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Response of Yield and Yield Components of Tef [*Eragrostis Tef* (Zucc.) Trotter] to Optimum Rates of Nitrogen and Phosphorus Fertilizer Rate Application in Assosa Zone, Benishangul Gumuz Region

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ይህ የመስክ ላይ ሙከራ በቤንሻንጉል ጉሙዝ ክልል በአሶሳ ዞን በአሶሳና ባምባስ ወረዳ በአርሶ አደር ማሳዎች ላይ ለሁለት ተከታታይ ዓመታት (ከ2005 – 2006 ዓ.ም) የተከናወነ ሲሆን ዋና) ዓላማዉም የናይትሮጅንና የፎስፈረስ ማዳበሪያ ላይ ያላቸዉን ተጽዕኖ መገምገም ነበር፡፡ ይህንንም ለማጥናት አምስት(5) የናይትሮጅን እና አራት(4) የፎስፈረስ ደረጃዎች ድብልቅ በአጠቃላይ ሀያ (20) ተጠኚዎችን በFactorial combination RCBD ዲዛይንና በሦስት ድግግምሽ ተሞክሯል፡፡ ዉጤቱ እንደሚያሳየዉ የጤፍ ዕድገትና ምርት በናይትሮጂንና በፎስፈረስ ማዳበሪያ መጠቀም አመርቂ ለዉጥ አሳይቷል፡፡ በመሆኑም 46 ኪ.ግ ናይትሮጅን እና 10 ኪ.ግ ፎስፈረስ በሄክታር በመጠቀም 1681.1 ኪ.ግ የጤፍ ምርት በሄክታር ተገኝቷል፡፡ ይህ የማዳበሪያ መጠን ምንም ማዳበሪያ ካልተጨመረበት ጋር ሲነፃፀር በ137% የምርት ጭማሪን ያስገኛል፡፡ የዋጋ አዋጭነትን ስንመለከትም ይህ የማዳበሪያ መጠን አዋጭ መሆኑን ያረጋግጣል፡፡ ስለዚህም 46 ኪ.ግ ናይትሮጅን እና 10 ኪ.ግ ፎስፈረስ በሄክታር መጠቀም ከፍተኛ የሆነ ትርፍ ያለዉና አዋጭ የማደበሪያ አጠቃቀም መሆኑ ተረጋግጧል፡፡

Abstract

Tef (Eragrostis tef) is one of most important food crops grown in Benishangul Gumuz region of Ethiopia and is produced in different agro-ecologies in the region. However, its productivity is constrained by a number of problems, of which soil nutrient is the most important one. Information on the response of tef to Nitrogen (N) and Phosphorus (P) fertilizers in Assosa Zone is inadequate. Field experiments were conducted at two locations for two years (2012-2013) to investigate the response of tef to N and P fertilization. Five levels of nitrogen (0, 23, 46, 69 and 92 N kg ha^{-1}) and four levels of phosphorus (0, 10, 20 and 30 kg P ha^{-1}) were studied in factorial combinations in a randomized complete block design (RCBD) with three replications. The results revealed substantial responses of tef to the main effect of N and P on days to heading and panicle length, the main effect of N on days to emergency, and the main effect of P on days to 90% physiological maturity. Nitrogen by P interaction effect was significant on plant height, straw and grain yield. Grain yield increased significantly from 708.6 to 1681.1 kg ha^{-1} with increase in the level of N and P from the control (0/0 N/P) to 46 kg N and 10 P kg ha^{-1}. The magnitude of increase in grain yield due to application of 46 kg N along and 10 kg P ha^{-1} was 137 % higher as compared to the control. The partial budget analysis also indicates that applications of 46 kg N ha^{-1} and 10 kg P ha^{-1} are the most economical fertilizer rates to tef growers compared to the other levels in the study area.

Introduction

Tef (*Eragrostis tef* **)** is among the major cereal crops in Ethiopia both in terms of area coverage and nutritional importance(CSA, 2016). It is one of the leading traditional food crops of Ethiopia. It ranks second in the country following maize in total production (CSA, 2016). The crop is utilized in different forms where the grain is used for human consumption and homemade beverage, while the straw is commonly used as feed to animals (Seyfu, 1997). Similarly, Tef is the food crop in the Benishangul-Gumuz region in general and in Assosa zone in particular. Tef production in the zone is found both in shifting and permanent farming systems, which are practiced among natives and settlers farming communities, respectively.

The productivity of tef has been by far lower than the potential yields obtained on research stations and on farm verification trials which could be attributed to several abiotic factors though the genetic potential of the crop also takes vital share. Further its productivity varies from region to region in the country depending on agroecological suitability, availability of improved cultivars and farmers' management practices. The growth, development and yield of cereal crops can be adversely affected when there is deficiency or excessive supply of any of the essential elements and other toxic substances (Hay and Walker, 1992).

In Benishangul Gumuz region, especially in Assosa zone, its productivity (1.2 t ha^{-1}) lagged behind the national average i.e. 1.57 t ha^{-1} (CSA, 2016). Poor soil fertility, erratic rainfall, and suboptimal management practices could be among the main factors to be responsible. Soil nutrient status is widely constrained by the limited use of inorganic and organic fertilizers and by loss of nutrients mainly due to erosion and leaching (Balesh et al., 2007; Gete *et al*., 2010; Getachew *et al*., 2014). Many smallholder farmers do not have access to synthetic fertilizer because of its high price, lack of credit facilities, poor distribution, and other socio-economic factors. Consequently, crop yields are low, and the sustainability of the current farming system is at risk.

