

Effect of vermicompost and blended fertilizers rates on yield and yield components of Tef (*Eragrostis tef* (Zucc.) Trotter)

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Tef is a staple crop in Ethiopia in which its yield is constrained by poor soil fertility management. Therefore, a field experiment was conducted for two consecutive years during 2016 and 2017 on clayey textural soil to assess the effect of vermicompost and inorganic fertilizer rates on yield and yield components of tef. Accordingly, field experiment with four levels of vermicompost (0, 2, 4 and 6 t ha⁻¹) and four levels of NPS (0, 100, 150 and 200 kg ha⁻¹) were arranged in randomized complete block design (RCBD) in a factorial combination with three replications. A tef variety, qunco was used as test crop. Analysis of the data revealed that highest grain yield (2269.80 kg ha⁻¹) was obtained from the treatment of 4 t vermicompost ha⁻¹ + 150 kg NPS ha⁻¹. Significantly highest straw yield (6480.60 kg ha⁻¹) was obtained from the treatment of 6 t vermicompost ha⁻¹+200 kg NPS ha⁻¹, but statistically similar with 4 t vermicompost ha⁻¹ +150 kg NPS ha⁻¹. To evaluate the feasibility of the treatments with view of farmers' practices, a partial budget analysis was conducted on straw and grain yield of tef and accordingly the highest marginal rate of return 4184% were obtained from combined fertilization of 4 t vermicompost ha⁻¹ and 150 kg NPS ha⁻¹. Therefore, based on the data obtained from this study application of 4 t vermicompost ha⁻¹ and 150 kg NPS ha⁻¹ will be recommended as profitable for the production of tef at Beles kebele Tahtay Koraro district.

Key words: Integrated nutrient management, NPS fertilizer tef yield, vermicompost.

INTRODUCTION

Tef is one of the most stable food crop originated and diversified in Ethiopia. It is highly preferred by Ethiopian people for consumption as food, since it is nutritionally rich and free of protein gluten (Ketema, 1991; Merga, 2018). Tef performs well at an altitude of 1800 to 2100 m above sea level, annual rainfall of 750 to 850 mm, growing season's rainfall of 450 to 550 mm and a temperature of 10 to 27°C although it can adapt wide

range of agro-climatic conditions (Ketema, 1993). Moderately fertile clay and clay loam textural soils are ideal for tef growing. It can also withstand moderate water logged conditions (Anonymous, 1994).

According CSA (2017/2018) area coverage of tef crop in Ethiopia was around 23.85% (3,023,283.50 ha) first and in terms of grain yield production it was about 17.26% (5,283,401.2 t) second after maize. Report of

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CSA (2017/2018) an area coverage and grain yield production of tef in Tigray region was approximately to 21.79% (167,748.72 ha) and 15.10% (257,906.10 t), respectively which was second only to sorghum in both productions. The national tef average grain yield was 1.75 t ha⁻¹ which was higher than the regional tef yield (1.54 t ha⁻¹).

Farming systems in Ethiopia lack sustainability due to nutrient losses by soil erosion, lack of soil fertility restoring inputs and unbalanced nutrient using (Ajayi et al., 2007; Hirpa et al., 2009). Estimated essential plant nutrients loss in Africa was approximately 50 kg ha⁻¹ year⁻¹ (Janssen et al., 1995). Inorganic fertilizers overcome soil fertility problems and responsible for increasing large part of world's food production (Sanchez and Leakey, 1997). Increment of crop yield from 30 to 50% has resulted from application of commercial fertilizers (Vlek, 1990; Stewart et al., 2005). However, chemical fertilizers in effect, "kill" soil properties while organic fertilizers improve and sustain the soil (Goel and Duhan, 2014). Excessive and inappropriate use of chemical fertilizers is the major cause of nutrient imbalance and degrading our soil (Singh et al., 2001; Meena et al., 2003; Mahajan et al., 2008; Mukhtar et al., 2011). There is no substitute for nutrients in providing high production (Ahmad, 1992). There is no absolute replacement of chemical fertilizers as the soils of Ethiopia are low in nutrients and organic matter. Nutrient recycling by use of organic manures is preferred to restore nutrient removed by crops (Jobe, 2003). Vermicompost is particularly good for farmers, consumers and ultimately for soil as it can be used as a resource for maximizing crop productivity on sustainable basis and with more financial safe in comparison to these chemical fertilizers (Singh and Chauhan, 2009). Vermicompost increase soil organic carbon, nitrates, phosphates, exchangeable calcium and some other nutrients for plants (Orozco et al., 1996). Vermicompost is the recently organic fertilizer in supplementing chemical fertilizers for sustainable development of agriculture (Gupta, 2003).

But, application of only organic manures inefficiently improves the yield per unit area (Satyanarayana et al., 2002; Jobe, 2003). Higher cost of chemical fertilizers joined with its scarcity and non availability at market during growing period of crops resulted in farmers fail to apply these fertilizers to their crop field in time. On the other hand, organic manure is readily available to the farmers and the price is also low (Alam et al., 2007). In addition to that, applications of manures reduce the environmental pollution but chemical fertilizers cause environmental pollution during manufacturing in the industry (Rathier and Frink, 1989) and caused water eutrophication which is resulted in increasing of unwanted species of aquatic plants and algae formation, degradation of water quality and water environment, bad water odor and dying of fish (Göksu et al., 2003; Sönmez et al., 2008).

Therefore, integrated management of plant nutrients

can lessen this problem and can be suitable for any farming system and socio-economic conditions (Lamps, 2000). Integrated plant nutrient management is the application of inorganic fertilizer in combination with organic fertilizer to maintain soil fertility and to balance nutrient supply in order to boost up the crop yield per unit area (Patra et al., 2000; Aulakh et al., 2008; Mahajan et al., 2008; Roberts, 2010). Organic matter is an imperative indicator of soil fertility Rahman et al. (2007) by improve soil structure, nutrient exchange and maintain soil physical conditions (Becker et al., 1995; Ayoub, 1999). Organic matter also reduces the level of carbon dioxide in the atmosphere that contributes positively to climate change (Anon et al., 2003). This trial was, therefore, conducted to study the effect of application rate of organic (vermicompost) and nitrogen, phosphorus and sulfur (NPS) on the growth and yield of tef.

