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Effects of Integrated Nutrient Management on Yield and Yield Attributes of Tef [Eragrostis tef (Zucc.) Trotter] in Gondar Zuriya District, North Ethiopia

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Abstract
A field experiment was conducted in 2014 and 2015 growing seasons in Gondar Zuria district to investigate the effect of integrated nutrient management on yield and yield related parameters of tef. The experiment consisted of 14 treatments. These treatments were formed by combining of different levels of inorganic fertilizers and compost. The levels of inorganic fertilizer ranged from 0% to 100% of recommended nitrogen and phosphorous (RNP) rate. In the study area, the recommended application of nitrogen and phosphorous was 64 kg ha^{-1} urea and 46 kg ha^{-1} DAP, respectively. The compost was applied at 4 different levels (0, 4, 8, and 12 t ha^{-1}). The treatments were laid out in a Randomized Complete Block Design (RCBD) with three replications. The data were analyzed using Statistical Analysis Software (SAS) and means were separated by least significance difference test at 5% probability level for statically significant parameter. The two years pooled result showed that integrated nutrient management significantly affected plant height, panicle length, and grain and biomass yield of tef. Application of 75% RNP combined with 12 t ha^{-1} compost, and 75% RNP combined with 4 t ha^{-1} compost increased grain yield by 338 and 324%, respectively compared to unfertilized plots. The maximum economic profit was recorded from application of 75% RNP combined with 4 t ha^{-1} compost. Therefore, it can be recommended to apply 75% RNP combined with 4 t ha^{-1} compost for high yield and economically profitable tef production in the study area.

Keywords: compost; inorganic fertilizer; nutrient management; tef; yield; economic profit
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1. Introduction

Ethiopia is the center of origin and diversity of tef [*Eragrostis tef* (Zucc.) Trotter] which is the major staple food crop in the country mainly used in the form of *Injera.* It is richer in calcium, phosphorus and iron than the other major cereal crops (maize, barley, wheat and sorghum). Its average carbohydrate and protein content is about 74% and 11%, respectively (Degene *et al.,* 2012). Its straw is also a nutritious and highly preferred livestock feed to that of other cereals. Moreover, it is the major cash earning crop for the farming community as the market price of its grain and straw is higher than other cereals. It is also among export commodity at national level.

Having such great nutritional and economic values, tef is the first crop in terms of area coverage and the second in grain production. It covers 23.85% cultivated area and 17.26% total production of the grain crops (Central Statistical Agency, 2010). However, its average grain yield 0.8 t ha^{-1}in farmer's fields, which is far below the average annual yield of other major cereal crops due to several production constraints (Degene *et al.,* 2012). The easiest way to increase these nutrients in the soil is the addition of inorganic fertilizers (usually urea and DAP). However, high cost of inorganic fertilizers coupled with the low affordability of our small holder farmers is the biggest obstacle for fertilizer use in Ethiopia. Inorganic fertilizers are costly for farmers to apply at the recommended rates. On the other hand, sole application of organic matter is constrained by access to sufficient organic inputs, low nutrient content, high labor demand for preparation and transporting. Thus, the integration of organic and inorganic sources may improve and sustain crop yields without degrading soil fertility status (Devi *et al.,* 2007; Degene *et al.,* 2012; Agegnehu *et al.,* 2014). This problem drives the use of combined application of inorganic fertilizers and organic manures such as Farm Yard Manure (FYM), compost and green manures as an alternative source of nutrients in addition to inorganic fertilizers to sustain productivity.

Organic farming is about 41% more economical than inorganic farming and helps the farmers to maintain returns with less input. It is also environmental friendly and at the same time maintains soil fertility. Organic manure application is therefore the way towards sustainable development for a developing country like Ethiopia (Devi *et al.,* 2007). Moreover, organic manures, besides supplying nutrients to the current crop, often leave a substantial residual effect on the succeeding crop in the system. The efficiency of applied inorganic fertilizers also increased when applied along with organic manures. FYM application in combination with minimum N is an alternative and sustainable practice of soil management for crop production. Since compost, poultry manure and FYM are in abundant quantity in Ethiopia, it is a good opportunity for diverting inorganic farming to organic farming system. As a result, sustainable development could be achieved in the country.

