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Impact of Mixed Fertilizer Applications under Different Planting Methods and Seed Rates on Yield, Yield Components and Nutrient Use Efficiency of Tef [Eragrostis tef (Zucc.) Trotter]

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Abstract
Inappropriate agronomic and input management practices such as continuous utilization of DAP and urea with surface broadcast method of application has led to inefficient nutrient use, which could finally cause low productivity of tef. Thus, this study was conducted on two soil types (Vertisol and Cambisol) in Northern Ethiopia during the 2011 main crop season to examine the different compound fertilizer applications under different planting methods and seed rates. An improved tef variety 'Quncho' (Dz-Cr-387) was used as a test crop and 5 treatments evaluated using RCBD with 3 replications. The treatments were: 1) band application of complete fertilizer under drill seed in row at 5 Kg ha^{-1} seed rate; 2) broadcast complete fertilizer and seed (at 25 Kg ha^{-1} seed rate); 3) band application of DAP and urea under drill seed in row at 5 Kg ha^{-1} seed rate; 4) broadcast DAP and urea and seed (at 25 Kg ha^{-1} seed rate); 5) broadcasting tef at 25 Kg ha^{-1} seed rate with no fertilizer application (control). The treatments showed significant post harvest residual effects on the soil available P, but insignificant effect on total N in both trials. Band application of complete fertilizer under the row planting tef at 5 Kg ha^{-1} seed rate significantly improves agronomic efficiency, nutrient uptake, nutrient recoveries and crude protein content as compared to the other treatments.
Keywords: Band application. Complete fertilizer. DAP + urea. Crude protein. Nutrient uptake. Nutrient recoveries. Marginal rate of return. Soil types.

Introduction

Eragrostis tef is the only cereal crop species in the genus Eragrostis cultivated for its grain (Abebe, 2001) and it is the most important staple food used by more than 60% of the population in Ethiopia (Ahmed, 2008; Yenesew *et al*., 2011). Its grains have a protein content of 11% (Deckers *et al,* 2001; Doris, 2002; Kefyalew, 2008) and provide about two-thirds of the daily dietary protein intake of most Ethiopians (Deckers *et al,* 2001). Nowadays in Europe, tef is begining to be considered as a health food; especially for Celiac disease patients since it is gluten free (Spaenij-Dekking *et al*., 2005; Hopman, 2008). However, its production and productivity is still very low with national average yield of 1.15 Mg ha^{-1} (CSA, 2011a). Some reasons for the low productivity are use of traditional agronomic practices and inefficient fertilizer use.

According to CSA (2011b), in Ethiopia, 90.05% of the fertilizer is applied on cereals; out of it 39.53% is applied on tef, 26.04% on wheat, 17.38% on maize, and the remaining on other cereals. Although the amount of fertilizer applied on cereal crops for the year 2010/11 showed an increase of 23.8% over 2009/10, average tef yield in 2009/10 was 1.11 Mg ha^{-1} compared to 1.15 Mg ha^{-1} in 2010/11 (CSA, 2011a and CSA, 2011b), revealing an increase of only about 2.8% in productivity. This indicates the amount of fertilizer used alone may not probably bring concomitant yield increase. Hence, the common and inefficient fertilizer application practice (surface broadcasting) on tef should be replaced by band application method to improve fertilizer use efficiency.

The prime purpose of fertilizers is to improve the quantity and quality of agricultural products (White, 2006); but fertilizers used by farmers in Ethiopia are only DAP and urea. It is clear that DAP and urea applications have notably increased yield of improved tef varieties up to 2.27 Mg ha^{-1} (Tekalign *et al*. 2001; Balesh *et al*., 2005). However, the permanent use of these fertilizers could lead to facilitate mining of other essential plant nutrients which limit crop yield. As stated by White (2006), on many soils where K is adequate initially, regular N and P fertilizer use stimulates growth and greater withdrawal of the nutrients inducing K-deficiency symptoms to appear. That is why; nowadays some soils in Ethiopia are also deficient in nutrients like K, S, and other micronutrients.

Based on their primary nutrient content, fertilizers that contain single-nutrient such as urea, ammonium nitrate, and TSP are referred to as 'straight' or 'simple' fertilizers (FAO/IFA, 2000; McCauley *et al*., 2009). In contrast, fertilizers containing more than one primary nutrients such as MAP, DAP, potassium nitrate, ammonium sulphate are termed as multi-nutrient or compound fertilizers (White, 2006); and a fertilizer or blend of fertilizers containing all the three primary nutrients (NPK) such as Yara Milla Careal (YMC) are called 'complete' fertilizers (McCauley *et al*., 2009).