MATERIALS AND METHODS

Area description

The field experiment was conducted for two consecutive years during 2016 and 2017 main cropping season under rain fed conditions at Shire Soil Research Center site in Beles kebele Tahtay Koraro district, North Western zone of Tigray regional state (Figure 1). The altitude of the district varies between 1957 m above sea level. Vertisols are the dominant soil types in the area. The study area is found in a semi-arid climatic zone and has mixed crop-livestock farming system. It received mono-modal erratic distribution of rainfall, with annual rainfalls of 1088.7 and 919.5 mm during the growing seasons of 2016 and 2017, respectively (Figure 2a). The average monthly temperatures were 20.7, 20.77°C, respectively in the years of 2016 and 2017 (Figure 2b).

Experimental design and treatment

The experiments were conducted at site of Shire Soil Research Center at Tahtay Koraro district. Permanent site and plots were used for conducting the experiment. The field experiments contain a total of sixteen (16) treatments. The treatments were four levels of Vermicompost (0, 2, 4, 6 t ha⁻¹) and four levels of new blended fertilizer (NPS) (0, 100, 150 and 200 kg ha⁻¹). The treatments were arranged in factorial arrangement and were laid out in RCBD with three replications. The plot size was 3 × 4 m (12 m²) and the net harvested plot size area was 10.4 m². The spacing between rows, plots and replications was 0.2, 1 and 1.5 m, respectively. Zn (2 kg ha⁻¹) and B (1 kg ha⁻¹) fertilizers were applied foliarly for all treatments except control treatment as uniform before head initiation. A full dose of blended fertilizer (NPS) was applied at planting time close to seed drilling line. The recommended seed rate of 10 kg ha⁻¹ quncho variety was used and sown by drilling method at each row. All recommended cultural practices (plowing, weeding, pesticides, etc.) for tef crop was done as per the recommendation of the study area.

Soil and vermicompost samples analysis

Before planting surface composite soil sample was collected from experimental site for site characterization and the soil sample was taken at a depth of 0 to 20 cm, auger was used for collecting the

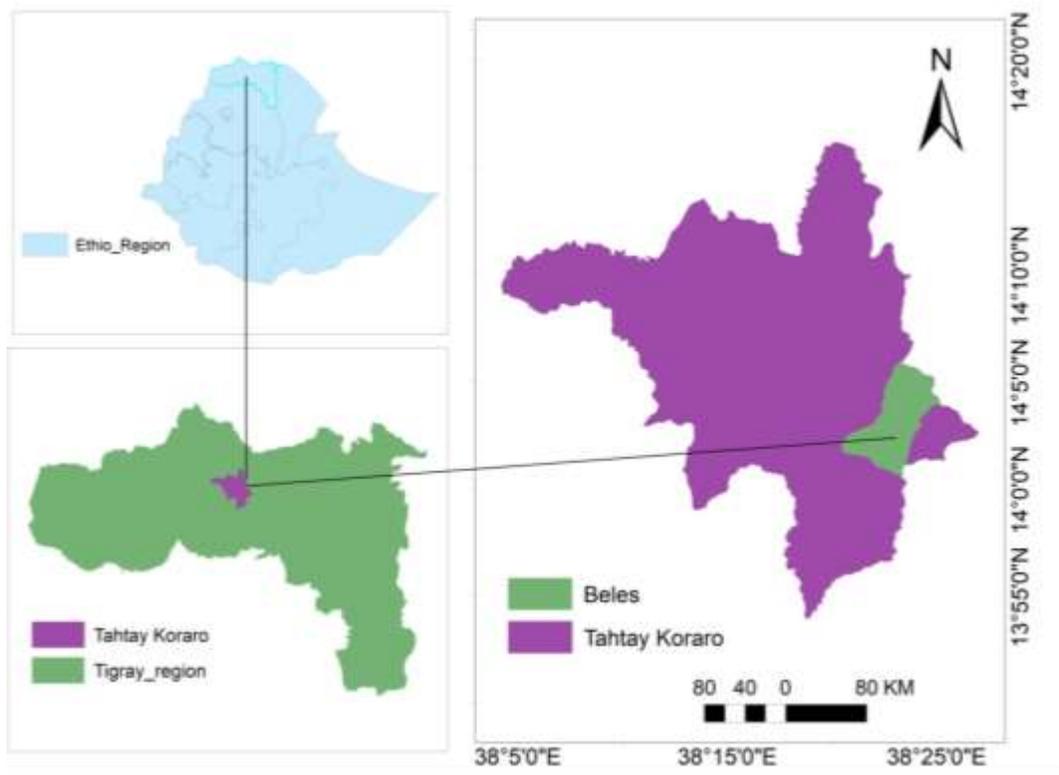


Figure 1. Location of the study area.

