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Research Paper

Combination of Organic and Inorganic Fertilizer to Improves Tef (Eragrostis tef) Yield and Yield Components and Soil Properties on Nitisols, in the Central Highlands of Ethiopia

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Abstract

A field experiment was made to evaluate combination of organic and inorganic fertilizers on yield and yield components of tef and soil properties. The study was conducted for three consecutive cropping seasons (2015-2017) on farmers' fields in Welmera district of Oromiya Regional State. The objective of this study was to evaluate the response of organic and inorganic nutrient source on growth and yield of tef under balanced fertilizers. The treatments included eleven selected combinations of organic and inorganic nutrient sources (Farm yard manure, Compost, Nitrogen and Phosphorus). The design was randomized complete block with three replications. Results revealed that tef yield and yield components were significantly affected by the application of organic and inorganic fertilizer sources. The highest tef grain yield (2042.6 $kgha^{-1}$) was obtained from the applications of 25% compost with 75% recommended nitrogen and phosphorus fertilizer. While, highest biomass yield (8535.4 $kgha^{-1}$) was obtained from the applications of full doses of recommended N and phosphorus fertilizers. Application of the different organic fertilizers improves the organic matter, Total N, available P and pH of the soil in the study area. The result also showed that the highest marginal rate of return was obtained from application of 50% FYM (farm yard manure) + 50% recommended nitrogen and phosphorus fertilizer, which is economically the most feasible alternative for tef production on nitisols of central Ethiopian highlands. Therefore, based on the MMR application of 50% FYM (farm yard manure) + 50% recommended nitrogen and phosphorus fertilizer can be recommended for tef production for the study areas.

1. Introduction

Cereals are an important dietary protein and energy source throughout the world (Bos et al., 2005). Tef is grown as important cereal in Ethiopia (Abeba, 2009). It is national obsession and is grown by an estimated 6.3 million farmers (Claire et al., 2014). It has also recently been receiving global attention particularly as a 'health food' due to the absence of gluten and gluten-like proteins in its grains (Spaenji et al., 2005). Tef has significantly highest share in Ethiopia in area of production and it was reported that tef covered 27.02% of the total area under cereal production followed by maize 17.3% (CSA, 2017/18).

Tef performs well at an altitude of 1800-2100 mater above sea level annual rainfall of 750-1100 mm, a temperature of 10°C-27°C it can adapt wide range of agro-climatic conditions (Ketema, 1993). Moderately fertile clay and clay loam soils are ideal for tef. It can also withstand moderate water logged conditions (National Soil Service, 1994). Regardless of its wider adaptation, productivity of tef is low in the country with

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the national average grain yield of 1.65 tons ha^{-1} (CSA, 2017/18). This is mainly because of low soil fertility (Negassa et al., 2013) and severe organic matter depletion (IFPRI, 2010) aggravated by low rate of chemical fertilizer application. The rate of chemical fertilizer application is low in the country due to unaffordable price for resource-poor smallholder farmers (Endale, 2011). The continued use of chemical fertilizers is also not recommendable as it causes for health and environmental hazards such as ground and surface water pollution by nitrate leaching (Pimentel D., 1996).

One of the possible options to make use of low rate of chemical fertilizer application without nutrient deficiency of the soil could be recycling of organic wastes. But it is also difficult to attain sustainable productivity either by inorganic fertilizers or organic sources alone (Godara, 2012). The best remedy for soil fertility management is, therefore, a combination of both inorganic and organic fertilizers, where the inorganic fertilizer provides nutrients and the organic fertilizer mainly increases soil organic matter and improves soil structure and buffering capacity of the soil (Godara, 2012). The combined application of inorganic and organic fertilizers is also widely recognized as a way of increasing yield and improving productivity of the soil sustainably (Mahajan et al., 2008). Nutrient management has major role to play in obtaining higher productivity and sustainable production of crops cannot be maintained by using chemical fertilizers alone, because of deterioration in soil physical and biological environments (Khan et al., 2008). Several researchers (Singh et al., 2001) have demonstrated the beneficial effect of integrated nutrient management in mitigating the deficiency of many secondary and micronutrients.