Research results showed that integrated nutrient management (INM) increased the grain yield of tef. Combining application of FYM with half dose of the recommended rate of NP fertilizers gave the highest grain yield of tef than sole application of either organic or inorganic fertilizers. Grain yield increment of 45% was obtained due to combined application of FYM and inorganic NP over inorganically treated plots (Kassahun *et al*., 2010). The combined application of cotton residues, FYM and vermicompost gave the highest values of plant height, leaves number and fresh weight (Abdalla *et al.,* 2012). There are only few studies on INM of tef under field conditions in Ethiopia at large and no trial in the study area in particular. Therefore, the objective of the study was to investigate the effects of integrated nutrient management on yield and yield attributes of fef.

2. Materials and methods

2.1. Experimental Site

A field experiment was carried out at Lay Tseda Kebele, which is located in Gonder Zuria district, North Western Ethiopia in 2014 and 2015 main growing season. The district is found between 37.26° to 37.30° longitude and 12.26° to 12.29° latitude (Figure 1). The elevation ranges from 1107 to 3022 meter above sea level. It has annual temperature of 14-20°C with the mean 17.9°C. It receives annual total rainfall ranging 1030-1223 mm with mean of 1100 mm.

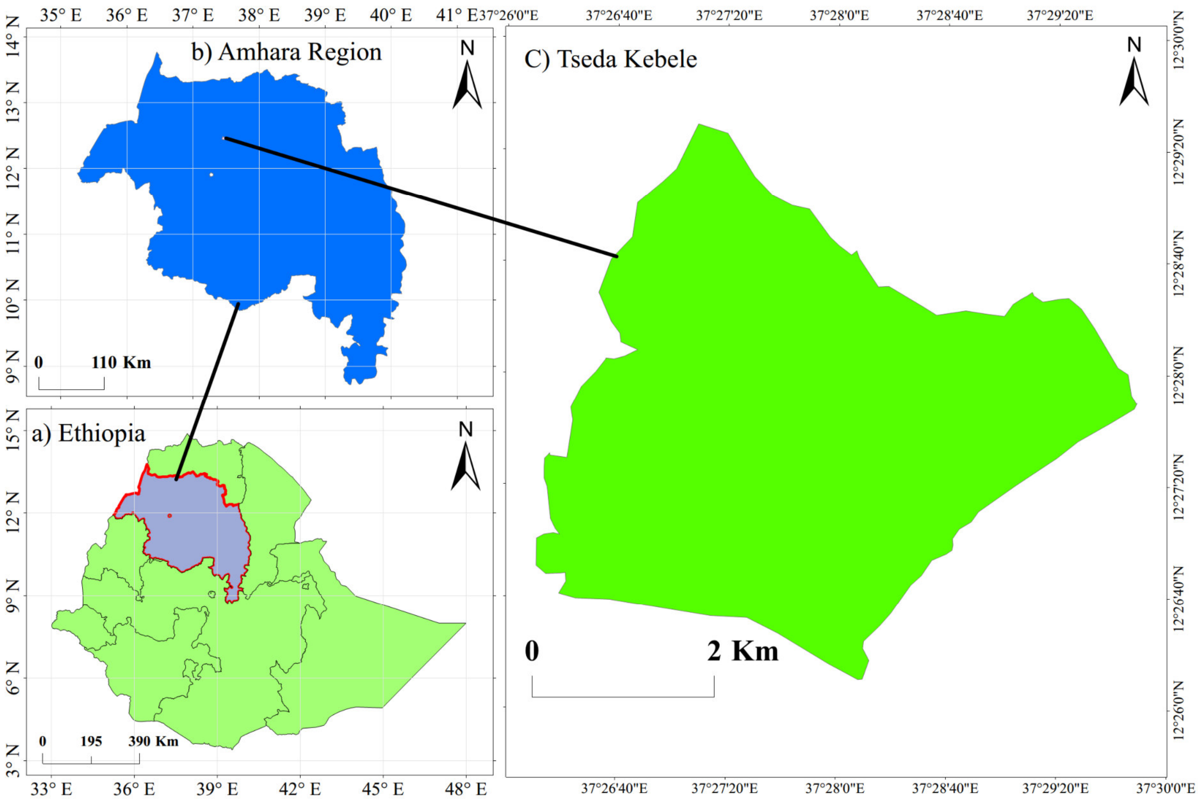

Figure 1. Experimental site: a) regional map of Ethiopia; b) Amhara region; and c) experimental area i.e. Tseda kebele