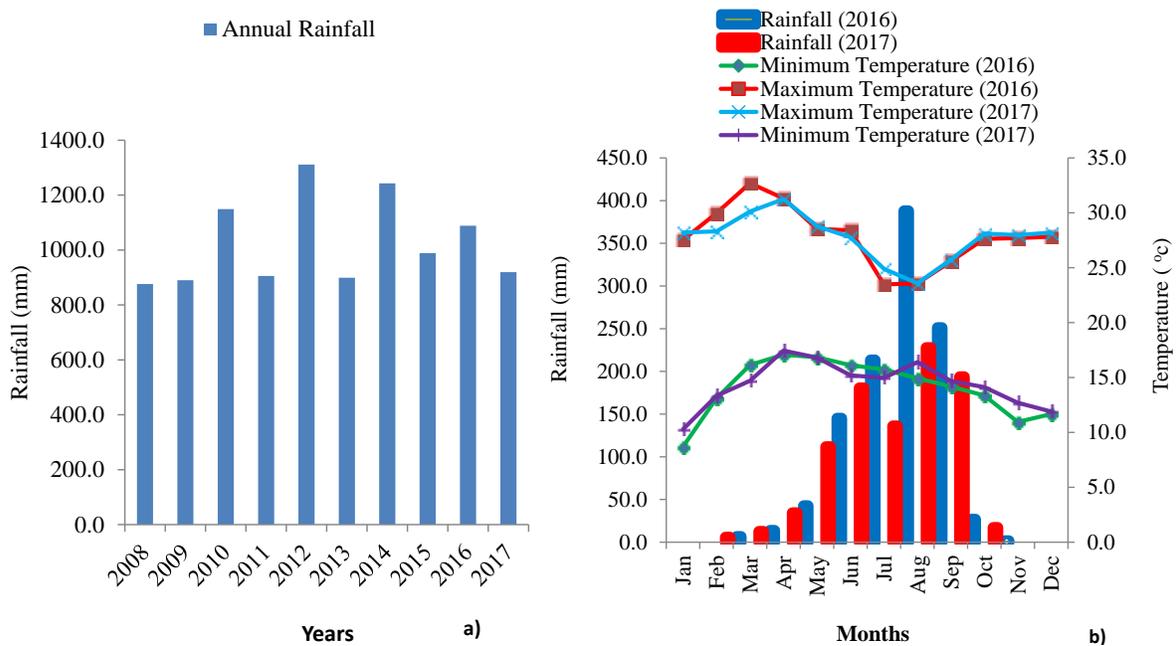


Figure 2. Ten years (2008 to 2017) annual rainfall (a), and monthly rainfall, maximum and minimum temperatures (b) measured in the study area during experimental years of 2016 and 2017.

disturbed sample. The collected sample was properly labeled, packed and transported to the Shire Soil Research Center and

Table 1. Soil physiochemical properties pre-planting.

Parameter	Value	Rating	Reference
% Sand	19	-	-
% Silt	22	-	-
% Clay	59	-	-
Textural class	Clay	-	-
OC (%)	0.550	Very low	Emerson (1991); Charman and Roper (2007)
OM (%)	0.95	Very low	Emerson (1991); Charman and Roper (2007)
Total N (%)	0.048	Low	Bruce and Rayment (1982)
pH	6.75	Neutral	Bruce and Rayment (1982)
ECe (dS/m)	2.32	Slightly saline	Richards (1954).
Ava. P (ppm)	2.65	Very low	Holford and Cullis (1985)
CEC [cmol(+)/kg]	34.3	High	Metson (1961)
Exchangeable base			
Na[cmol(+)/kg]	0.21	Low	Metson (1961)
K [cmol(+)/kg]	0.52	Moderate	Metson (1961)
Mg [cmol(+)/kg]	14.91	Very high	Metson (1961)
Ca [cmol(+)/kg]	17.49	High	Metson (1961)

Table 2. Chemical properties of vermicompost.

Chemical properties	Values
pH	7.40
EC(dS/m)	1.70
OC (%)	23.00
Total N (%)	1.7
Total P (ppm)	8200
Total K (ppm)	11000

prepared for analysis according to the standard procedures.

Soil texture was determined using the Bouyoucos hydrometer method (Bouyoucos, 1962). The pH of the soil was measured in the supernatant suspension of a 1:2.5 soil to water ratio using a pH meter (Rhoades, 1982). And electrical conductivity (EC) 1:2.5 soil to water suspension was measured according to the method described by (Jakson, 1967). Organic carbon (%) was determined by method as described by (Walkely and Black, 1934). Available P (ppm) was analyzed by employing the Olsen method Olsen et al. (1954) using ascorbic acid as the reducing agent. Total nitrogen was measured using Kjeldahl method as described by (Bremner and Mulvaney, 1982). Exchangeable cations (Ca^{2+} , Mg^{2+} , Na^+ , and K^+) and CEC in $\text{cmol}(+) \text{kg}^{-1}$ soil was determined by ammonium acetate method. The laboratory soil result was revealed in Table 1.

For conducting of the experiment organic fertilizer vermicompost was used as component of the treatments. Source of vermicompost was Lantana camara weed plant by the digestion of it by earth worms as worm cast. The organic carbon, N, P, K, pH and EC of vermicompost used in the experiment were determined used the standards applied for soil and the results are illustrated in Table 2.

Agronomic data collection and analysis

Data collected for the experiment were days to 50% heading, days

to 90% maturity, plant height (cm), biomass yield (kg ha^{-1}), straw yield (kg ha^{-1}), grain yield (kg ha^{-1}) and harvest index (%). Data were collected for the experiment on yield and yield component related parameters on plot basis and converted to hectare. Harvest index was calculated by considering the ratio of grain yield to biomass yield.

The collected data were subjected to statistical two way analysis of variance (ANOVA) using SAS version of 9.0 (SAS, 2002). Significant difference between and among treatment means were assessed using the least significant difference (LSD) at 0.05 level of probability (Gomez and Gomez, 1984).

To evaluate the feasibility of different treatments partial budget analysis technique of CIMMYT (1988) was applied to straw and grain yield. The partial budget analysis was performed based on the field price of the crop with prices of 0.82 and 0.11 \$ kg^{-1} for grain and straw of tef, respectively. The partial budget analysis also included all the variable costs of fertilizers application, transportation, vermicompost production costs and prices of each fertilizer that vary for each treatment. Based on the CIMMYT manuscript it is expected that experimental yields are often higher than the yields that farmers could expect using the same treatments. Hence, in economic calculations, the straw and grain yield has been adjusted to 10% lower than the actual yield obtained from the experimental plots to make the representative yield at the farmers' fields, (CIMMYT, 1988).