There are also some research reports in Ethiopia that revealed the combined effect of organic (Vermicompost, compost and manure) and chemical (NP) fertilizer enhanced the yield of tef and reduced the amount of recommended chemical fertilizer by half (Girma et al., 2017). Similarly, effect of organic sources (compost and manure) and chemical (NP) fertilizer enhanced the yield of teff and reduced the amount of recommended chemical fertilizer by half (Kassahun et al., 2012 and Agegnehu et al., 2014) Though there is a huge variation in crop response to different NP fertilizer rates, 64/46 N/P2O5 kgha^{-1} was given by Ministry of Agriculture and Rural Development as national blanket recommendation (Yadeta et al., 2012). Farmers in Ethiopia have also awareness about compost and have been preparing and using huge amount especially in central highlands of Ethiopia (personal comminution). However, there is little information about the rate of application of compost and chemical fertilizer in the study area either to apply in sole or in combination. This work, therefore, aimed to determining the effect of organic and inorganic fertilizers and their combinations on the yield and yield components of tef.

2. Materials and Methods

2.1. Experimental Site

The experiment was conducted in the District of Welmera and Ejere, West Shewa Zone of Oromia National Regional State for three consecutive cropping seasons (2015, 2016 and 2017). The experiment site is located at 09^0 03′ N latitude and 38^0 30′ E longitude and altitude 2400 meter above sea level for welmera and 09^0 02′ N and 38^0 26′ E (Figure 1) and an altitude of 2200 meter above sea level for Ejere. Distance of Welmera and Ejere 30 and 45 km west of Addis Ababa respectively. The mean annual rainfall of the study area was 1100mm of which about 85% falls from June to September and the rest from March to May (Holeta Agricultural Research unpublished Metrological data). The mean annual temperature is about 14.3^{0}c, with the mean maximum and minimum temperatures of 21.7^{0}c and 6.9^{0}c respectively (Figure 2).

The major soil types of the trial sites are Eutric Nitisols (FAO-WRB, 2006). The crops widely grown in the study area include wheat (*Triticum aestivum* L.), barley (*Hordeum vulgare* L.), *tef* (*Eragrostis tef*), faba bean (*Phaseolus vulgaris* L.) and potato (*Solanum tuberosum* L.*)*(Personal communication).

2.2. Experimental materials and layout

The experimental Compost and farm yard was prepared following the standard procedure for compost preparation (Suparno et al. 2013). The weight of the compost and farm yard manure was measured for each level at air dried (at 10.5% moisture) bases right before application. The teff variety named kuncho (DZ-Cr-387), which was developed and released by Debrezeit

