.2	5211.8^{ab}	6565^{ab}	1800.6	1445^{a}	1430.8^{ab}
90	6700.8	5256^{a}	6954.3^{a}	1692.8	1407.6^{a}	1498.8^{a}
LSD0.05	ns	469.5	445.7	ns	187.9	126.7

**Means followed by same letter at each location are not significantly influenced at P>0.05 level of probability following DMRT, LSD least significance difference*

Table 4. The two-way interaction of N and P on biomass and grain yield of tef

Location	N/P	Biomass yield (Kgha^{-1})				Grain yield (Kgha^{-1})			
	rate	0	30	60	90	0	30	60	90
Moretinajiru*	0	2053.0	2128	2261	2074	7301	708	732	619
	60	4825.1	5293	5027	5018.5	1535	1655	1662	1564
	120	7546.4	7470	7590	7821	2043	1980	1923	1937
	180	8871.1	9029	9032	8825	2199	2310	2252	2090
	240	9344.3	9758	10117	9766	2224	2266	2434	2254
$LSD_{0.05}$		ns				ns			
Ensaro	0	1422^{k}	1461^{k}	1422^{k}	1514^{jk}	541	569	588	563
	60	2933^{ij}	3629^{hi}	3945^{fghi}	3759^{ghi}	974	1194	1326	1187
	120	4424^{efgh}	5248^{def}	5742^{cde}	5775^{cde}	1280	1445	1604	1547
	180	5180^{defg}	6239^{bcd}	7104^{abc}	7061^{abc}	1518	1646	1818	1761
	240	5749^{cde}	7259^{ab}	7846^{a}	8171^{a}	1531	1809	1889	1980
$LSD_{0.05}$		1451.4				ns			
Merhabete	0	1735^{i}	1940^{hi}	1784^{i}	1990^{hi}	360^{i}	453^{i}	424^{i}	491^{i}
	60	3253^{gh}	4152^{fg}	4505^{fg}	5165^{f}	692^{hi}	911.5^{gh}	1069^{fgh}	1156^{defg}
	120	5255^{ef}	6606^{de}	7583^{cd}	7833^{cd}	1087^{efg}	1470^{cde}	1775^{abc}	1821^{abc}
	180	6639^{d}	8630^{bc}	9246^{ab}	9400^{ab}	1329^{def}	1862^{ab}	1966^{a}	2002^{a}
	240	7288^{cd}	9374^{ab}	9708^{ab}	10385^{a}	1530^{bcd}	1975^{a}	1921^{ab}	2025^{a}
$LSD_{0.05}$		1378.7				392			

**Means followed by same letter in each location are not significantly influenced at P>0.05 level of probability following DMRT; LSD least significance difference*

The interaction of soil type with N rate also *found* significantly influenced biomass yield in Ensaro and Merhabete, grain yield in Moretinajiru and Merhabete, harvest index in all districts, plant height in Moretinajiru and Merhabete and number of tillers in Moretinajiru district (Table 4 and 5).

In Ensaro district, the tef yields observed from heavy Vertisols were found superior over light Vertisols at every N level. This might be due to the highest N loss through leaching and denitrification on such kind of soil. Ammonia fixation also affects fertilizer efficiency in heavy Vertisols (Finck and Venkateswarlu, 1982). The increased in tef yield were found 170% (548 Kgha^{-1}), 45% (436 Kgha^{-1}), 37% (470 Kgha^{-1}), 39% (562 Kgha^{-1}) and 52.9% (772 Kgha^{-1}) at 0, 60, 120, 180 and 240 Kgha^{-1} N) respectively. In Moretinajiru district, the yield observed from heavy

Vertisols were found superior over the yield recorded from light Vertisols only in the first three rate of N. After forward, the yield observed from light Vertisols is higher than from heavy Vertisols. Nevertheless, in Merhabete district the yield recorded from light Vertisols from the first three N rate were higher on light Vertisols (Table 6).

Table 5. The impact of soil type on growth, yield related and yield of tef

Parameters	Moretinajiru		Ensaro		Merhabete	
	HVS	LVS	HVS	LVS	HVS	LVS
BY*	6746.2	6602.9	5678.3^{a}	4086.9^{b}	5979.3	6339.3
GY	1761.9	1745.8	1648.2^{a}	1090.8^{b}	1296.8	1344.4
HI	0.28^{a}	0.27^{b}	0.32^{a}	0.28^{b}	0.22	0.22
PH	73.3^{b}	79.3^{a}	74.4^{a}	67.1^{b}	92^{b}	102.4^{a}
PL	28.4^{b}	30^{a}	27.6^{a}	27^{b}	33.4^{b}	36.7^{a}
NT	5.1^{a}	4.2^{b}	4.0	4.1		