RESULTS AND DISCUSSION

Effects of vermicompost and NPS fertilizer rates on phenological, growth, and yield and yield component parameters of tef crop

Phenological parameters

Days to 50% heading:

The interaction of vermicompost and NPS fertilizers and impact of NPS had brought significant effect (Table 3) on days to 50% heading. Tef crop that did receive high vermicompost and NPS headed earlier than those that receive no fertilizer or low fertilizer. Generally, all the treated plots excluding the unfertilized plot, 2 t vermicompost ha⁻¹, 4 t vermicompost ha⁻¹ and 6 t ha⁻¹ plus basal application of Zn and B to all these mentioned vermicompost amounts had significantly lowest number of days to 50% heading. This may indicate the increased rate of chemical fertilizers increase the matrix potential of the soil and short period of moisture content in the study area speed up heading of the crop at that time. Early headings of tef were perhaps due to highest rate of vermicompost and NPS fertilizers encourage the crop in early establishment, rapid growth and development. In line with this result, Mitiku et al. (2014) had found that application of farmyard manure, vermicompost and nitrogen, phosphorus and potassium (NPK) fertilizers hastened days to heading and maturity as compared to unfertilized plots. This result is also in agreement with findings of Sewnet (2005) who reported of early flowering with an increased amount of N application in rice. In contrast, Abraha (2013) reported that heading was found significantly delayed at the highest N fertilizer rate when compared to the lowest dose of application on tef, wheat and barley crops.

However, at the time of plots fertilized with vermicompost only there were no significant variation. On the other hand, when plots were fertilized with single NPS fertilizer there were significant effects on headings of tef. The delayed days to headings of tef were recorded at the plots treated without NPS fertilizer. Early headings of tef were measured from application of high levels of NPS fertilizers.

Days to 90% maturity:

It was observed that 90% days of maturity of tef crop were significantly affected by single levels of NPS fertilizer plus basal application of Zn and B fertilizers, but not by the combined application of vermicompost and NPS plus basal application of Zn and B fertilizers and single levels of vermicompost plus basal application of Zn and B fertilizers (Table 3). When plots were fertilized with only levels of NPS fertilizer there were significant effects on headings of tef. The extended days to maturity of tef

was measured at plots treated without NPS fertilizer. Early days to maturity of tef were recorded from application high levels of NPS fertilizers. This is probably due to the fact that chemical fertilizers enlarge the matrix potential of the soil and short period of moisture content in the soil of study area speed up heading of the crop at that growing period. Application of optimum (NPS) fertilizers encouraged early establishment, rapid growth and development. Similarly Mitiku et al. (2014) had articulated that fertilization of NPK fertilizers hastened days to maturity as compared to unfertilized plots.

Growth parameters

Panicle length

The combined application of vermicompost and NPS fertilizers and main effect of NPS fertilizer significantly ($P < 0.0001$) affected the panicle height of tef crop but this was not so in case of sole application of vermicompost fertilizer (Table 4). Thus tallest panicle height (49.30 cm) was found from plots that received vermicompost at 6 t ha⁻¹+nil NPS plus basal applied Zn and B fertilizers but this was not significantly different from other using treatments of 2, 4 and 6 t vermicompost ha⁻¹ in various combination of NPS fertilizers. However, there was no consistent augmentation of plant height in all increased doses of the treatments. While the shortest panicle height (35.27 cm) was obtained from control plot and from all plots those fertilized with interaction of nil vermicompost with the levels of NPS (100, 150 and 200 kg ha⁻¹). In line with this finding, Fayera et al. (2014) reported that the application of balanced fertilizer and efficient utilization of nutrients leads to high photosynthetic productivity and accumulation of high dry matter, which ultimately increases panicle length and grain yield.

While plots were treated with different amounts of NPS significant variation between the levels were shown. Plots received three levels of NPS (100, 150 and 200 kg ha⁻¹) did not show significant variation among them but had brought significant longest panicle height over the plot fertilized without NPS fertilizer.

Plant height

The effects of combined application of vermicompost and NPS fertilizers, and at their individual levels brought significant effect on plant height of tef crop (Table 4). Longest plant height (120.27 cm) was obtained from application of vermicompost at 4 t ha⁻¹+200 kg NPS ha⁻¹ plus basal applied Zn and B fertilizers, and this was not significantly different from using (0, 2, 4, 6) t vermicompost ha⁻¹ with various combination of positive NPS fertilizers. In some increased combined application of vermicompost and NPS fertilizers inconsistent plant heights were observed. The plant heights were shortest

Table 3.Heading and maturity of tef under the effect of vermicompost and NPS fertilizers.

VC(t ha ⁻¹)	NPS (kg ha ⁻¹)					NPS (kg ha ⁻¹)				
	0	100	150	200	Mean	0	100	150	200	Mean
	DH (days)					PM (days)				
0	70.67 ^a	61.0 ^{Cd}	59.00 ^d	59.33 ^d	62.50	113.50	111.67	111.00	110.83	110.00
2	73.33 ^a	59.00 ^d	59.00 ^d	58.33 ^d	62.42	109.50	109.67	110.33	109.33	109.79
4	73.33 ^a	59.67 ^d	59.00 ^d	58.67 ^d	62.67	108.50	109.00	108.17	108.00	109.42
6	69.67 ^b	63.33 ^c	58.67 ^d	58.67 ^d	62.58	108.50	108.83	108.17	107.67	109.08
Mean	71.75 ^a	60.75 ^b	58.92 ^c	58.75 ^C		111.75 ^A	109.71 ^B	108.54 ^b	108.29 ^b	
CV (%)			4.48					3.18		
LSD (P=0.99) for VC			NS				LSD (P=0.81) for VC		NS	
LSD (P<0.0001) for NPS			1.6				LSD (P=0.0035) for NPS		2.00	
LSD (P<0.0001) for VC*NPS			3.23				LSD (P=0.30) for VC*NPS		NS	

Where, means followed by the same letters are not significantly different (P≤0.05), VC =vermicompost, NPS= (nitrogen, phosphorus, sulfur), DH = days to headings, PM = physiological maturity.

Table 4.Panicle length and plant height of tef under the effect of vermicompost and NPS fertilizers.