Little or no nutrient use efficiency trials were done on tef as affected by complete fertilizers that have proportional combination of macro and micronutrients against DAP and Urea under different planting methods and seeding rates of cereal crops, especially tef. Hence, the objectives of this experiment were: to examine the effect of mixed fertilizer applications under different planting methods and seed rates on (1) yield, crude protein and nutrient use efficiency of tef, (2) total N and available P post harvest residues.

Materials and methods

Description of the study area

The study was undertaken in one of the potential tef growing areas of North Ethiopia, Tigray region, in two soil types of Tahtay-Koraro district during the 2011 main crop season. These experimental soils namely Cambisol and Vertisol are situated at 13^{0}88'36" to 14^{0} 08' 57"N latitude and 38^{0}04'30" to 38^{0} 17' 02" E longitudes at an altitude of 1902m and 1917m respectively.

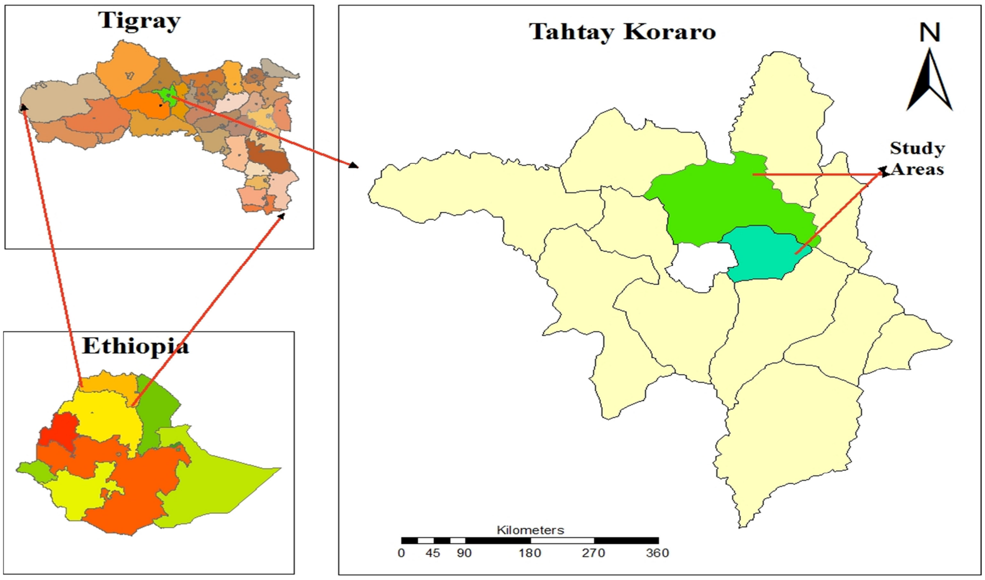


Fig 1 Geographical location of the study area

The mean annual rainfall of this location for the past 15 years (1997-2011) was 1031.3 mm and of the cropping season (2011) was 905.5 mm. Rainfall distribution of the study areas are characterized by unimodal pattern in which the main rainy season of study area extend from June to September. The average temperature of these study areas for the past 15 years revealed 20.92 ^{O}C with a mean maximum temperature record (30.97 ^{O}C) in April and the mean minimum (11.4 ^{O}C) in January.

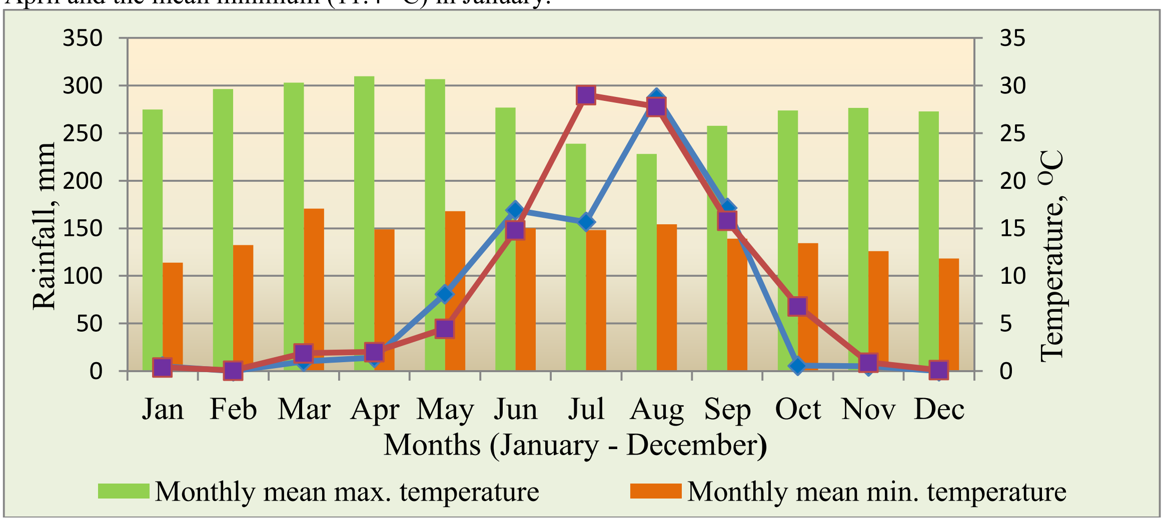


Fig 2 Monthly rainfall for 2011, monthly mean rainfall for the period1997-2011, Monthly mean maximum and monthly mean minimum temperature for the period1997-2011.