**BY= Biomass yield (Kgha^{-1}); GY = Grain yield (Kgha^{-1}); HI = Harvest index; PH = Plant height (cm); PL= Panicle length (cm); Nt = Number of tillers per plant; Means followed by same letter at each location in a row are not significantly influenced at P>0.05 level of probability following DMRT, HVS = heavy Vertisols, LVS = light Vertisols*

Table 6. Interaction of N rate with soil type on biomass and grain yield of tef

Location	N rate/Soil	Biomass yield (Kgha^{-1})		Grain yield (Kgha^{-1})	
		HVS	LVS	HVS	LVS
Moretinajiru*	0	2187	2032.6	791.4^{d}	540.5^{e}
	60	5052.4	5021.8	1627.2^{c}	1565.4^{c}
	120	7774.3	7327.4	1983.4^{b}	1949.7^{b}
	180	8986.2	8861.0	2187.2^{ab}	2255.2^{a}
	240	9731.1	9771.8	2220.5^{a}	2418.1^{a}
Ensaro	0	1938.1^{f}	1068.2^{g}	869.4	321.7
	60	4129.9^{d}	3116^{e}	1412.2	976.6
	120	6098^{c}	4657.1^{d}	1730.5	1260.8
	180	7517.7^{b}	5498.4^{c}	1997.7	1435.9
	240	8707.7^{a}	6095^{c}	2231.3	1458.9
Merhabete	0	1576^{e}	2290.6^{e}	354.7^{f}	547.8^{f}
	60	3905.5^{d}	4812.5^{c}	815.6^{e}	1168.6^{d}
	120	6705.6^{b}	6989.4^{b}	1498.5^{c}	1596.9^{bc}
	180	8532.8^{a}	8397.2^{a}	1837.4^{ab}	1718.4^{bc}
	240	9176.3^{a}	9206.9^{a}	1977.5^{a}	1690^{bc}

**Means followed by same letter at each location are not significantly influenced at P>0.05 level of probability following DMRT; HVS = heavy Vertisols; LVS = light Vertisols.*

Partial Budget Analysis: The combined application of N and P at the rate of 180/0, 240/30, and 240/90 on heavy Vertisols with cereal precursor crops resulted in the highest net benefit of 102480 ETB, 84619 ETB, and 94402 ETB in Moretina Jiru, Ensaro, and Merhabete areas respectively. For the same type of Vertisols with pulse precursor crops, application of 180/30, 240/90, and 120/60 Kgha^{-1} N/P resulted in the highest net benefit of 103975 ETB, 94402 ETB, and 81448 ETB in the respective areas (Table 24). The combined application of N and P at the rate of 240/60, 180/60, and 180/90 on light Vertisols with cereal precursor crops resulted in the highest net benefit of 105664 ETB, 72697 ETB, and 70419 ETB in Moretina Jiru, Ensaro, and Merhabete areas respectively. For the same type of Vertisols with pulse precursor crops, application of 240/90, and 240/90 Kgha^{-1} resulted in the highest net benefit of 113429 ETB, and 57863 ETB in Moretina Jiru, and Ensaro areas, respectively (Table 7).

Table 7. Net benefit as influenced by location, precursor crop, soil type, N and P rate

		N/P	Heavy Vertisols				Light Vertisols			
LOC	Pre	rate	0	30	60	90	0	30	60	90
Mo	Cereal	0	23163	24223	11017	12543	24126	29603	32073	20368
		60	58815	69232	60195	51753	56892	63418	75756	61240
		120	89268	83859	77005	73121	81072	76302	71600	82824
		180	102480	92735	95700	81319	94276	93195	89025	91031
		240	94339	94667	101146	94742	94163	104441	105664	88236
	Pulse	0	46637	36332	40269	33531	11354	12045	18052	10669
		60	68429	73568	65112	69599	77647	58912	58231	51662
		120	87909	90505	87915	81907	101036	81890	88029	87965
		180	90680	103975	93652	85602	100876	102079	107146	95227
		240	93350	94749	98412	89782	112610	96211	109423	113429
En	Cereal	0	26510	20621	22916	12967	14392	18578	18414	14142
		60	40542	40346	49589	41139	37000	45143	48349	33109
		120	57748	57446	60293	54000	54015	43094	60495	56500
		180	69546	64931	67857	70803	58855	60126	72697	64036
		240	73192	84619	82360	82407	59035	61541	71225	55115
	Pulse	0	41700	39283	34652	41922	7553	8213	6197	4150
		60	55681	65721	61707	52986	20574	29906	34295	36179
		120	64065	76908	71416	71553	26843	43103	47042	43572
		180	77752	72918	84123	86505	28841	49855	50213	41662
		240	77458	81348	86214	94402	25927	47511	46541	57863
Me	Cereal	0	11382	9947	7002	7781	18128	23052	18647	18640
		60	20329	27969	33347	32733	34173	40446	43809	51358
		120	35295	49950	61326	58535	48865	57738	61751	65699
		180	52339	687933	73322	72772	48705	66947	67251	70419
		240	53723	76189	74137	80685	53621	66223	64086	64650
	Pulse	0	18053	202340	21099	24471				
		60	25753	33708	35085	33379				
		120	39221	59806	81448	81355				
		180	45354	76161	81220	72855				
		240	65212	76189	70666	69778				