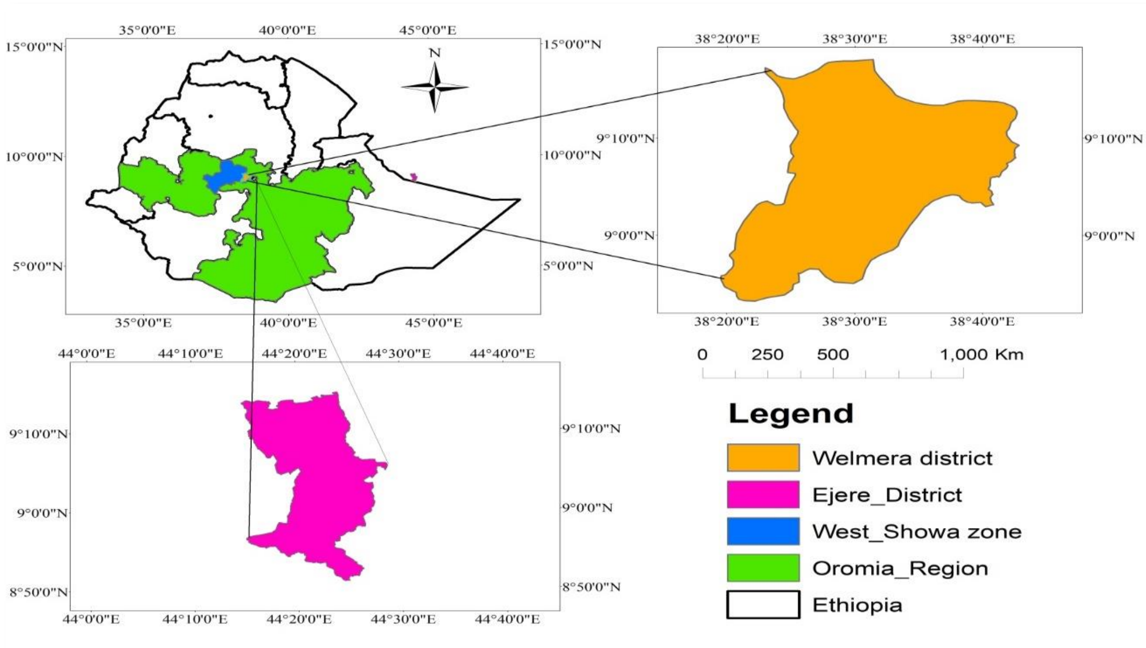

Figure 1: Map of the study area

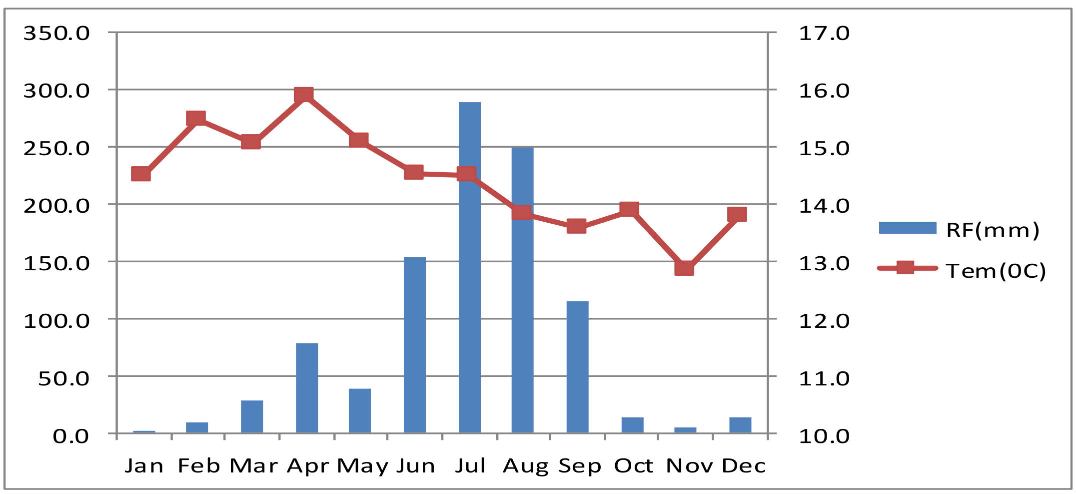

Figure 2: Annual rainfall and average mean of temperature in Holeta from 2006 to 2017 (Source: Holeta Agricultural Research Center Meteorological Report).

Agricultural Research Centre in 2006 was used for the experiment. It is a high yielding white-seeded cultivar adapted to a wide range of altitudes. Urea (46% N) and DAP (18% N and 46% P_2O_5) were used as a source of nitrogen and phosphorus. The experiment was laid out in randomized complete block design (RCBD) in factorial arrangement and treatments were replicated three times. The trial was carried on permanent plots during the experimental period. The gross plot size was 3 m × 3 m (9 m^2) and the net plot size was 2.6m × 2.5 m (6.5 m^2). Compost was incorporated to the soil on prepared seedbeds twenty one days before planting and chemical fertilizers (NP) were applied during planting and seeds were row planted at the rate of 12 $kgha^{-1}$. All other cultural practices were uniformly applied as per the recommendations.