Experimental design and treatments

Improved tef variety 'Quncho' (Dz-Cr-387) was used as a test crop and five treatments in each soil type were arranged in a randomized complete block design (RCBD) with three replications.

The treatments were: band application of complete fertilizer under drill seed in row at 5 Kg ha^{-1} seed rate (T1); broadcast seed (at 25 Kg ha^{-1} seed rate) with complete fertilizer (T2); band application of DAP and urea under drill seed in row at 5 Kg ha^{-1} seed rate (T3); broadcast seed (at 25 Kg ha^{-1} seed rate) with DAP and urea (T4); and Control (seed broadcasted at 25 Kg ha^{-1} with no fertilizer) (T5).

The complete fertilizer (Yara Milla Cereal) constitutes 23N-10P-5K-3S-2Mg-0.3%Zn. Thus, 278 kg YMC mixed with 39.5kg TSP gives 64 kg N and 46 kg of P (as P_2O_5) that can be obtained from 100 kg DAP and 100 kg urea. Hence, irrespective of the fertilizer type used, recommended amount of Nitrogen (64 kg/ha) and Phosphorus (46 Kg ha^{-1} as P_2O_5) were applied for all the treatments except the control.

Total area of one experimental site was 414m^2 and the size of each plot was 4m*5m = 20m^2 with one meter free space between blocks and plots. The land was thoroughly ploughed 4 times before planting and date of sowing was 19th July on Vertisol and 20th July on Cambisol. Seed rates of 5 Kg ha^{-1} for row planting and recommended seed rate of 25 Kg ha^{-1} for the broadcast were used. For the row planted treatments, seeds were drilled at 20cm spacing between rows and placed under shallow soil cover. During planting, 100 Kg ha^{-1} DAP (46% P as P_2O_5 and 18%N) and 39.5 Kg ha^{-1} TSP (46% P as P_2O_5) were applied. However, YMC and Urea were applied in splits and the 178 Kg ha^{-1} YMC was applied at planting and the remaining 100 Kg ha^{-1} at tillering. In the same way 50kg urea was applied at planting and the other 50kg during tillering. Generally, 23 Kg ha^{-1} N was applied during tillering for all the treatments except the control.

In the row plating plots, fertilizers were applied in the soil as band application (5-8 cm away from the seed planting) by making a shallow furrow along the tef row and depositing the fertilizer on the bottom of the furrow not to contact with the seed and then covering with soil. For the broadcast plots the fertilizer was broadcasted on the surface of the land. At tillering stage, fertilizers were side dressed for the row planted tef and top dressed for the broadcasted tef. Weeding was carried out three times during the growing season. Harvesting was done after 115 days of sowing and threshing was done by hand.

Agronomic data collection

Average reading of twenty randomly selected plants from each plot was used for measuring the agronomic data on panicle length and panicle seed weight. However, grain yield, straw yield, and harvest index (the ratio of the total grain yield to the total biomass yield harvested on dry weight basis) were recorded from net plot size of 3m x 4m=12m^2 to avoid border effect.

Soil samples preparation and laboratory analysis

Two composite soil samples, one for each soil type were taken from a depth of 0-15cm using auger prior to sowing to represent the entire field. From each study area 30 subsamples were collected and these soil samples were dried, composited, sieved through 2mm sieve to have 1kg composite sample for each study site. The collected soil samples were then analyzed for selected physic-chemical properties mainly soil texture, pH, total N, available P, available S, available Zn, exchangeable bases, CEC, EC, $CaCO_3$ (Calcium carbonate) and soil organic matter content at National soil testing center, Addis Ababa.

Similarly after harvest, ten soil samples were collected from each plot at a depth of 0-15cm and were mixed thoroughly, air dried, ground and sieved to pass through 2 mm size sieve to analyze Available P and further sieved to pass through a 0.5 mm size sieve for the analysis of total nitrogen.

Routine soil laboratory procedures were used to analyze the different soil physical and chemical properties: Texture (Particle size distribution) was determined by the hydrometer method (Bouyoucos, 1962); Soil pH in a suspension of 1:2.5 soil water ratio by using pH meter (Peach, 1965); Electrical conductivity of the soil extract was determined using EC meter (Sahlemedin and Taye, 2000). Organic matter content of the soil was estimated from the organic carbon content determined using Walkley and Black (1934) method. To obtain percent of soil organic matter, percent of organic carbon was multiplied by 1.724 since the organic matter is conventionally assumed to contain 58% carbon (58/100 = 1.724).