**LOC = location; Me = Merhabete district; En = Ensaro district; Mo = Moretinajiru district.*

Conclusion and Recommendation

Most of the Ethiopian soils contain low nutrient content due to erosion and absence of nutrient recycling. Low availability of Nitrogen and Phosphorus has been demonstrated to be major constraint to cereal production in Ethiopia. The analysis of variance showed that N rate, Precursor crops and soil types significantly influenced most of the measured parameters. Nevertheless, application of different rate of P significantly influenced biomass and grain yield in Ensaro and Merhabete district. Increasing N rate from zero to 240 Kgha^{-1} N, grain yield also progressively increased in both locations. However, the rate in which the yield increased will progressively decreased. In Ensaro site, the increased in grain yield were found to be 107% (605 Kgha^{-1}), 160% (905 Kgha^{-1}), 198% (1121 Kgha^{-1}) and 219% (1237 Kgha^{-1}) respectively. Likewise, the increased in this parameter in Merhabete district with those rates were found to be 122% (525 Kgha^{-1}), 256% (1106 Kgha^{-1}), 314% (1358 Kgha^{-1}) and 331% (1431 Kgha^{-1}), respectively. Application of P fertilizer in the rate of 60 and 90 Kgha^{-1} P increased grain yield of tef by 24% (276) and 50% (499 Kgha^{-1}) compared with the lowest grain yield observed from the P un-fertilized control plot, respectively. The yield obtained from heavy Vertisols were found superior over from light Vertisols. The yield increments were found ~1% (16 Kgha^{-1}) in Moretinajiru, 51% (557 Kgha^{-1}) in Ensaro and ~4% (48 Kgha^{-1}) in Merhabete. Likewise, tef yield recorded from pulse precursor increased tef yield by 7.2% (122.8 Kgha^{-1}) in Moretinajiru and 13.5% (173.6 Kgha^{-1}) in Merhabete district. In Moretinajiru district, application of 240/60 Kg N/P could be recommended for heavy and light Vertisols having cereal precursor crop. For pulse precursor, application of 240/90 and 180/30 Kg N/P resulted in higher tef yield on light and heavy Vertisols, respectively. Application of 240/90 N/P resulted in higher tef yield on both soil types having pulse precursor crop. Likewise, application of 240/30 and 180/30 NP resulted in higher tef yield on heavy and light Vertisols having cereal precursor, respectively. In Merhabete district, application of 120/90 N/P resulted in higher tef yield on heavy Vertisols having pulse precursor. Application of 90 Kg P with 240 and 180 Kgha^{-1} N resulted in higher tef yield on cereal precursor having heavy and light Vertisols, respectively.

The combined application of N and P at the rate of 180/0, 240/30, and 240/90 on heavy Vertisols with cereal precursor crops resulted in the highest net benefit in Moretina Jiru, Ensaro, and Merhabete areas respectively. For the same type of Vertisols with pulse precursor crops, application of 180/30, 240/90, and 120/60 Kgha^{-1} N/P resulted in the highest net benefit in the respective areas. The combined application of N and P at the rate of 240/60, 180/60, and 180/90 on light Vertisols with cereal precursor crops resulted in the highest net benefit in Moretina Jiru, Ensaro, and Merhabete areas respectively. For the same type of Vertisols with pulse precursor crops, application of 240/90, and 240/90 $Kgha^{-1}$ resulted in the highest net benefit in Moretina Jiru, and Ensaro areas, respectively (Table 24). Therefore, these treatment combinations were recommended for the district, soil type and precursor crops.