VC(t ha ⁻¹)	NPS (kg ha ⁻¹)					NPS (kg ha ⁻¹)				
	0	100	150	200	Mean	0	100	150	200	Mean
	PL (cm)					PH (cm)				
0	70.67 ^a	61.0 ^{Cd}	59.00 ^d	59.33 ^d	62.50	72.60 ^e	109.17 ^{abc}	110.57 ^{abc}	117.63 ^{ab}	102.49
2	73.33 ^a	59.00 ^d	59.00 ^d	58.33 ^d	62.42	75.30 ^e	109.83 ^{abc}	108.70 ^{abc}	112.90 ^{ab}	101.68
4	73.33 ^a	59.67 ^d	59.00 ^d	58.67 ^d	62.67	86.03 ^{de}	98.00 ^{cd}	113.10 ^{ab}	120.27 ^a	104.35
6	69.67 ^b	63.33 ^c	58.67 ^d	58.67 ^d	62.58	84.27 ^{de}	104.33 ^{bc}	109.77 ^{abc}	120.03 ^a	104.60
Mean	71.75 ^a	60.75 ^b	58.92 ^c	58.75 ^C		79.55 ^c	105.33 ^b	110.53 ^{ab}	117.71 ^a	
CV (%)			12.99					12.48		
LSD (P=0.81) for VC			NS				LSD (P=0.83) for VC		NS	
LSD (P<0.0001) for NPS			3.27				LSD (P<0.0001) for NPS		7.40	
LSD (P<0.0001) for VC*NPS			6.54				LSD (P<0.0001) for VC*NPS		14.81	

Means followed by the same letters are not significantly different (P≤0.05), VC =vermicompost, NPS= (nitrogen, phosphorus, sulfur), PL = panicle length, PH = plant height.

for treatments having plots fertilized with interaction of all levels of vermicompost with zero NPS fertilizer. The increment of plant height is due to sufficient supply of balanced

essential nutrients from vermicompost and NPS fertilizers. In agreement with this experiment, Kondappa et al. (2009) observed that integrated nutrient management treated plots showed

improved growth and yield of chilli. Alike, Degwale (2016) also observed that interacted application of vermicompost and NP fertilizers had resulted on increased plant height of onion.

Table 5. Biomass and grain yield of tef under the effect of vermicompost and NPS fertilizers.

VC (t ha ⁻¹)	NPS (kg ha ⁻¹)					NPS (kg ha ⁻¹)				
	0	100	150	200	Mean	0	100	150	200	Mean
	BY (kg ha ⁻¹)					GY (kg ha ⁻¹)				
0	2759.8 ^g	5141.0 ^{de}	6488.9 ^{Bc}	6451.7 ^{Bcd}	5210.4 ^c	538.6 ^H	1301.7 ^{ef}	1520.2 ^{cde}	1660.2 ^{bcd}	1255.17 ^c
2	3401.7 ^{fg}	5393.2 ^{Cde}	6145.3 ^{bcd}	7034.2 ^{ab}	5493.6 ^c	779.4 ^{gh}	1461.2 ^{def}	1651.5 ^{bcd}	1752.8 ^{bc}	1411.21 ^b
4	4379.5 ^{ef}	5427.4 ^{cde}	7984.6 ^a	7140.2 ^{ab}	6232.9 ^b	909.4 ^g	1400.7 ^{def}	2269.8 ^a	1641.3 ^{bcd}	1555.29 ^{ab}
6	5940.6 ^{Bcd}	6587.2 ^{bc}	7254.7 ^{ab}	8150.4 ^a	6983.2 ^a	1223.2 ^f	1571.5 ^{cde}	1885.3 ^b	1669.9 ^{bcd}	1587.46 ^a
Mean	4120.4 ^c	5637.2 ^b	6968.4 ^a	7194.10 ^a		862.62 ^d	1433.8 ^c	1831.69 ^a	1681.03 ^b	
CV (%)			19.6			17.41				
LSD (P<0.0001) for VC			673.24			LSD (P<0.0001) for VC		145.27		
LSD (P<0.0001) for NPS			673.24			LSD (P<0.0001) for NPS		145.27		
LSD (P<0.0001) for VC*NPS			1346.5			LSD (P<0.0001) for VC*NPS		290.54		

Means followed by the same letters are not significantly different ($P \leq 0.05$), VC =vermicompost, NPS= (nitrogen, phosphorus, sulfur), BY = biomass yield, GY = grain yield.

In the same way, Shrivastava et al. (2018) studied that application of farmyard manure and vermicompost with inorganic fertilizers resulted in better cell division, cell expansion and enlargement that led to higher plant height of *W. somnifera* at different crop development stages. Likewise, Getachew (2009) reported that the use of organic manures in combination with mineral fertilizers maximized the plant height of barley. Kannan et al. (2013) reported that integrated nutrient management had positive effect on maize height. The growth, flowering and yields of field strawberries increased after applications of food wastes and paper waste vermicompost experimental soils, at rates of 2.5 or 5 ton ha⁻¹, supplemented with inorganic fertilizers (Arancon et al., 2004). In contrast, Assefa et al. (2016) found that interaction of compost and NP fertilizer did not show significant effect on plant height of tef.

Inversely, plots treated with sole levels of vermicompost showed no significance effect

on plant height of tef. The non-responsiveness of vermicompost might be due to slow release of nutrients. Similarly with the current finding, Assefa et al. (2016) found that treating of tef crop with compost did not reveal significance difference. Whereas plots were fertilized with levels of NPS only significant variation amongst levels of NPS were shown. Plot received NPS at the dose of 200 kg ha⁻¹ did show significant effect over plots treated with no fertilizer and plots received 100 kg ha⁻¹ of NPS but not in cease of fertilizer of 150 kg NPS ha⁻¹.