Total Nitrogen determination was done by macro Kjeldahl method (Khee, 2001). Olsen method was used to determine available phosphorous content of the soil (Olsen and Sommers, 1982), available S using turbidimetric method (Kowalenko, 1985), and available Zn was determined according to Lindsay and Norvell (1978) method using DTPA as an extractant; in which the amount of these nutrients in the extracts is determined by the atomic absorption spectrophotometer. Cation exchange capacity and exchangeable bases were determined by ammonium acetate extraction method (Okalebo *et al*, 1993).

Plant analysis and crude protein determination

Sixty plant samples were randomly collected from each plot for the determination of N and P uptake by plants.

Plant samples for laboratory analysis were prepared according to the procedures described in Sahlemedhin and Taye (2000). The N and P concentration in the plant material were determined from the dry ashed samples. Crude protein content in the plant part of tef was determined by multiplying the total nitrogen in the plant part by 5.7.

Nutrient use efficiency determinations

Agronomic efficiency (AE, kg crop yield increase per kg nutrient applied) and apparent nutrient recovery efficiency (RE, kg nutrient taken up per kg nutrient applied) are amongst the agronomic indicators that describe nutrient use efficiency (Mosier *et al.,* 2004); and were calculated based on fertilizer input and plant uptake, according to Balesh *et al* (2007).

N yield in Kg ha^{-1} (N uptake by grain) = $\frac{\text{grain yield (kg/ha)} \times \text{\%N concentration}}{100}$

P yield in Kg ha^{-1} (P uptake by grain) = $\frac{\text{grain yield (kg/ha)} \times \text{\%P concentration}}{100}$

Agronomic efficiency of the treatments = $\frac{\text{grain yield of treatment} - \text{grain yield of control}}{\text{N rate applied}}$

Apparent N recovery (%ANR) = $\frac{\text{N yield of treatment} - \text{N yield of control}}{\text{N rate applied}} \times 100$

Apparent P recovery (% APR) = $\frac{\text{P yield of treatment} - \text{P yield of control}}{\text{P rate applied}} \times 100$

Statistical Analysis

The data collected on crop and soil parameters were checked for its normality and analyzed statistically through one-way analysis of variance (ANOVA) procedures. Least Significant Difference (LSD) was used for mean comparison among treatments using JMP 5 (SAS, 2002).

Results and Discussion

Soil physical and chemical properties of the study sites

Before planting soil fertility of the Vertisol was relatively higher than the Cambisol (Table 1). Both soils have high silt proportion (44%), but they differ in the relative proportion of sand and clay. Hence, according to Soil Survey Staff (2003), textural class of the Vertisol and Cambisol soils is silt clay and loamy respectively.

Based on London (1991), both study soils have low total N and organic carbon. The EC value indicated that both experimental soils are nonsaline. Available P was medium in Vertisol while low in the Cambisol. In addition, CEC was very high on the Vertisol whereas high on the Cambisol. On the other hand, According to Havlin *et al*. (2005), Zn concentration was medium or marginally deficient in both study soils, with 0.83ppm on Vertisol and 0.64ppm on Cambisol whereas available S value indicated deficit on the Cambisol and sufficient on the Vertisol.

Table 1 Pre – planting soil properties of the experimental areas from the upper 0-15cm depth

Soil Property	**Experimental soil type**	
	Vertisol (site 1)	Cambisol (site 2)
Physical property		
Particle size distribution (%)		
Sand (%)	16	30
Silt (%)	44	44
Clay (%)	40	26
Textural class	Silt clay	Loam
Chemical properties		
pH (1:2.5 water)	6.7	6.9
% $CaCO_3$	4.4	4.2
EC (ds/m)	0.117	0.075
Exc. Na (cmol(+)/kg)	2.01	1.77
Exc. K (cmol(+)/kg)	1.08	0.34
Exc. Ca (cmol(+)/kg)	12.46	15.86
Exc. Mg (cmol(+)/kg)	14.24	9.28
CEC (cmol/Kg)	42.64	38.31
BS (%)	69.86	71.03
Organic Carbon (%)	0.78	0.69
Organic Matter (%)	1.35	1.19
Total N (%)	0.086	0.074
C/N ratio	10:1	11:1
Available P (ppm)	5.96	4.84
Available Zn (ppm)	0.83	0.64
Available S (ppm)	26	3

CEC: cation exchange capacity; OC: organic carbon; OM: organic matter; Exc. K: exchangeable K; Exc. Na: Exchangeable Na; Exc. Ca: Exchangeable Ca; Exc. Mg: Exchangeable Mg; BS: Base saturation

Previous findings indicated that the optimum/ideal soil pH range for the growth of most crops is around neutral (6 to 7.5). Accordingly, Soils of the study sites were almost neutral (very slightly acidic) with pH value of 6.7 on Vertisol and 6.9 on Cambisol; consequently both soils can be rated as optimum/ideal for tef crop production and nutrient availability. Likewise, Tefera and Belay (2006) reported tef is normally grown on soils of neutral pH and poorly tolerates acid soil with pH below 5.