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Appendix Table 1. Mean square value of biomass, grain yield and harvest index as influenced by N and P rate, Precursor crop

Source of variation	Mean squares values with respective degrees of freedom in parenthesis								
	Biomass yield (Kgha^{-1})			Grain yield (Kgha^{-1})			Harvest Index		
	Mo	En	Me	Mo	En	Me	Mo	En	Me
Year (1)	36511875***	1232230^{ns}	69832^{ns}	5963987***	25099926***	3653761***	0.1972***	0.8255***	0.03344***
Block (3)	5995867**	59208750***	16081338**	863173*	327324^{ns}	35233^{ns}	0.04374**	0.3014***	0.00021^{ns}
Rep (2)	2492886^{ns}	65889^{ns}	3998771^{ns}	59623^{ns}	176934^{ns}	58331^{ns}	0.00213^{ns}	0.025^{ns}	0.01334*
Prec(1)	17962980***	7415683^{ns}	8362538*	1362968**	3130^{ns}	345717^{ns}	0.0004^{ns}	0.0761*	0.07473***
N (4)	930301711***	581534972***	740552984***	40530372***	26437356***	29658522***	0.13426***	0.2308***	0.00905**
P (3)	1668704^{ns}	50175202***	84952526***	274411^{ns}	2025693***	4901715***	0.00692^{ns}	0.0051^{ns}	0.00358^{ns}
Prec:N (4)	889153^{ns}	1481558^{ns}	2816193^{ns}	289443^{ns}	757857^{ns}	216986^{ns}	0.00393^{ns}	0.0028^{ns}	0.00089^{ns}
Prec:P (3)	51723^{ns}	4945692^{ns}	415382^{ns}	35311^{ns}	700057^{ns}	65303^{ns}	0.00777^{ns}	0.0276^{ns}	0.00054^{ns}
N:P (12)	661569^{ns}	4745003*	5833586***	96451^{ns}	148863^{ns}	314622**	0.00189^{ns}	0.0076^{ns}	0.00236^{ns}
Prec:N:P (12)	840522^{ns}	749780^{ns}	564532^{ns}	173374^{ns}	132500^{ns}	104744^{ns}	0.00899*	0.0059^{ns}	0.00087^{ns}
Residuals(*,**,***)	872066	2239752	1490623	131746	358796	120507	0.00467	0.0131	0.00266

*Degree of freedom for biomass (*Moretinajiru (Mo)=437; ** Ensaro (En) =497; *** Merhabatai (Me)=357) grain yield (* Moretinajiru = 437; ** Ensaro= 497 ***; Merhabatai = 357), Harvest Index (* Moretinajiru=436; ** Ensaro= 497; *** Merhabatai= 357)*

Appendix Table 2. Mean square value of Plant height, panicle length and number of tillers as influenced by N and P rate, Precursor crop

Source of variation	Mean squares values with respective degrees of freedom in parenthesis							
	Plant height (cm)			Panicle length (cm)			Number of tiller	
	Mo	En	Me	Mo	En	Me	Mo	En
Year (1)	1933***	3425***	30792***	1251.7***	1839.9***	4043***	838.8***	52.79***
Block (3)	72^{ns}	2474***	3252***	74.3*	237.4***	232***	19.5**	5.86^{ns}
Rep (2)	21^{ns}	164^{ns}	401*	13.8^{ns}	0.2^{ns}	101**	34***	0.53^{ns}
Prec(1)	1137***	1501***	1171***	494.7***	53**	74**	2.6^{ns}	0.01^{ns}
N (4)	27031***	28084***	10880***	2011.4***	2553***	657***	29.1***	43.41***
P (3)	37^{ns}	1458***	615***	10.3^{ns}	140.2***	28^{ns}	4.1^{ns}	8.07^{ns}
Prec:N (4)	245**	207^{ns}	127^{ns}	42^{ns}	9.3^{ns}	13^{ns}	2.5^{ns}	1.13^{ns}
Prec:P (3)	13^{ns}	219^{ns}	9^{ns}	17.8^{ns}	28.3*	6^{ns}	0.5^{ns}	4.97^{ns}
N:P (12)	59^{ns}	125^{ns}	57^{ns}	32^{ns}	10.9^{ns}	11^{ns}	0.9^{ns}	2.44^{ns}
Prec:N:P (12)	53^{ns}	55^{ns}	22^{ns}	13.4^{ns}	3.8^{ns}	7^{ns}	0.3^{ns}	2.36^{ns}
Residuals(*,**,***)	53	123	68	18.9	7.6	11	1.8	2.43

Degree of freedom for Plant height (Moretinajiru (mo)=425; ** Ensaro (En)= 492; ***Merhabatai (Me)=357) panicle length (* Moretinajiru=425; ** Ensaro= 492 ***; Merhabatai=357); number of tiller (* Moretinajiru=425; ** Ensaro= ***=492; Merhabatai= 357)*