2.2. Treatments and Design

The experiment consisted of 14 treatments (Table 1). These treatments were formed by combining of different levels of inorganic fertilizers and compost. The levels of inorganic fertilizer ranged from 0% to 100% of recommended nitrogen and phosphorous (RNP) rate. In the study area, the recommended application of nitrogen and phosphorous was 64 kg ha^{-1} urea and 46 kg ha^{-1} DAP, respectively. The compost was applied at 4 different levels (0, 4, 8, and 12 t ha^{-1}). The field experiment was laid out in Randomized Complete Block Design (RCBD) with three replications. Size of each plot was 6 m^2 (3 m x 2 m). Plots and blocks were separated by 1 m and 2 m, respectively.

Table 1. Treatment combination at different levels of inorganic fertilizer and compost.

Treatment ID	Inorganic fertilizer	Compost (t ha^{-1})
T1	0	0
T2	100% RNP (64 kg ha^{-1} Urea and 64 kg ha^{-1} DAP)	0
T3	75% RNP (48 kg ha^{-1} Urea and 34.5 kg ha^{-1} DAP)	4
T4	75% RNP (48 kg ha^{-1} Urea and 34.5 kg ha^{-1} DAP)	8
T5	75% RNP (48 kg ha^{-1} Urea and 34.5 kg ha^{-1} DAP)	12
T6	50% RNP (32 kg ha^{-1} Urea and 23 kg ha^{-1} DAP)	4
T7	50% RNP (32 kg ha^{-1} Urea and 23 kg ha^{-1} DAP)	8
T8	50% RNP (32 kg ha^{-1} Urea and 23 kg ha^{-1} DAP)	12
T9	25% RNP (16 kg ha^{-1} Urea and 11.5 kg ha^{-1} DAP)	4
T10	25% RNP (16 kg ha^{-1} Urea and 11.5 kg ha^{-1} DAP)	8
T11	25% RNP (16 kg ha^{-1} Urea and 11.5 kg ha^{-1} DAP)	12
T12	0	4
T13	0	8
T14	0	12

Note: RNP is the Recommended Nitrogen and Phosphorus Application Rate

2.3. Agronomic Practice

All the cultural practices other than the treatments were practiced as per the recommendation for the crops. Compost was prepared using different organic materials including crop residues, leaves and soft parts of different herbs, vegetable and fruit wastes. Appropriate procedures for compost preparation was followed and it was applied a week before sowing tef seeds. The land was plowed three times. The seed of tef (Koncho variety) was drilled at rows spacing of 20 cm at mid of July in 2014 and 2015 main growing season. All doses of DAP and half of urea was applied at sowing time, while the remaining half urea was applied at tillering stage. Twice hand weeding was done.

2.4. Soil and Compost Sample Analysis

Before land preparation, soil samples were randomly collected from 0-30 cm soil depth surface layer of the experimental field and composite sample was formed to determine soil texture, pH, organic carbon content, total nitrogen (N) and available phosphorus (P). Compost was also analyzed for pH, OC, Organic matter (OC), N and P Organic matter was calculated as Om = OC x 1.72. All these samples were analyzed following standard laboratory procedures as described by Sertsu and Bekele (2000). The soil texture of the experimental area was clay, which has low organic matter (1.73%), very low nitrogen (0.09%) and available phosphorus (4.26 ppm) contents. The nutrient contents of the compost, which was applied as organic fertilizer, had 230 ppm available phosphorus, 15.245 organic matter and 0.77% total nitrogen content (Table 2).