Generally, low to moderate (except available S of Cambisol rated as high) content of organic matter, total N, available P, available Zn and other soil characteristics of both experimental soils may possibly be due to continuous ploughing and cultivation of mono-cropping (e.g. tef) for a long period of time. In addition, it could also be due to erosion from intense and narrow rainfall distribution in the study areas. Removal of crop residue and limited use of manure/compost on cultivated land may cause deterioration of organic matter, soil structure and loss of nutrients. Prasad and Power (1997) reported that high temperature and the cracking nature of the Vertisol could lead to low SOM and Total N that enhances the leaching of Nitrate and Sulphate.

Residual effect of the selected nutrient elements

It is believed that synthetic fertilizers are generally soluble under favorable conditions, supplying the plant with nutrients in a quick manner. Consequently this might improve crop performance but significant residual effect might not be expected (Girmay *et al*., 2009). For this reason, post harvest total N content of the treatments (Table 2) did not show much variation with the baseline soil fertility status (Table 1) in both trial soils. Similar result was found by Haftamu *et al*. (2010) and Abay *et al*. (2011).

As indicated on Table 2, available P was significantly affected by compound fertilizer applications under different planting methods of tef. On both experimental soils, the highest significant value of available P was recorded on the DAP + urea treated plots; and the notablly lower value from the control treatment.

Table 2 Impact of the treatments on the post harvest soil residues of N and P content

Treatments	Experimental soils			
	Vertisol (Site 1)		Cambisol (Site 2)	
	Total N (%)	Available P (ppm)	Total N (%)	Available P (ppm)
T1	0.074^{a}	4.46 ± 0.141^{c}	0.083^{a}	4.1 ± 0.112^{d}
T2	0.069^{a}	5.00 ± 0.077^{b}	0.100^{a}	5.36 ± 0.102^{b}
T3	0.07^{a}	6.00 ± 0.07^{a}	0.081^{a}	6.34 ± 0.1^{a}
T4	0.067^{a}	5.90 ± 0.28^{a}	0.067^{a}	5.7 ± 0.018^{b}
T5	0.064^{a}	3.96 ± 0.122^{d}	0.070^{a}	3.14 ± 0.029^{d}
Significant level	ns	*	ns	*

Levels designated by same letter in columns are not significantly different at $P < 0.05$.
* Stands for significant and 'ns' stands for non significant difference at $P < 0.05$.

Total N on post harvest soil did not show significant differences among the different treatments. However, plots treated with T3 (band application of DAP + urea and drill seed in row at 5 Kg ha^{-1} seed rate) and T4 (broadcast seed (at 25 Kg ha^{-1} seed rate) and DAP + urea) on Vertisol and T3 on Cambisol showed significantly higher available P than plots treated by the other treatments. This might be because of the relatively smaller uptake of P supplied from DAP than from the complete fertilizer (YMC + TSP) by the plant and the inherent fixing nature of P on soil particles.

Yield and yield components

It is evident from Table 3 that significantly higher panicle length, panicle seed weight and harvest index were found from band application of complete fertilizer under drill seed in row at 5 Kg ha^{-1} seed rate (T1) followed by the band application of DAP and urea under drill seed in row at 5 Kg ha^{-1} seed rate (T3); and lower result of all the above parameters was recorded from the control (T5) on both soil types.

Table 3 Panicle Length, Panicle Seed Weight and Harvest Index as affected by the treatments.

Treatment	Panicle length (cm)		Panicle seed weight (g)		Harvest Index	
	Vertisol	Cambisol	Vertisol	Cambisol	Vertisol	Cambisol
T1	55.57^{a}	55.33^{a}	55.57^{a}	55.33^{a}	0.28^{a}	0.27^{a}
T2	51.03^{ab}	50.80^{bc}	51.03^{ab}	50.80^{bc}	0.24^{b}	0.22^{b}
T3	53.33^{ab}	52.23^{ab}	53.33^{ab}	52.23^{ab}	0.27^{a}	0.27^{a}
T4	47.83^{b}	47.73^{c}	47.83^{b}	47.73^{c}	0.23^{b}	0.21^{b}
T5	30.70^{c}	28.43^{d}	30.70^{c}	28.43^{d}	0.19^{c}	0.17^{c}
Significant level	**	**	**	**	**	**

Levels not connected by same letter in columns are significantly different at $P < 0.01$.
** Stands significant at $P < 0.01$