Appendix Table 3. Mean square value of biomass, grain yield and harvest index as influenced by N and P rate, Soil type

Source of variation	Mean squares values with respective degrees of freedom in parenthesis								
	Biomass yield (Kgha^{-1})			Grain yield (Kgha^{-1})			Harvest Index		
	Mo	En	Me	Mo	En	Me	Mo	En	Me
Year (2)	36511875***	1232230^{ns}	69832^{ns}	5963987***	25099926***	3653761***	0.19775***	0.8255***	0.03344***
Block (3)	5995867*	59208750***	16081338**	863173*	327324^{ns}	35233^{ns}	0.04375**	0.3014***	0.00021^{ns}
Rep (2)	2492886^{ns}	65889^{ns}	3998771^{ns}	59623^{ns}	176934^{ns}	58331^{ns}	0.00211^{ns}	0.025^{ns}	0.01334*
Soil (1)	113652^{ns}	336944918***	17014^{ns}	524581*	48614713***	17149^{ns}	0.05234***	0.2831***	0.0003^{ns}
N (4)	930301711***	581534972***	740552984***	40530372***	26437356***	29658522***	0.13373***	0.2308***	0.00905*
P (3)	1668704^{ns}	50175202***	84952526***	274411^{ns}	2025693***	4901715***	0.00695^{ns}	0.0051^{ns}	0.00358^{ns}
Soil:N (4)	782716^{ns}	14019349***	3767293*	620060***	458772^{ns}	1234227***	0.04258***	0.0594***	0.01487***
Soil:P (3)	2008382^{ns}	1760569^{ns}	700247^{ns}	119995^{ns}	373172^{ns}	112223^{ns}	0.00099^{ns}	0.0233^{ns}	0.00116^{ns}
N:P (12)	661569^{ns}	4745003***	5833586***	96451^{ns}	148863^{ns}	314622***	0.00186^{ns}	0.0076^{ns}	0.00236^{ns}
Soil:N:P (12)	673502^{ns}	560544^{ns}	546552^{ns}	130147^{ns}	84470^{ns}	6644^{6ns}	0.00599^{ns}	0.0059^{ns}	0.00097^{ns}
Residuals (*,**,***)	905039	1499602	1501554	131244	266525	110923	0.00432	0.0122	0.0027

Degree of freedom for biomass (Moretinajiru (Mo)=437; ** Ensaro (En)=497; *** Merhabatai (Me)= 357) grain yield (* Moretinajiru=437; ** Ensaro= 497; *** Merhabatai = 357), Harvest Index (* Moretinajiru=436; ** Ensaro= 497; *** Merhabatai= 357)*

Appendix Table 4. Mean square value of Plant height, panicle length and number of tillers as influenced by N and P rate, Precursor crop

Source of variation	Mean squares values with respective degrees of freedom in parenthesis							
	Plant height (cm)			Panicle length (cm)			Number of tillers	
	Mo	En	Me	Mo	En	Me	Mo	En
Year (2)	1933***	3425***	30792***	1251.7***	1839.9***	4043***	838.8***	1839.9***
Block (3)	72^{ns}	2474***	3252***	74.3^{ns}	237.4***	232***	19.5***	237.4***
Rep (2)	21^{ns}	164^{ns}	401**	13.8^{ns}	0.2^{ns}	101**	34***	0.2^{ns}
Soil (1)	2729***	8027***	4167***	60.8^{ns}	114.5***	504***	10.8*	114.5***
N (4)	26929***	28057***	10880***	2062.6***	2552***	657***	27.8***	2552***
P (3)	37^{ns}	1523***	615***	10.3^{ns}	143.2***	28*	4.1^{ns}	143.2***
Soil:N (4)	156*	187^{ns}	205**	5.1^{ns}	13.4^{ns}	18^{ns}	8.2***	13.4^{ns}
Soil:P (3)	38^{ns}	384*	12^{ns}	27.4^{ns}	22.9*	1^{ns}	0.6^{ns}	22.9*
N:P (12)	58^{ns}	129^{ns}	57^{ns}	32.1^{ns}	10.9^{ns}	11^{ns}	0.9^{ns}	10.9^{ns}
Soil:N:P (12)	52^{ns}	84^{ns}	52^{ns}	15.7^{ns}	3^{ns}	11^{ns}	1.1^{ns}	3^{ns}
Residuals (*,**,***)	51	108	58	19.6	7.5	9	1.7	7.5

Degree of freedom for Plant height (Moretinajiru (Mo)=425, ** Ensaro (En)= 492 ***Merhabatai (Me)=357) panicle length (* Moretinajiru=425, ** Ensaro= 492 ***Merhabatai=357), number of tiller (* Moretinajiru=425, ** Ensaro= ***Merhabatai= 357)*

References

Achakzai, A.K.K., Taran, S.A., 2011. Effect of seed rate on growth, yield components and yield of mash bean grown under irrigated conditions of arid uplands of Balochistan, Pakistan. Pak J Bot 43, 961-969.