2.3. Treatment Combinations

T1= Negative control

T2= Recommended NP

T3= Recommended FYM based on N equivalency

T4= Recommended Compost based on N equivalency

T5= 25% Recommended FYM based on N equivalency + 75% Recommended NP

T6= 50% Recommended FYM based on N equivalency + 50% Recommended NP

T7= 75% Recommended FYM based on N equivalency + 25% Recommended NP

T8= 25% Recommended Compost based on N equivalency + 75% Recommended NP

T9= 50% Recommended Compost based on N equivalency + 50% Recommended NP

T10=75% Recommended Compost based on N equivalency + 25% Recommended NP

T11=33% FYM +33% Compost +33% Recommended NP

Samples were collected from well decomposed farmyard manure and compost before they were applied to the field. Then their N and P contents were analyzed in the laboratory to determine the rate of application of each treatment, which was based on recommended N equivalent rate for the test crop. The contents of N and P before application in the analyzed samples were 0.88% N and 0.68% P for conventional compost both on 55% dry weight basis and 1.72% N and 0.76% P for farm yard manure on 50% dry weight basis. Manure and compost were applied to the field three weeks before sowing and thoroughly mixed in the upper 15 to 20 cm soil depth. Nitrogen and P fertilizers were applied in the form of Urea and DAP respectively. To minimize the loss and increase its efficiency half rate of N was applied as split at planting and the remaining half was side dressed at tillering stage of the crop whereas all P rates were applied as basal application during planting time. The seed was drilled at the recommended seed rate of 15kg/ha in row on 5th, 8th and 6th July of 2015, 2016 and 2017 respectively. To avoid variability came by sowing date, the trial was planted at the same date at both districts because of Welmera and Ejere districts were classified under similarly agro-ecology and crop planting calendar for both districts from July 1- July 12 are the critical time for tef. All recommended agronomic management practices were carried out during the crop growth period as per needed.

2.4. Data Collection and Analysis

Composite surface soil samples were collected from experimental fields (0-20 cm depth) before treatment application. Similarly, soil samples were collected after harvest of the crop from each plot and then composited by replication to obtain one representative sample per treatment. The collected samples were analyzed for the determinations of pH, organic carbon (OC), total N and available P. Soil pH was determined with a pH meter from soil: water of 1:1 (w/v) (Carter, 1993). Organic carbon was determined by the method of Walkley and Black (1934) and total N using Kjeldahl method (Jackson, 1958). Available P was determined following the procedures of Bray and Kurtz (1945).

Collected plant samples include grain yield, above ground total biomass, plant height and panicle length. Grain and biomass yield were measured based on plant samples taken from ten central rows (2.6m x 2.5m= 6.5m^2), plant height was measured (in cm) by taking five randomly selected plants per plot from the soil surface to the tip of the crop at full maturity stage. Grain yield was adjusted to a moisture content of 12.5% before taking sample weight.

The agronomic data were subjected to analysis of variance (GLM procedure) using SAS statistical computer package (SAS, 2002). The total variability for each trait was quantified using separate and pooled analysis of variance over years using the following model (Gomez and Gomoz, 1984):

$$Pijk = \mu + Yi + Rj\ (i) + Tk + Ty\ (ik) + eijk$$

Where pijk is total observation, μ = grand mean, yi= effect of the ith year, Rj (i) is effect of the jth replication (with in the ith year), Tk is effect of the Kth treatment with ith year TY (ik) is the interaction of kth treatment with ith year and eijk is the random error. Duncan multiples range test (DMRT) at 5% probability level was used to detect differences among means.

2.5. Economic Analysis

Economic data was collected to assess the costs and benefits associated with different treatments, partial budget, dominance and marginal analyses following technique described by CIMMYT (1988). The average yield was adjusted downwards by 10% to reflect the difference between the experimental yield and the expected yield of farmers from the same treatment. This is because, experimental yields even from on-farm experiments under representative conditions, are often higher than the yields that farmers could expect using the same treatments. For calculation the three years average market grain price of teff (ETB 20 kg^{-1}), farm-gate price of Urea and DAP fertilizers (ETB 11kg^{-1} and

13.5 kg^{-1}) respectively. Variable cost ratio (VCR) was calculated as a ratio of value of increased crop output to the cost of fertilizer applied. VCR measures the average gain in the value of crop output per kg of fertilizer applied.