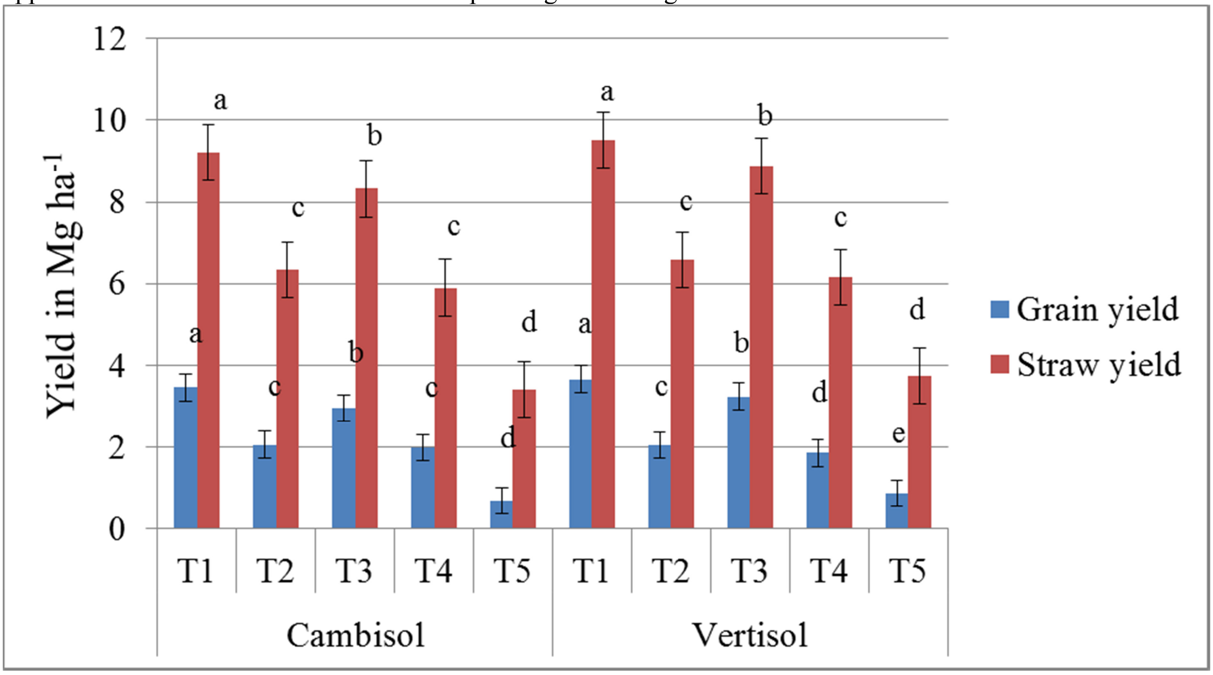
However, only T1 on both soils consistently show significant higher than T2, T4 and T5 for panicle seed weight and panicle length except for Vertisol with T2. Non significant result for panicle length, panicle seed weight and harvest index was found between T1 and T3 for both soils except on Cambisol for panicle seed weight. This show planting methods at different seed rate are more important in influencing plant parameter regardless of the fertilizer type. Applying fertilizer close to the seed improves nutrient availability and promotes growth than broadcasting method.

Highest harvest index was obtained from row planted tef at 5 Kg ha^{-1} seed rate with complete fertilizer and the lower value from control in both sites. The low harvest index could be associated with the absence of nutrients in the soil available for the crop to take. The absence of nutrient retards growth and finally leads to fail to produce well matured grains before the rainfall ceases.

Tef grain and straw yield were significantly influenced by the combined effect of planting method at different seed rate and fertilizer type. Fig 3 shows that grain yield of plots on both soils treated with band application of complete fertilizer under row planting tef at 5 Kg ha^{-1} seed rate (T1) was significantly higher than the other treatments involved and this was followed by the band application of DAP and urea under the row planting tef at 5 Kg ha^{-1} seed rate (T3). Broadcasting seed (at 25 Kg ha^{-1} seed rate) with complete fertilizer (T2) and broadcasting seed (at 25 Kg ha^{-1} seed rate) with DAP and urea (T4), on the other hand, gave non-significant results on both soil types. These observations revealed that the combined effect of planting method and plant population regardless of the fertilizer type plays vital role in influencing grain yield. Straw yield follows the same statistical output except that T3 show significantly different straw yield compared to T4.

In the same manner, straw yield of tef was significantly affected by the combined effect of planting method at different seed rate and fertilizer type (Fig 3). The highest straw yield 9.5 Mg ha^{-1} on Vertisol and 9.21 Mg ha^{-1} on Cambisol was measured from the band application of complete fertilizer under the row planting tef at

5 Kg ha^{-1} seed rate followed by 8.87 Mg ha^{-1} on Vertisol and 8.32 Mg ha^{-1} on Cambisol from the band application of DAP and urea under the row planting tef at 5 Kg ha^{-1} seed rate.