Yield and yield components

Biomass yield

The combined application of vermicompost and NPS under balanced fertilizer significantly ($P < 0.0001$) increased the biomass yield. Each single level of fertilizers of vermicompost and NPS

had also significance effect on biomass yield of tef (Table 5). Therefore, the highest biomass yield (8150.40 kg ha⁻¹) was obtained from plots treated with 6 t vermicompost ha⁻¹+200 kg ha⁻¹ NPS plus basal application of Zn and B fertilizers. However, it was not significantly different from using of 6 t vermicompost ha⁻¹+150 kg NPS ha⁻¹, 4 t vermicompost ha⁻¹ + 150 kg NPS ha⁻¹, 4 t vermicompost ha⁻¹+200 kg NPS ha⁻¹, and 2 t vermicompost ha⁻¹ + 200 kg NPS ha⁻¹. All these treatments uniformly took basal application of Zn and B fertilizers. It was clearly observed that with increased levels of the combination of the fertilizers there were increasing of biomass yields consistently in almost of the treatments. Devi et al. (2011) reported that it might be due to adequate quantities and balanced proportions of plant nutrients in vermicompost supplied to the crop as per its need during the growth period resulting in favorable increase in yield attributing characters.

In the same way, biomass yield was significantly affected by the main effect of NPS fertilizer under

balanced fertilizer, and vermicompost levels. In general at the level of 150 and 200 kg ha⁻¹ NPS plus basal of Zn and B fertilizers significantly higher grain yield was found as compared to the nil and 100 kg ha⁻¹ NPS fertilizer. The smallest biomass yield was measured from fertilization of nil NPS fertilizer. Similarly, highest biomass yield was also recorded from vermicompost application at the rate of 6 t vermicompost ha⁻¹ as compared with the other three levels of vermicompost (0, 2, 4 t ha⁻¹). The least yield was obtained from nil level and 2 t vermicompost ha⁻¹.

Grain yield

The analysis of the variance indicated that combined application of vermicompost and NPS and main effect vermicompost and NPS fertilizers significantly ($P < 0.0001$) increased the grain yield (Table 5). Therefore, the highest grain yield (2269.80 kg ha⁻¹) was obtained from plots treated with 4 t vermicompost ha⁻¹+150 kg NPS ha⁻¹ plus basal application of Zinc and Boron which increased over the control by 321.42%. The lowest (538.60 kg ha⁻¹) was found from control. The increase in grain yield due to interaction effects at this rate could be attributed to the positive effects of vermicompost in increasing the efficiency of synthetic fertilizer by preventing losses of nutrients and releasing of the nutrients within the growing period. In agreement with this result, Fayera et al. (2014) postulated that fertilization with balanced fertilizer leads to high photosynthetic efficiency and accumulation of high dry matter, which finally enhance grain yield of tef. Manivannan et al. (2009) stated that the increased growth and yield of the beans, may be due to the application of vermicompost which indirectly influences the physical conditions of the soil and support better aeration to the plant roots, absorption of water, induction of N, P and K exchange there by resulting better growth of the plants. This is in agreement with reports of Bayu et al. (2006) and Makinde and Ayoola (2010) who concluded that high and sustainable crop yields are only possible with integrated use of mineral fertilizers and organic matter. Tilahun et al. (2013) also verified that integrated fertilizers application gave the maximum grain yield compared to the control. Babbu et al. (2015) also reported that the highest maize grain yield was in treatment having NPK with farm yard manure (FYM), whereas the lowest was in non-treated plots. Likewise, Quansah (2010) also indicated that the use of organic (household waste and poultry manure compost) and inorganic fertilizers (NP) increased maize grain yield separately, but, the yields obtained by the combined treatments were significantly higher than their sole treatments. Assefa *et al.* (2016) found that interaction of compost (2.5, 5, and 7.5 t ha⁻¹) and NP (64:46 kg ha⁻¹) fertilizer had significant effect on grain yield of tef.

Grain yield was significantly affected by the main effect of NPS fertilizer under balanced fertilizer.

Generally, at the level of 150 and 200 kg ha⁻¹ NPS plus basal of Zn and B fertilizers significantly higher grain yield was found as compared to the nil and 100 kg ha⁻¹ NPS fertilizer. From sole application of vermicompost highest yield was found from the rate of 6 t ha⁻¹ as contrasted with nil and 2 t ha⁻¹, but not statistically significance than 4 t ha⁻¹.

Straw yield

The ANOVA showed that straw yield of tef was significantly affected by the interaction of vermicompost and NPS fertilizers, and also by both main effect of NPS and vermicompost fertilizers (Table 6). The highest straw yield (6480.60 kg ha⁻¹) was obtained from plots treated with combined application 6 t ha⁻¹ of vermicompost and 200 kg NPS ha⁻¹ plus basal application of Zn and B fertilizers whereas the lowest value (2221.20 kg ha⁻¹) was obtained from control. At the tef crop grown plot received integrated 6 t ha⁻¹ of vermicompost and 200 kg NPS ha⁻¹ increased the straw yield by 129% over the control. But, the highest straw yield obtained from 6 t vermicompost ha⁻¹+200 kg NPS ha⁻¹ was not significantly different from using of 6 t vermicompost ha⁻¹+150 kg NPS ha⁻¹, and 4 t vermicompost ha⁻¹+150 kg NPS ha⁻¹. This implies that vermicompost supply good sources of essential nutrient of N and P which leads better straw growth of tef. The increase in straw yield as result of the interaction of vermicompost and NPS fertilizers due to vermicompost may have enhanced the efficiency of chemical fertilizer. Similar with this result, Sarwar et al. (2008) who reported that straw yield was significantly increased by the application of organic fertilizers along with inorganic fertilizers. Furthermore, Devi et al. (2011) and Singh et al. (2011) found that addition of vermicompost with or without phosphate solubilizing bacteria produced significantly higher grain and biological yields of wheat than the application of chemical fertilizers alone.

On the other hand, main effects of vermicompost and NPS fertilizers have brought significance difference on straw yield of tef. Treatments of plots with only amount of vermicompost at the dose of 6 t ha⁻¹ gave highest yields. The lowest straw yield was recorded from application nil and 2 t vermicompost ha⁻¹. On the other hand when plots were treated with single NPS fertilizer largest yield was measured from application of 200 kg NPS ha⁻¹, this was significantly not different from 150 kg NPS ha⁻¹. The lowest yield was found from control treatment.