Table 2. Physic-chemical properties of soil and compost.

Properties	pH	EC	av. P (ppm)	OM (%)	T. N (%)
Compost chemical properties	6.65	-	230	15.24	0.77
Soil chemical properties	7.23	0.07	4.26	1.73	0.09
Soil particles	Sand	Silt	Clay	Textural Class	
Size (%)	27.28	31.28	41.44	Clay	

Note: EC = electric conductivity, av. P = available phosphorus, OM= organic matter, T.N = total nitrogen

2.5. Data Collection and Analysis

At harvest, ten plants were selected randomly from each experimental plot and data were collected on plant height, number of leaves per plant and panicle length and panicle length. The biomass and seed yield were recorded by harvesting the net plot area and converted to kg ha^{-1}. The moisture content was adjusted to 12.50%. Harvest index was calculated by dividing grain yield by biomass yield.

To evaluate the economic feasibility of treatments, partial budget analysis was done following the procedures described by CIMMYT (1988). Grain yield was adjusted downwards by 10% assuming that farmers may obtain yields 10% lower than recorded by research results in small plots. The farm get price of grain during cropping season was used to calculate gross benefit as a product of market price and adjusted mean grain yield of chickpea for each treatment. Then the net benefit was calculated as the difference between gross benefit and total costs that vary. Treatments were listed according to increase in total costs that vary. The dominance analysis was done to select potentially profitable treatment (un-dominated treatments) and to eliminate treatment that has net benefits less than or equal to the treatments with lower costs that vary (dominated treatments). The Marginal

Rate of Return (MRR) was calculated as:

$$MRR\ (\%) = \frac{\Delta NB}{\Delta TVC}\ x\ 100, \qquad [1]$$

Where, ΔNB = change in net benefit, ΔTVC = change in total variable cost.

All the data collected from each plot were subjected to Analysis of variance (ANOA) using SAS statistical software to determine the significance difference among treatments. Treatment means were separated using least significant difference (LSD) test at 5% level.

3. Results and Discussion

3.1. Effects of Integrated Nutrient Management on Yield and Yield Attributes of Tef

The result of two years combined analysis of variance showed that integrated nutrient management appreciably affected plant height, panicle length, grain and biomass yield, while the effect on harvest index and number of leaves was not significant (Table 3).

Application of compost alone and the unfertilized plots produced the shortest plant height and panicle length, while the longest values were observed from 150 kg ha^{-1} inorganic fertilizer, which was at par with integrated application of RNP and compost in different proportions (Table 3). This could be because high nitrogen from integrated application of compost and fertilizers favors vegetative growth of tef, which results in taller plants and hence panicle length. The improvement of the parameters due to NP fertilizer or application of integrated nutrient management is in agreement with that of Abdalla *et al.* (2012), who observed the highest plant height of tef with combined application of cotton residue + FYM+ vermicompost in Sudan.

The maximum grain (1.89 t ha^{-1}) and biomass (7.50 t ha^{-1}) yields were recorded with application of 75% RNP combined with 12 t ha^{-1} compost, which was statistically at par with application of 100% RNP, 75% RNP combined with 4 t ha^{-1} compost, and 75% RNP combined with 8 t ha^{-1} compost. The minimum grain yield was produced from unfertilized treatments or application of compost alone at any rates (4, 8 or 12 t ha^{-1}). The application of 75% RNP combined with 12 t ha^{-1} compost, and 75% RNP combined with 4 t ha^{-1} compost increased grain yield by 324 and 338% respectively, compared to unfertilized plots.

Table 3. Effect of Integrated Nutrient Management on yield and yield related attributes of tef.