Levels not connected by same letter in the same graph colour are significantly different at $P < 0.01$.

Fig 3 Results for Grain Yield (Mg ha^{-1}) and Straw Yield (Mg ha^{-1})

The reasons for the superiority of row planting at 5 Kg ha^{-1} seeding rate against broadcasting at 25 Kg ha^{-1} seed rate could be due to band application of the treatments would facilitate nutrient utilization; the lower seed rate might reduce plant population density which could minimize competition for moisture and sunlight.

Comparable yield superiority of the complete fertilizer over the DAP and Urea source of fertilizer on both planting methods could be associated with the additional nutrients involved in the complete fertilizer (K, S, Mg and Zn) other than N and P. In addition to this, Havlin et al. (2005) reported that application of P and Zn nutrients in soils which are marginally deficient in P and Zn improves crop yield, indicating positive interaction of P and Zn. However, high P availability or application of P fertilizer alone could induce Zn deficiency in plants, commonly known as P – induce Zn deficiency (Cakmak and Marschner, 1987). Thus, application of Zn containing P fertilizer on Zn and/or P deficient soils could improve tef yield. Positive and higher response to complete fertilizer is an indication of the soil's deficiency on the nutrients like N, P, K, S, Mg, and Zn.

In this experiment the grain yield obtained from row planted tef at low seeding rate (fig 3) irrespective of the fertilizer type is more than two times higher than the national and regional (1.15 Mg ha^{-1}) average tef productivity during the period 2010/11 (CSA, 2011a). The possible reasons for this yield increase could be due to the low seed rate, yield potential of the variety, and efficient resource utilization (sunlight, moisture and nutrients). Fufa et al. (2001) reported that there is an ample chance to increase tef productivity by integrating high yielding varieties and improved management practices.

Protein quality, agronomic efficiency, nutrient uptake and recoveries

Band applications of compound fertilizers under different planting methods have influenced not only yield but also crude protein content of tef grain. The maximum protein content of tef grain in Cambisol and in Vertisol was obtained from the complete fertilizer banded in row planting tef at low seeding rate (5 Kg ha^{-1}) and from the band application of DAP and urea along the row planting tef at low seeding rate (5 Kg ha^{-1}) (Table 4). However, significantly lower protein content of tef grain was measured in the control in both locations and this was due to poor soil fertility.

Protein content of tef planted in row (at 5 Kg ha^{-1} seed rate) with complete fertilizer (T1) is not statistically different from tef planted in row (at 5 Kg ha^{-1} seed rate) with DAP and urea fertilizers (T3) on both soils. Protein yield is however consistently significantly higher on tef planted in row (at 5 Kg ha^{-1} seed rate) with complete fertilizer than the other treatments. The slight superiority of the complete fertilizer treated tef plots in protein content of grain in both planting methods and experimental fields might be due to the additional nutrients especially, K and S supplied by complete fertilizer in which, S and K are important for protein formulation (FAO/IFA, 2000).

Significantly higher grain protein content and protein yield offered from row planting tef at low

seeding rate (5 Kg ha^{-1}) than broadcasting (25 Kg ha^{-1}) even both received the same amount and type of fertilizer. This result is in harmony with the findings of Amjad and Andreson (2006), El-Afandy (2006), and Kabesh *et al.* (2009) who reported that protein content of wheat grain was significantly higher with drill method of sowing than broadcasting. In contrast, Pandey and Kumar (2005) and Abd El-Lattief (2011) found that protein content in grain of wheat was unaffected by sowing methods. Thus, this study and all the above findings could indicate that the significant difference in protein content might be due to the plant population density difference.
However, the N and P uptake was significantly influenced by compound fertilizer sources and planting methods with different seed rates. The combined effect of band application of the complete fertilizer along with the row planting method at low seeding rate (5 Kg ha^{-1}) significantly improved the N and P uptake of the grain (Table 4) compared with the other treatments involved except that of T3 (DAP + urea banded under the row planting tef with low seed rate) on the Vertisol. Result of agronomic efficiency is consistent with this finding. The possible reason for the superiority of the complete fertilizer over DAP and urea might be due to additional nutrients (S, Mg, Zn) of the complete fertilizer could facilitate uptake of P and N. London (1991) affirmed that S has an acidifying effect and can enhance uptake of other elements which agrees with the findings of Habtegebrial and Singh (2006), who confirmed significantly better N uptake of grain due to the combined N and S fertilization.
Table 4 Agronomic efficiency; grain protein quality; and nutrient uptake and recoveries.