Harvest index

Harvest index was significantly ($P < 0.0001$) affected by the interactive effect of compost and NPS chemical fertilizer rates, and by main effect of NPS and

Table 6. Straw yield and harvest index of tef under the effect of vermicompost and NPS fertilizers.

VC(t ha ⁻¹)	NPS (kg ha ⁻¹)					NPS (kg ha ⁻¹)				
	0	100	150	200	Mean	0	100	150	200	Mean
	SY (kg ha ⁻¹)					HI (%)				
0	2221.2 ^h	3839.3 ^{ef}	4968.7 ^{bcd}	4791.5 ^{bcd}	3955.2 ^c	20.12 ^e	25.5 ^{abc}	23.38 ^{cde}	26.2 ^{abc}	23.8 ^{bc}
2	2622.4 ^{gh}	3931.9 ^{def}	4493.8 ^{cdef}	5281.4 ^{bc}	4082.4 ^c	22.99 ^{cde}	27.09 ^{ab}	26.94 ^{ab}	25.14 ^{bc}	25.54 ^a
4	3470.1 ^{fg}	4026.6 ^{def}	5714.80 ^{ab}	5498.9 ^{bc}	4677.6 ^b	21.07 ^{de}	26.07 ^{abc}	28.73 ^a	23.4 ^{cde}	24.82 ^{ab}
6	4717.4 ^{bcd}	5015.6 ^{bcd}	5369.4 ^{abc}	6480.6 ^a	5395.8 ^a	21.32 ^{de}	23.79 ^{bcd}	26.1 ^{abc}	20.66 ^{de}	22.97 ^c
Mean	3257.8 ^c	4203.4 ^B	5136.7 ^a	5513.1 ^a		21.37 ^c	25.62 ^a	26.29 ^a		23.85 ^b
CV (%)			21.77			12.35				
LSD (P<0.0001) for VC			566.18			LSD (P=0.02) for VC		1.72		
LSD (P<0.0001) for NPS			566.18			LSD (P<0.0001) for NPS		1.72		
LSD (P<0.0001) for VC*NPS			1132.4			LSD (P<0.0001) for VC*NPS		3.45		

Means followed by the same letters are not significantly different (P≤0.05), VC =vermicompost, NPS= (nitrogen, phosphorus, sulfur), SY =straw yield, HI=harvest index.

vermicompost fertilizers (Table 6). The highest harvest index was measured from integrated use of 4 t vermicompost ha⁻¹+150 kg NPS ha⁻¹ fertilizers as a result of higher conversation efficiency of dry matter to grain part of tef, but the smallest value was found from the control treatment. The highest harvest index was increased by 42.80% over the control treatment. The control treatment and highest combination of vermicompost and NPS fertilizers had smallest harvest index due to the vegetative growth of tef in control treatment remains sterile (unconverted the dry mass to the economic part), while in the highest combinations of vermicompost and NPS fertilizers vegetative part of tef continuously develop until the rainfall withdrew and not speed up to produce grain. Though the augmentation was not consistent, the harvest index showed increasing trend with increasing of interaction of vermicompost and NPS fertilizers. The increase in harvest index with increasing rates of both compost and NPS fertilizer could be due to the fact that compost and NP fertilizer encouraged

more vegetative growth and grain in a proportional way since the harvest index is the ratio of grain yield to dry biomass yield. In line to this result, Agegnehu et al. (2014) reported that increased harvest index of rice with application of 15 t compost ha⁻¹, 83 kg N ha⁻¹ and 50 kg superphosphate ha⁻¹ over the control. In contrast to this result, Gebrekidan and Seyoum (2006) reported that harvest index constantly declined with increasing levels of applied N (150 kg ha⁻¹) though they found that harvest index increased with the application of P fertilizer at the rate of 26.4 kg ha⁻¹ while further input beyond this optimum range resulted in highly significant reduction in rice crop.

In addition, harvest index of tef crop increased significantly by the application of NPS fertilizer at the levels of 100, 150 and 200 kg ha⁻¹ over the nil NPS fertilizer, but there was no significance variation among the three levels of NPS (100, 150 and 200 kg ha⁻¹). Harvest index was also affected by the main effect of vermicompost where largest harvest index was measured from application 2 t

vermicompost ha⁻¹ plus basal application of Zn and B fertilizers but this was not statistically different from 4 t vermicompost ha⁻¹ plus basal application of Zn and B fertilizers. The smallest harvest index was obtained from 6 t vermicompost ha⁻¹ plus basal application of Zn and B fertilizers.

Partial budget analysis

As it was presented in Table 7 the net farm benefit was calculated taking all possible field variable costs and all benefits of straw and grain yields of tef. The maximum farm net benefits of \$ 2037.39/ha⁻¹ were obtained from the interaction application of 4 t vermicompost ha⁻¹ and 150 kg NPS ha⁻¹ plus basal Zn and B fertilizers and this was followed by treatments of nil vermicompost + 100 kg NPS ha⁻¹, nil vermicompost + 150 kg NPS ha⁻¹, 2 t vermicompost ha⁻¹ + nil NPS, 2 t vermicompost ha⁻¹ + 200 kg NPS ha⁻¹, and nil vermicompost + 200 kg NPS ha⁻¹, respectively. In this study area partial budget analysis revealed

Table 7. Partial budget analysis of VC and NPS fertilizers effect on straw and grain yield of tef.