Adamu, M., 2018. Response of Wheat to NP Fertilizer Rates, Precursor Crops and Types of Vertisols in Central Highlands of Ethiopia. Journal of Agricultural Science 10, 231-244.

Anderson, R.L., 2008. Growth and yield of winter wheat as affected by preceding crop and crop management. Agronomy Journal 100, 977-980.

Angus, J., Kirkegaard, J., Hunt, J., Ryan, M., Ohlander, L., Peoples, M., 2015. Break crops and rotations for wheat. Crop and pasture science 66, 523-552.

Arcand, M.M., Knight, J.D., Farrell, R.E., 2014. Differentiating between the supply of N to wheat from above and belowground residues of preceding crops of pea and canola. Biology and Fertility of Soils 50, 563-570.

Asfaw, A.G., Gedamu, S.A., Abushe, H.T., Mekonen, T.T., Muhamed, S.B., Shibeshi, T.H., 2020. Fertilizer-Nitrogen use optimization for Tef in South Wollo Zone of Ethiopia. African Journal of Agricultural Research 16, 811-818.

Assefa, A., Tana, T., Abdulahi, J., 2016. Effects of compost and inorganic np rates on growth, yield and yield components of tef (Eragrotis tef (Zucc.) Trotter) in Girar Jarso district, Central Highland of Ethiopia. Journal of Fertilizer and Pesticides 7, 174.

Azene, B., Berhanu, F., Gashaw, G., Getachew, F., Habitamu, G., 2005. Managing land: A practical guide book for development agents in Ethiopia. Technical hand book, 282.

Bennett, D., Izanloo, A., Reynolds, M., Kuchel, H., Langridge, P., Schnurbusch, T., 2012. Genetic dissection of grain yield and physical grain quality in bread wheat (Triticum aestivum L.) under water-limited environments. Theoretical and Applied Genetics 125, 255-271.

Berhe, T., Zena, N., 2008. Results in a trial of system of tef intensification (STI) at Debrezeit. Proceedings of Annual Research Review Workshop, pp. 16-17.

Bock, B., 1984. Efficient use of Nitrogen in cropping systems. Nitrogen in crop production, 273-294.

Bouyoucos, G.J., 1951. A recalibration of the hydrometer method for making mechanical analysis of soils 1. Agronomy journal 43, 434-438.

Chanyalew, Y., Wondale, L., Tigabie, A., Legesse, A., Getachew, T., 2018. Participatory Agricultural Production System Analysis: Implication For Research And Development Intervention In North Shewa Zone.

Chapman, H.D., 1965. Cation exchange capacity in methods of soil analysis. Part 2 Agronomy Monograph 9, 891-894.

CIMMYT, 1988. From agronomic data to farmer recommendations: an economics training manual. CIMMYT.

Cottenie, A., 1980. Soil and plant testing as a basis of fertilizer recommendations.

CSA, 2018/19

Report on Area and production of major crops- 2018/19 Meher season.

D'Andrea, A.C., 2008. T'ef (Eragrostis tef) in ancient agricultural systems of highland Ethiopia. Economic Botany 62, 547-566.

DUDAL, R., 1963. Dark clay soils of tropical and subtropical regions. Soil Science 95, 264-270.

Food and Agriculture Organization (FAO). 2000. Problem Soils Database: Vertisols.

Finck, A., Venkateswarlu, J., 1982. Chemical properties and fertility management of Vertisols. Transactions 12th International Congress Soil Science Symposium Paper, pp. 61-79.

Giday, O., Gibrekidan, H., Berhe, T., 2014. Response of tef (Eragrostis tef) to different rates of slow release and conventional urea fertilizers in Vertisols of Southern Tigray, Ethiopia. Advances in Plants & Agriculture Research 1, 1-8.

Haileslassie, A., Priess, J., Veldkamp, E., Teketay, D., Lesschen, J.P., 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 & environment 108, 1-16.

Hailu, H., Mamo, T., Keskinen, R., Karltun, E., Gebrekidan, H., Bekele, T., 2015. Soil fertility status and wheat nutrient content in Vertisol cropping systems of central highlands of Ethiopia. Agriculture & Food Security 4, 1-10.