3. Results and Discussion

3.1. Effects of combination nutrient use on soil chemical properties

Mean soil chemical properties such as pH, organic carbon (OC), N and P measured for samples was taken after harvesting. The result showed that higher concentrations of pH, total nitrogen (TN) and organic carbon (OC) were recorded from full dose application of farm yard manure (FYM) (Table 1). The lowest soil pH, TN, and OC were recorded from the negative control and the highest value of available phosphorus was obtained from full dose of compost. Though the values of OC were generally rated as low (Jones, 2003), the highest OC, 1.72% was recorded from plots treated with full doses of farm yard manure and the least (1.22%) was from the negative control treatment (Table 1). Likewise, the total N and available P determined after harvesting is rated medium (Tekalign, 1991). As mentioned above for OC, the highest soil total N (0. 26%) was recorded from plots treated with full doses of farm yard manure. The lowest soil N content 0.18% was obtained from negative control treatment as usual. Similarly, the highest soil available P (17.2 mg kg^{-1}) was recorded from plots treated with full doses of compost.

The highest pH value 5.2 was recorded from full doses of farm yard manure .The average soil pH of the experimental field after harvest was found to be 4.87, which is indicate some improvements but the soil still in acidic range. The lowest soil pH (4.26) was recorded from negative control treatment. Similarly, Ano and Ubochi (2007) reported that application of animal manure and compost increased soil pH. According to Murphy (2007) rating, CEC content of soil after harvesting was very low (<6), low (6 to 12), medium (12 to 25), high (25 to 40), and very high (>40). The result showed that the cation exchange capacity of study areas was medium (22.8 $Cmol_c kg^{-1}$). While the highest value of sulfur was obtained from application of full doses of farm yard manure (3.66 ppm). This may due to combination organic and inorganic sources nutrient provides excellent opportunities to overcome all the imbalances besides sustaining soil health and enhancing crop production. According to Vanlauwe *et al.* (2001) the direct interactions between chemical fertilizer and organic matter can improve soil fertility by restocking nutrients lost through leaching and by modifying the pH of the rhizosphere and making unavailable nutrients available. Generally, the above results indicate that combination use of organic and inorganic nutrient sources have significant improvement in the overall condition of the soil as well as agricultural productivity if best alternative option is adopted in the tef production area.

Table 1: physical and chemical soil characteristics (0-20cm depth) of the experimental site after crop harvesting

Treatments	Soil physic-chemical properties						
	Textural class	pH (H_2O)	TN (%)	Av.P (ppm)	Sulfur (ppm)	OC (%)	CEC $Cmol_c kg^{-1}$
Negative	Clay	4.26	0.18	10.6	2.82	1.22	18.6
RNP	Clay	4.6	0.20	14.5	2.86	1.61	19.1
FYM	Clay	5.2	0.26	15.4	3.66	1.72	22.8
Com	Clay	5.06	0.24	17.2	2.74	1.64	18.2
25%FYM + 75% RNP	Clay	4.8	0.22	13.6	2.16	1.48	20.4
50%FYM + 50% RNP	Clay	4.9	0.22	14.8	3.08	1.58	18.8
75%FYM + 25% RNP	Clay	5.02	0.25	16.4	3.24	1.66	20.6
25% Com + 75% RNP	Clay	4.8	0.22	15.6	3.28	1.63	19.7
50% Com + 50% RNP	Clay	5.0	0.21	14.2	2.66	1.58	18.5
75%Com + 25% RNP	Clay	4.8	0.23	15.6	3.17	1.62	21.8
33%FYM +33% Com + 33% RNP	Clay	5.18	0.24	16.8	2.91	1.64	22.2
Ground mean		**4.87**	**0.225**	**14.97**	**2.96**	**1.58**	**20.06**

TN=Total; Av.P=Available phosphorus; OC=Organic carbon; CEC=Cation exchange capacity