Treatments	ID	PH	NL	PL	HI	BY	GY
Unfertilized	T1	45.31 ^{de}	4.40	24.12^{e}	0.23	1.89^{d}	0.43^{e}
100% RNP	T2	75.37^{a}	4.54	37.38^{a}	0.23	7.50^{a}	1.67^{ab}
75% RNP +12 t ha^{-1}	T3	68.80 ^{ab}	4.77	32.08 ^{ab}	0.27	7.50^{a}	1.89^{a}
75% RNP +4 t ha^{-1}	T4	68.86 ^{ab}	4.61	32.98^{ab}	0.27	7.34^{ab}	1.86^{ab}
75% RNP+8 t ha^{-1}	T5	71.24^{ab}	4.44	33.74^{ab}	0.28	7.10^{ab}	1.84^{ab}
50% RNP +12 t ha^{-1}	T6	70.42 ^{ab}	4.58	35.27^{ab}	0.26	6.20^{ab}	1.55^{b}
50% RNP +8 t ha^{-1}	T7	68.41 ^{ab}	4.68	33.66^{ab}	0.38	5.80^{ab}	1.53^{bc}
50% RNP +4 t ha^{-1}	T8	67.85 ^{ab}	4.14	32.33 ^{ab}	0.27	5.65^{bc}	1.50^{bc}
25% RNP +8 t ha^{-1}	T9	63.60 ^{bc}	4.19	30.51^{bc}	0.25	4.97^{c}	1.27^{d}
25% RNP +4 t ha^{-1}	T10	64.85 ^{bc}	4.78	31.96^{b}	0.24	5.22^{c}	1.23^{d}
25% RNP +12 t ha^{-1}	T11	58.84 ^{bc}	4.32	27.73^{cde}	0.26	4.76^{c}	1.21^{d}
4 t compost ha^{-1}	T12	47.48 ^{de}	4.08	23.83^{e}	0.17	2.20^{d}	0.37^{e}
8 t compost ha^{-1}	T13	53.31 ^{de}	4.01	27.80^{cd}	0.21	2.65^{d}	0.55^{e}
12 t compost ha^{-1}	T14	49.40 ^{de}	4.25	26.75^{de}	0.19	2.99^{d}	0.55^{e}
LSD (p<0.05)		8.38*	NS	5.33*	NS	1.76*	0.34*
CV (%)		11.61	9.8	14.98	40.25	29.65	24.29

Simple Pearson correlation analysis indicated that yield and yield attributes of tef had strong positive correlation to each other. Grain yield showed highly significant (**) relationship with harvest index (r= 0.66), leaf number (r= 0.64), plant height (r= 0.95), panicle length (r= 0.88) and biomass yield (r= 0.99) (Table 4). The present result is in agreement with finding of Tesfahunegn (2014), who reported that inorganic fertilizer and integrated nutrient management significantly improved tef yield at Dura of Northern Ethiopia. Similarly, Edward *et al.* (2007) reported improvement of tef yield by about 86% with application of compost compared to unfertilized check. The combined application of inorganic fertilizer and compost also improved biomass, which agree with Chala and Gurmu (2017) study in Tigray region. Their result showed that maximum biomass (3.14 t ha^{-1}) was observed under the application of 50% RNP combined with 4.8 t ha^{-1} compost. Mebratu *et al.* (2016) found that application of 100% RNP combined with 5 t ha^{-1} compost on the local variety exhibited best maximum yield on mid highlands vertisoils of Ethiopia. However, the present result was different from that of Ayalew *et al.* (2011), who reported that no need to apply any type of fertilizer for tef production at Hawassa as there was no response of the three tested tef varieties to the application of NP fertilizers due to high soil N and P content at the site.

Table 4. Pearson correlation analysis of yield and yield attributes.

	BY	GY	HI	NL	PH
GY	0.99**				
HI	0.57*	0.66**			
NL	0.65*	0.64**	0.54*		
PH	0.96**	0.95**	0.61*	0.58*	
PL	0.90**	0.88**	0.56*	0.58*	0.97**

Note: BY = biomass yield, GY = grain yield, HI = Harvest index, NL = Number of leaves, PH= Plant height, * = significant, ** = highly significant