Soil type	Treatment	AE	Protein (%)	protein Yield (Kg ha^{-1})	P uptake (Kg ha^{-1})	N uptake (Kg ha^{-1})	ANR (%)	APR (%)
Vertisols	T1	48^{a}	11.72^{a}	518^{a}	12.43^{a}	82.88^{a}	110^{a}	53^{a}
	T2	13^{b}	10.32^{bc}	255.8^{c}	5.4^{b}	40.92^{c}	45^{c}	18^{b}
	T3	41^{a}	11.24^{ab}	444^{b}	12.2^{a}	71^{b}	92^{b}	52^{a}
	T4	17^{b}	10^{c}	224.7^{c}	4.6^{b}	36^{c}	37^{c}	4^{b}
	T5	-	7.33^{d}	77^{d}	1.9^{c}	12.3^{d}		
	Significant level	*	*	**	**	**	**	**
Cambisol	T1	48^{a}	12.54^{a}	525.5^{a}	10.65^{a}	84^{a}	114^{a}	46^{a}
	T2	23.4^{c}	10.6^{b}	263.4^{c}	4.76^{c}	42^{c}	48^{c}	17^{c}
	T3	39^{b}	11.34^{ab}	406.7^{b}	8.6^{b}	65^{b}	84^{b}	36^{b}
	T4	22.3^{c}	10.43^{b}	252^{c}	4.2^{d}	40.3^{c}	45^{c}	14^{c}
	T5	-	8.32^{c}	70.3^{d}	1.4^{e}	11.24^{d}	-	-
	Significant level	*	*	**	**	**	**	**

Means not sharing the same letter in the same column are significantly different.
* Stands significant difference at $P < 0.05$; and ** stands significant difference at $P < 0.01$. ANR- apparent N recovery; APR- apparent P recovery; AE- agronomic efficiency kg grain/kg N

The current estimate of N recovery from mineral fertilizers is about 33- 50% Cassman *et al.* (2002) and about 45% for applied P Tilman *et al.* (2002) for cereal crops production. However in this study, ANR was higher than the above findings when fertilizer is banded in row beneath the row planting tef at low seeding rate and the other treatments are lower than the above findings. APR of this study is lower than the above finding except band application fertilizer under the row planting tef with low seeding rate which is higher than the above finding. Because, crop response to added fertilizer could be strongly influenced by environmental conditions such as soil temperature and moisture. Additionally, factors such as rate of fertilizer applied, method of application and chemical form used can all affect nutrient recoveries.

Higher nutrient uptake and apparent nutrient recovery were recorded from the banded application of complete fertilizer along with the line planting tef at 5 Kg ha^{-1} seed rate (T1); and lower apparent nutrient recovery was measured in the broadcasted tef treated with DAP-Urea fertilizers (T4). This was probably due to the efficiency of band fertilizer application which prevents loss of nutrients through runoff, leaching and volatilization; and due to lower plant population density which facilitate nutrient uptake by reducing competition. This is in accord with Turk and Tawaha (2002) who affirmed P application by band placement is more efficient due to a better contact with moist soil. Similarly, Balesh et al. (2007) reported, broadcast method of fertilizer application during the peak period of rain can cause the N loss in the form of gas (N_2O) and through runoff, especially on Vertisol in which high soil moisture and poor drainage are the unique properties of these soil types.

Comparing treatments with same planting method, complete fertilizer treatments (T1 and T2) showed higher nutrient recovery than the DAP and urea treated plots (T3 and T4) although not significantly different from T3 (tef grown in row with DAP and urea) on Vertisol. This was perhaps application of S, Zn, K and Mg may stimulate uptake of N and P nutrients. Habtegebrial and Singh (2009) stated that S application with N improves the nitrogen use efficiency by 28%.

In general tef yield and protein quality have increased in the complete fertilizer treated plots than the plots treated with DAP and Urea although the difference is not statistically significant particularly in the case of drilling method. This confirms with Habtegebrial *et al* (2007) who stated crop yield and quality are found to decrease when N is applied without S in S deficient soils. Similarly, Alemayehu (2010) indicated that when N is fertilized with S there is 3% yield increase in maize, which is in fact lower than value obtained for tef in this study.

Conclusion

Band applications of mixed fertilizer integrated with sowing methods at different seeding rates appreciably resulted significant variation on yield, yield components, tef nutrient use efficiency and crude protein content. The low response of the control treatment in all agronomic parameters can be attributed to the low fertility status and high seed rate (25 Kg ha^{-1}).

Band application of complete fertilizer under row planting tef at low seeding rate (5 Kg ha^{-1}) improves yield, plant nutrient uptake, nutrient recoveries and crude protein as compared to the other treatments. This indicates micro and macro nutrients deficiency, broadcast method of sowing at high seeding rate and susceptibility to lodging are the major tef growing problem in the study areas.

Hence, proper fertilizer application method (band application instead of broadcasting) under the row planting tef with low seed rate (5 Kg ha^{-1}) is very important practice for tef crop production in the study area and other locations which have similar soil and other environmental conditions.

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