3.2. Effects of combination organic and inorganic nutrient on Tef yield and yield components

The combined analysis of variance over three years showed that the effect of combination organic and inorganic nutrients was highly significant (p<0.01) on grain yield, biomass and day to physiological maturity but significantly affected at (p<0.05) plant height, panicle length and harvest index. The highest grain yield and plant height of tef (2042.6 kg ha^{-1} and 101.7cm respectively) were obtained from the application of 25% compost and 75% recommended rate of nitrogen and phosphorous. While the highest biomass yield (8535.4kg^{-1}) was obtained from application of full dose of recommended nitrogen and phosphorus. The result of date physiological maturity was high at application of full dose of farm yard manure (146.8) and compost (146.3) and followed by negative control treatment (table 2). The application of 25% compost with 75% recommended N and P has also given comparable grain yield as compared to application of full dose of recommended N and P from inorganic fertilizer. Negative control treatment was given the lowest grain and biomass yields under all tested parameters (table 2). Therefore, the results of this study has clearly indicated that it is possible to fairly increase tef yield through combined or multiple nutrient application approach, rather than applying nutrient from one source. In line with the current result, research findings of Tekalign Mamo *et al*. (2001), Getachew Agegnehu *et al.* (2011) and Girma *et al.*, (2017) indicated that wheat has showed significance response to the combined soil fertility management treatments containing both organic and inorganic forms under farmers' field condition that they could be considered as alternative options for sustainable soil and crop productivity in the degraded highlands of Ethiopia.

The highest (37.9cm) panicle length was recorded from application of 25% FYM + 75% Rec NP, whereas the lowest (29.0cm) panicle length was obtained from negative control treatments. This result is in line with many authors (Ejaz *et al.* 2002; Wakene *et al*., 2014) reported that panicle length of cereals were increase with increasing as NP rates increased. Harvest index shows the physiological efficiency of plants to convert the fraction of photo-assimilates to grain yield. Harvest index was significantly affected at (P< 0.005) to the combination of organic and inorganic nutrient sources, the highest (32.6%) and lowest (23.3%) harvest index was obtained from control treatments and recommended nitrogen and phosphorus respectively. In contrast, a mean HI of about 50% with a positive trend due to increasing nitrogen rate had previously reported in Ethiopia (Taye *et al*., 2002). There was substantial variation in harvest index of different from verities to varieties.

Table 2: Effects of organic and inorganic fertilizers application on Tef yield and yield components

Treatments	GY(kg/ha)	BY(kg/ha)	Ph(cm)	Pl(cm)	DPM	HI
Negative	746.7^{e}	2505.1^{g}	72.9^{c}	29.0^{c}	146.2^{a}	32.6^{a}
Rec NP	1980.4^{ab}	8535.4^{a}	102.0^{a}	36.0^{ab}	137.4^{d}	23.3^{b}
FYM	1279.1^{cd}	4212.1^{efg}	91.4^{ab}	33.6^{ab}	146.8^{a}	30.9^{ab}
Compost	1028.1^{cd}	3863.6^{fg}	81.8^{bc}	31.6^{bc}	146.3^{a}	26.8^{ab}
25% FYM + 75% Rec NP	1956.0^{ab}	6358.6^{bcd}	100.8^{a}	37.9^{a}	138.1^{d}	23.8^{b}
50% FYM + 50% Rec NP	1804.7^{ab}	7378.8^{ab}	98.4^{a}	34.9^{ab}	140.1^{cd}	24.6^{ab}
75% FYM + 25% Rec NP	1363.3^{cd}	5717.2^{bcde}	91.8^{ab}	34.6^{ab}	143.7^{ab}	24.1^{ab}
25% Comp + 75% Rec NP	2042.6^{a}	7388.9^{ab}	101.7^{a}	35.0^{bc}	137.4^{d}	27.9^{ab}
50% Comp + 50% Rec NP	1608.40^{bc}	6813.1^{bc}	93.0^{ab}	35.6^{ab}	142.6^{bc}	31.7^{ab}
75% Comp + 25% Rec NP	1323.8^{cd}	5222.2^{cdef}	94.3^{ab}	35.3^{ab}	144.8^{ab}	25.8^{ab}
33% FYM + 33% Comp + 33% Rec NP	1319.3^{cd}	4853.5^{def}	90.9^{ab}	34.1^{ab}	144.9^{ab}	27.9^{ab}
Critical range (CR)	405.5	1707.3	14.3	4.56	3.18	8.65
CV (%)	17.4	19.2	9.9	8.52	1.43	20.4