TRT	VC (t ha ⁻¹)	NPS (kg ha ⁻¹)	BA (kg ha ⁻¹)		ASY (kg ha ⁻¹)	ADSY (kg ha ⁻¹)	AGY (kg ha ⁻¹)	ADGY (kg ha ⁻¹)	TVC (\$ ha ⁻¹)	TR (\$ ha ⁻¹)	NB (\$ ha ⁻¹)	MRR
			Zn	B								
T1	0	0	0	0	2221.20	1999.08	538.60	484.74	0.00	610.94	610.94	-
T5	2	0	2	1	2622.40	2360.16	779.40	701.46	1220.00	826.56	784.07	407
T2	0	100	2	1	3839.30	3455.37	1301.70	1171.53	1875.25	1327.95	1262.63	2097
T9	4	0	2	1	3470.10	3123.09	909.40	818.46	2440.00	1004.30	919.32	D
T3	0	150	2	1	4968.70	4471.83	1520.20	1368.18	2812.88	1597.98	1500.01	727
T6	2	100	2	1	3931.90	3538.71	1461.20	1315.08	3095.25	1453.95	1346.14	D
T13	6	0	2	1	4717.40	4245.66	1223.20	1100.88	3660.00	1355.70	1228.22	D
T4	0	200	2	1	4791.50	4312.35	1660.20	1494.18	3750.50	1683.46	1552.82	162
T7	2	150	2	1	4493.80	4044.42	1651.50	1486.35	4032.88	1648.15	1507.68	D
T10	4	100	2	1	4026.60	3623.94	1400.70	1260.63	4315.25	1418.77	1268.47	D
T8	2	200	2	1	5281.40	4753.26	1752.80	1577.52	4970.50	1798.99	1625.86	172
T11	4	150	2	1	5714.80	5143.32	2269.80	2042.82	5252.81	2220.35	2037.39	4184
T14	6	100	2	1	5015.60	4514.04	1571.50	1414.35	5535.25	1640.17	1447.37	D
T12	4	200	2	1	5498.90	4949.01	1641.30	1477.17	6190.50	1738.34	1522.72	D
T15	6	150	2	1	5369.40	4832.46	1885.30	1696.77	6472.88	1904.74	1679.28	D
T16	6	200	2	1	6480.60	5832.54	1669.90	1502.91	7410.50	1854.72	1596.60	D

VC=vermicompost, TRT=treatment, BA=basal application, ASY=average straw yield, NPS= (nitrogen, phosphorus, sulfur), ADSY=adjusted straw yield, AGY=average grain yield, ADGY=adjusted grain yield, TVC=total variable cost, TR=total revenue, NB=net benefit, MRR=marginal rate of return, D=dominated treatment. Yield adjustment=10%, price of tef straw = $\$0.11/\text{kg}^{-1}$, price of tef grain = $\$0.82/\text{kg}^{-1}$, minimum acceptable rate of return (MARR) =100% , , fertilizer transportation cost= $\$1.74/100\text{ kg}^{-1}$; fertilizer application cost=4man/day/200 kg; NPS Fertilizer cost= $\$0.57/\text{kg}^{-1}$; Zn Fertilizer cost= $\$1.01/\text{kg}^{-1}$, B Fertilizer cost= $\$0.47/\text{kg}^{-1}$,VC production cost= $\$1.43/100\text{ kg}^{-1}$, VC application cost=6man/day/6tons.

that combined application 4 t vermicompost ha⁻¹ and 150 kg NPS ha⁻¹, nil vermicompost and 100 kg NPS ha⁻¹, nil vermicompost and 150 kg NPS ha⁻¹, 2 t vermicompost ha⁻¹ and nil NPS, 2 t vermicompost ha⁻¹ and 200 kg NPS ha⁻¹, and nil vermicompost plus 200 kg NPS ha⁻¹ had highest marginal rate of return (MRR) over the minimum acceptable rate of return (100%). From the previously mentioned treatments highest MRR% with value of 4184 was obtained from the combined application of 4 t vermicompost ha⁻¹ and 150 kg NPS ha⁻¹ plus basal Zn and B fertilizers. This value implies that with 1 \$ cost it was

attained \$41.84 profit. Therefore, in Tahtay Koraro district integrated 4 t vermicompost ha⁻¹ and 150 kg NPS ha⁻¹ can be used for the production of tef (quncho variety).

CONCLUSION AND RECOMMENDATION

Previously, conventional compost and farmyard manure have been used as sources of organic fertilizer in Tigray. Recently, vermicompost technology has been widely disseminated through extension and nongovernmental organization in

the region in most of the districts and kebles on the assumption that vermicompost can be an alternative source of chemical fertilizers.

Based on this research was done on vermicompost along with NPS fertilizers and the results indicated that, combined application of vermicompost and NPS fertilizers significantly improved early heading and physiological maturity, panicle length, plant height, biomass yield, grain yield, straw yield and harvest index of tef crop. Increased rate of combined application of vermicompost and NPS fertilizers enhanced tef crop to initiate early heading and early maturity in

lesser number of days. The vegetative parameters like panicle length and plant height of tef crop were also significantly better by the higher rates of integrated application of vermicompost and NPS plus basal application of Zn and B fertilizers. The yield attributes like biomass, straw and grain yield were as well significantly enhanced by the higher rates of combined application of vermicompost and NPS fertilizers, particularly, combined application of 4 t vermicompost ha⁻¹ and 150 kg NPS ha⁻¹ plus basal application of Zn and B fertilizers brought highest yield almost in all the yield attributes.

According to the partial budget analysis the highest marginal rate of return was attained from combined application of 4 t vermicompost ha⁻¹ and 150 kg NPS ha⁻¹ plus basal application of Zn and B fertilizers. Therefore, it can be concluded that 4 t vermicompost ha⁻¹ and 150 kg NPS ha⁻¹ plus basal application of Zn and B fertilizers from the economic standpoint, it is more profitable to farmers at Beles kebele in Tahtay Koraro district. Therefore, based on the results of the study and the above conclusion, it can be recommended that; interactive application of 4 t vermicompost ha⁻¹ and 150 kg NPS ha⁻¹ plus basal application of Zn and B fertilizers could be recommended in terms of economic return and productivity of tef (quncho variety) in the study area. This rate also can be used as a point of reference for additional study at vermicompost and NPS fertilizer for different tef varieties.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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