3.2. Economic viability of integrated nutrient management

The partial budget analysis indicated that applications of treatments, except application 4 t compost ha^{-1} alone, are economically profitable compared to the unfertilized treatment. The maximum net benefit of (ETB 23,150 ha^{-1}) was obtained from application 75 kg ha^{-1} inorganic fertilizer combined with 4 t ha^{-1} compost with marginal rate of return (70%) greater than the minimum acceptable level (100%). The values of marginal rate of return (70%) indicates that a farmer can get a profit of ETB 50.70 for one ETB additional investment incurred to move from treatment 75 kg ha^{-1} inorganic fertilizer combined with 8 t ha^{-1} compost to 112.5 kg ha^{-1} inorganic fertilizer combined with 4 t ha^{-1} compost (Table 5). Therefore, combined application of 75 kg ha^{-1} inorganic fertilizer with 4 t ha^{-1} compost is economically profitable to be recommended for the study area. In line with the present finding, Chala and Gurmu (2017) obtained highest net return from application of 3.20 t ha^{-1} vermicompost + 2.37 t ha^{-1} conventional compost + 1.37 t ha^{-1} farmyard manure on vertisoils of central Ethiopian highlands.

Table 5. Economic feasibility of integrated nutrient management for tef production.

Treatments	BY	GY	ABY	AGY	TVC	NB	DA	MRR
Unfertilized	1890	430	1701	387	0	5958	-	-
100% RNP	7500	1670	6750	1503	1960	21323	D	-
75% RNP + 4 t ha^{-1}	7340	1860	6606	1674	1870	23150		5070
75% RNP + 8 t ha^{-1}	7100	1840	6390	1656	2270	22336	D	-
75% RNP + 12 t ha^{-1}	7500	1890	6750	1701	2670	22791	D	-
50% RNP + 4 t ha^{-1}	5650	1500	5085	1350	1380	18555		520
50% RNP + 8 t ha^{-1}	5800	1530	5220	1377	1780	18587		8
50% RNP + 12 t ha^{-1}	6200	1550	5580	1395	2180	18745	D	-
25% RNP + 4 t ha^{-1}	5220	1230	4698	1107	890	15985		1830
25% RNP + 8 t ha^{-1}	4970	1270	4473	1143	1290	15756	D	
25% RNP + 12 t ha^{-1}	4760	1210	4284	1089	1690	14573	D	-
4 t ha^{-1} compost	2200	370	1980	333	400	5243	D	-
8 t ha^{-1} compost	2650	550	2385	495	800	7030		134
12 t ha^{-1} compost	2990	550	2691	495	1200	6936	D	-

Note: BY = biomass yield, GY = grain yield, ABY = adjusted biological yield, AGY = adjusted grain yield, TVC = total variable cost, NB = net benefit, D = dominated, DA = dominance analysis.

4. Conclusion

The present finding revealed that integrated use of inorganic fertilizers with compost improved tef yield more than the use of either inorganic or compost fertilizer alone. The maximum grain yield was recorded from 75% RNP (48 kg N ha^{-1}and 34.5 kg P_2O_5 ha^{-1}) with 12 t ha^{-1} compost, which was at par with 75% RNP + 4 t ha^{-1} compost. The least mean grain yield was obtained from unfertilized treatments or application of compost alone (4, 8 and 12 t compost ha^{-1}). Combined application of 75% RNP (48 kg N ha^{-1} and 34.5 kg P_2O_5 ha^{-1}) with 12 t ha^{-1} compost and with 4 t ha^{-1} compost as well as 100% RNP (96 kg N ha^{-1} and 34.5 kg P_2O_5 ha^{-1}) increased grain yield by 324, 338 and 288% respectively, compared to unfertilized plots. Application of 75% RNP + 4 t ha^{-1} compost gave the maximum net benefit (ETB 23,150). Therefore, it can be recommended to apply 75% RNP + 4 t ha^{-1} compost for tef production in the study area. The result also suggested that integrated application of inorganic fertilizer with locally available organic manures such as compost is the best strategy to achieve higher crop yields and economically feasible tef production.

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Author Contributions

Study concept and design: Yenus. Analysis and interpretation of data: Yenus and Achenafi. Statistical analysis: Yenus. Drafting of the manuscript: Yenus. Revision of the manuscript for important intellectual content: Achenafi.

Competing interest statement

The authors declare no conflict of interest.