Hazelton, P., Murphy, B., 2016. Interpreting soil test results: What do all the numbers mean? CSIRO publishing.

Hubble, G., 1984. The cracking clay soils: definition, distribution, nature, genesis and use. The properties and utilization of cracking clay soils'.(Eds JW McGarity, EH Hoult, HB So) pp, 3-13.

Kassaye, A.Y., Shao, G., Wang, X., Shifaw, E., Wu, S., 2021. Impact of climate change on the staple food crops yield in Ethiopia: implications for food security. Theoretical and Applied Climatology 145, 327-343.

Ketema, S., 1997. Breeding, Genetics Resources, Agronomy, Utilization and Role in Ethiopian Agriculture. Bioversity International.

Kiflu, A., Beyene, S., 2013. Effects of different land use systems on selected soil properties in South Ethiopia. Journal of Soil Science and Environmental Management 4, 100-107.

Kirkegaard, J., Christen, O., Krupinsky, J., Layzell, D., 2008. Break crop benefits in temperate wheat production. Field crops research 107, 185-195.

Lal, R., 2017. Improving soil health and human protein nutrition by pulses-based cropping systems. Advances in Agronomy 145, 167-204.

Landon, J.R., 2014. Booker tropical soil manual: a handbook for soil survey and agricultural land evaluation in the tropics and subtropics. Routledge.

Leta, R., 2012. Effects of sowing method and inorganic fertilizer type on yield and yield components of

tef [Eragrostis tef (zucc.) Trotter] at Guduru Woreda, Western Oromia, Ethiopia. . Haramaya University, , Haramaya, Ethiopia.

Liben, M., 2004. The response of tef to Nitrogen and Phosphorus applications at Bichena and Yilmana-Denssa areas, northwestern Ethiopia. CSSE.

Lipiec, J., Kuś, J., Słowińska-Jurkiewicz, A., Nosalewicz, A., 2006. Soil porosity and water infiltration as influenced by tillage methods. Soil and Tillage research 89, 210-220.

Liu, K., Bandara, M., Hamel, C., Knight, J.D., Gan, Y., 2020. Intensifying crop rotations with pulse crops enhances system productivity and soil organic carbon in semi-arid environments. Field Crops Research 248, 107657.

Lupwayi, N.Z., Kennedy, A.C., 2007. Grain legumes in Northern Great Plains: impacts on selected biological soil processes. Agronomy Journal 99, 1700-1709.

Mamo, T., Erkossa, T., Tulema, B., 2000. Soil fertility and plant nutrition research on tef in Ethiopia. Narrowing the rift: Tef research and development. Proceedings of the International Workshop on Tef Genetics and Improvement, pp. 16-19.

Mamo, T., Haque, I., 1991. Phosphorus status of some Ethiopian soils, II. Forms and distribution of inorganic phosphates and their relation to available Phosphorus. Tropical agriculture.

Mamo, T., Richter, C., Heiligatag, B., 1996. Response of some varieties of durum wheat and tef to salt stress. African Crop Science Journal 4, 423-432.

Mazzilli, S.R., Ernst, O.R., de Mello, V.P., Pérez, C.A., 2016. Yield losses on wheat crops associated to the previous winter crop: Impact of agronomic practices based on on-farm analysis. European Journal of Agronomy 75, 99-104.

Melaku, M., 2008. Effects of seeding and Nitrogen rates on yield and yield components of tef [Eragrostis tef (Zucc.) at Adet, Northern western Ethiopia. M. Sc. Thesis, Haramaya University.

Mengel, K., Kirkby, E., 1987. Principles of plant nutrition. Bern. International Potash Institute, 687-695.

Mesfin, A., 1998. Nature and management of Ethiopian soils. Alemaya University of Agriculture, Ethiopia 272.

Muche, H., Yimer, F., Temesgen, M., 2014. Effects of conservation tillage integrated with 'Fanya Juus' structures on soil loss in Northern Ethiopia. Global Journal of Science Frontier Research 14, 1-12.

Nachimuthu, G., Watkins, M.D., Hulugalle, N.R., Weaver, T.B., Finlay, L.A., McCorkell, B.E., 2019. Leaching of dissolved organic carbon and Nitrogen under cotton farming systems in a Vertisol. Soil Use and Management 35, 443-452.

Olsen, S.R., 1954. Estimation of available Phosphorus in soils by extraction with sodium bicarbonate. US Department of Agriculture.

Owino, C., Sigunga, D., 2012. Effects of rainfall pattern and fertilizer Nitrogen on Nitrogen loss in bypass flow in Vertisols at the onset of rain season under tropical environments. Journal of Environmental Science and Water Resource 1, 207-215.