*, **= significant at P< 0.05 and P< 0.001, respectively; ns= not significant. Means in a column with the same letter are not significantly different from each other; GY= grain yield; BY= biomass yield; Ph= plant height; SL= panicle length; DPM= days physiological maturity, HI= Harvest index

Table 3: Partial budget and dominance analyses of organic and inorganic fertilizers trial on Tef

Treatments	DAP (kg/ha)	Urea (kg/ha)	Ave GY ($kgha^{-1}$)	Adj GY ($kgha^{-1}$)	GB (EB ha^{-1})	DAP (cost)	Urea (cost)	TCV (EB ha^{-1})	NB(EB ha^{-1})	MRR (%)
egative	0	0	746.7	672.0	13440.6	0	0	0	13440.6	
FYM	0	0	1279.1	1151.2	23023.8	0	0	0	23023.8	
Compost	0	0	1028.1	925.3	18505.8	0	0	0	18505.8	
75% FYM + 25% RNP	37.5	32.5	1363.3	1226.9	24539.4	506.3	357.5	863.8	23675.7	598.5
75% Comp + 25% RNP	37.5	32.5	1323.8	1191.4	23828.4	506.3	357.5	863.8	22964.7D	
33% FYM + 33% Comp + 33% RNP	50	43.5	1319.3	1187.4	23747.4	675	478.5	1153.5	22593.9D	
50% FYM + 50% RNP	75	65	1804.7	1624.2	32484.6	1012.5	715	1727.5	30757.1	819.9
50% Comp + 50% RNP	100	65	1956	1760.4	35208	1350	715	2065	33143	706.9
25% FYM + 75% RNP	100	113.5	1608.4	1447.7	28951.2	1350	1248.5	2598.5	26352.7D	
25% Com + 75% RNP	100	113.5	2042.6	1838.3	36766.8	1350	1248.5	2598.5	34168.3D	
RNP	150	130	1980.4	1782.4	35647.2	2025	1430	3455	32192.2D	

Ave GY=Average yield; Adj GY=Adjusted yield; GB= Growth benefit; TCV=Total cost varies; NB= Net benefit; MRR=Marginal rate of return.

3.3. Economic Analysis

The economic analysis showed that the application of 50% of farm yard manure plus 50% recommended N and P fertilizers provided the highest marginal rate of the return (MRR) of 819.9% (Table 3) suggesting for one birr invested in wheat production, the producer would collect birr 8.19 after recovering his investment. Since the MRR assumed in this study was 100%, the treatment with application of 50% of farm yard manure and 50% recommended NP gave an acceptable MRR. Therefore, the application 50% FYM (based on N equivalent rate) and 50% N and P fertilizers mentioned above is found economical to be recommended on Nitisols of the study area and similar locations in the central highlands of Ethiopia.

4. Conclusion

The results of three years result were significantly different from each other and the residual effect of the previous year fertilizer application as the plots were fixed during the experimental period. Results of soil analysis after harvesting revealed that application of organic fertilizer improved soil pH, OC, total N and available P. Based on marginal return rate the use of 50% recommended nitrogen and phosphorus fertilizers from inorganic sources plus 50% farm yard manure based on N equivalent ratio should be recommended for farmers because they were affordable options for increasing soil fertility status and tef yield with improving soil physical and chemical properties in the small-scale farming systems of the study area. Hence, combined or multiple use of chemical fertilizer and locally available organic fertilizer application is the best approach for achieving higher fertilizer-use efficiency, maximum yield and economic return of input than the sole application of either of the input types.

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