Patra, A.K., Burford, J., Rego, T., 1996. Volatilization losses of surface-applied urea Nitrogen from Vertisols in the Indian semi-arid tropics. Biology and fertility of soils 22, 345-349.

Pietola, L., Horn, R., Yli-Halla, M., 2005. Effects of trampling by cattle on the hydraulic and mechanical properties of soil. Soil and tillage research 82, 99-108.

Program, C.E., Maize, I., Center, W.I., 1988. From agronomic data to farmer recommendations: an economics training manual. CIMMYT.

Ross, S., King, J., Williams, C., Strydhorst, S., Olson, M., Hoy, C., Lopetinsky, K., 2015. The effects of three pulse crops on a second subsequent crop. Canadian Journal of Plant Science 95, 779-786.

Sigunga, D., Janssen, B., Oenema, O., 2002. Ammonia volatilization from Vertisols. European Journal of Soil Science 53, 195-202.

Sigunga, D., Janssen, B., Oenema, O., 2008. Effects of Fertilizer Nitrogen on Short-Term Nitrogen Loss in Bypass Flow in a Vertisol. Communications in soil science and plant analysis 39, 2534-2549.

Singh, R., Chaudhary, R., Somasundaram, J., Sinha, N., Mohanty, M., Hati, K., Rashmi, I., Patra, A., Chaudhari, S., Lal, R., 2020. Soil and nutrients losses under different crop covers in vertisols of Central India. Journal of Soils and Sediments 20, 609-620.

Solomon, S., Qin, D., Manning, M., Averyt, K., Marquis, M., 2007. Climate change 2007-the physical science basis: Working group I contribution to the fourth assessment report of the IPCC. Cambridge university press.

Somasundaram, J., Lal, R., Sinha, N.K., Dalal, R., Chitralekha, A., Chaudhary, R.S., Patra, A.K., 2018. Cracks and potholes in vertisols: characteristics, occurrence, and management. Advances in Agronomy 149, 93-159.

Spaenij-Dekking, L., Kooy-Winkelaar, Y., Koning, F., 2005. The Ethiopian cereal tef in celiac disease. New England Journal of Medicine 353, 1748-1749.

Stevenson, F., Kessel, C.v., 1996. The Nitrogen and non-Nitrogen rotation benefits of pea to succeeding crops. Canadian Journal of Plant Science 76, 735-745.

Strydhorst, S.M., King, J.R., Lopetinsky, K.J., Harker, K.N., 2008. Weed interference, pulse species, and plant density effects on rotational benefits. Weed Science 56, 249-258.

Syers, J.K., de Vries, F.P., Nyamudeza, P., 2001. The sustainable management of vertisols. Cabi.

Tadesse, T., Haque, I., Aduayi, E., 1991. Soil, plant, water, fertilizer, animal manure & compost analysis manual.

Team, R.C.D.T., 2018. R: A language and environment for statistical computing. 2014. R Foundation for Statistical Computing: Vienna, Austria.

Tefera, H., Ketema, S., Tefera, A., Belay, G., Sorrells, M., 2000. Production and importance of tef in Ethiopian agriculture. Narrowing the rift: tef research and development, Proceedings of the International workshop on tef genetics and improvement, pp. 16-19.

Terman, G., 1980. Volatilization losses of Nitrogen as ammonia from surface-applied fertilizers, organic amendments, and crop residues. Advances in agronomy 31, 189-223.

Tesfahun, W., 2018. Tef yield response to NPS fertilizer and methods of sowing in East Shewa, Ethiopia.

Tulema, B., Aune, J.B., Johnsen, F.H., Vanlauwe, B., 2008. The prospects of reduced tillage in tef (Eragrostis tef Zucca) in gare arera, West Shawa Zone of Oromiya, Ethiopia. Soil and Tillage Research 99, 58-65.

Walkley, A.J.a.B., I.A. , 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, 29-38.

Workneh, N., Mwangi, W., 1992. An economic analysis of the response of durum wheat to fertilizer: Implications for sustainable wheat production in the central highlands of Ethiopia. The Eighth Regional Wheat Workshop for Eastern, Central and Southern Africa. CIMMYT, pp. 177-185.

Zewdie, E., 2001. Study of the physical, chemical and mineralogical characteristics of some vertisols of Ethiopia.

Zhou, L., Chen, L., Li, R., Wu, Z., 2003. Behavior of soil urea N and its regulation through incorporating with inhibitors hydroquinone and dicyandiamide. Fertilization in the third millenium fertilizer, food security and environmental protection, proceedings 2, 3-9.