Tef research has been conducted in the region since the past few years and some promising varieties have been adapted and under production in the area. Among the released varieties, Quncho had better yield advantage over others under research and farmers' field. Yet, improvement of its production has not been possible due to a number of soil-plant-management related factors. Apparently, low soil fertility and inadequate nutrient management are among the major factors determining its yield level. Continuous cropping, high proportions of cereals in the cropping system, and the application of suboptimal levels of mineral fertilizers by farmers aggravates the situation in the area. The continuous removal of biomass (grain and crop residues) from crop land without adequate nutrient replenishment can rapidly deplete the soil nutrient reserves and jeopardize the sustainability of agricultural production (Gete *et al.*, 2010; Getachew *et al.*, 2015; Legesse, 2004). To maintain high crop production level, the nutrient status of the soil has to be maintained through crop rotation, addition of organic and inorganic fertilizers. Inorganic fertilizers are important inputs in any agricultural production system because they supply the required nutrients in a readily available form for immediate plant use. Generally, the recommended rate of fertilizer for tef is 25 - 40 kg N and 10- 20 kg P ha^{-1} on light soils such as Nitosols, Luvisols and Cambisols, and 50-60 kg N and 30-35 kg P per hectare for heavy soils such as Vertisols (Deckers *et al.,* 2001).

So far efforts regarding the determination of optimum fertilizer rates and other agronomic requirement of tef in the area are inadequate. s, Nitrogen and P are the most important nutrients among major yield limiting plant nutrients as they are required in large quantity by the crop. However, there is no adequate research information for nitrogen and phosphorus fertilizer application rates in the area. This implies that effort has to be made to improve the production and productivity of tef through application of appropriate level of N and P fertilizers. In view of this, the activity was initiated with the following objectives: 1) to investigate the main and interaction effects of different levels of N and P fertilizers on yield and yield components of tef; and 2) to determine the economic optimum N and P rates for tef production.

Materials and Methods

Description of the study area

The experiment was conducted in Assosa Zone, in two districts, namely Bambasi and Assosa, western Ethiopia, in the main rainy seasons of 2012 and 2013. The research sites are located between 1300 and1470 masl. with the minimum and maximum temperatures of 14.5 and 28.8^{o}C, respectively. The average annual rainfall is 1358mm of which 1128.5mm were received between May and October during the cropping season.

Treatments and experimental design

The fertilizer treatments consisted of factorial combinations of five levels of N (0, 23, 46, 69 and 92 kg N ha^{-1}) and four levels of P (0, 10, 20, and 30 kg P ha^{-1}). The experiment was conducted was laid out in a randomized complete block design (RCBD) with three replications on a plot size of 5 m x 4m. Urea and triple super phosphate (TSP) were used as the sources of N and P, respectively. Application of urea was in two splits, while the full rate of phosphorus was applied at sowing in band.

The experimental land was well prepared. Each plot and block was separated by 0.50 m and 1.5m, respectively. Tef (*Kuncho variety*, Dz-Cr-387) was used for the experiment with broadcast method. Important agronomic practices were uniformly applied to all experimental plots as often as required.

Soil sampling and analysis

Composite soil samples were collected from the experimental plots in a diagonal pattern from the depth of 0-20 cm before planting. Uniform slices and volumes of soil were obtained in each sub-sample by the vertical insertion of an auger and made a composite soil sample. The soil samples were dried, ground using a pestle and a mortar and allowed to pass through a 2-mm sieve and analyzed for the selected physico-chemical properties mainly organic carbon, total nitrogen, soil pH, available phosphorus, cation exchange capacity (CEC) and textural analysis using standard laboratory procedures.

Organic carbon(OC) content was determined by the volumetric method (Walkley and Black, 1934) as described in the Food and Agriculture Organization (FAO) guide to laboratory establishment for plant nutrient analysis (FAO, 2008) using 1.0 g of the prepared soil sample. Total nitrogen was analyzed by Micro-Kjeldhal digestion method with sulphuric acid (Jackson, 1962). The pH of the soil was determined according to FAO (2008) using 1:2.5 (weight/volume) soil sample to water solution ratio using a glass electrode attached to digital pH meter. The cation exchange capacity (CEC) was measured after saturating the soil with 1N ammonium acetate (NH_4OAc) and displacing it with 1N NaOAc (Chapman, 1965). Available phosphorus was determined by the Bray II method.

Data collection and analysis

Sampling and data collection were done from the center of each plot. Growth indicating parameters such as plant height, panicle length, and grain yield was collected. Plant height (cm) was measured from the base of the plant to the top most leaves of the plant. The average value was computed from five randomly selected plants. The grain yield was sampled and measured from the center of each plot, and converted to kg ha^{-1} for statistical analysis. Analysis of variance was performed following statistical procedures appropriate for the experimental design using SAS computer software. Whenever treatment effects were significant, the means were separated using the least significant difference (LSD) test at 5 % level of significance. The partial budget analysis was done following the method described in CIMMYT (1988).

Results and Discussion

Soil physico-chemical properties before sowing

Soil physical and chemical properties were analyzed for the surface composite soil sample taken from the experimental field. The texture of the soil was with particle size distribution of 53.8% clay, 30.2% and 16% silt. The soil texture is clayey. According to the rating of Landon (1991), the soil used for this study ranged from very strongly acidic (pH 4.29) to moderately acidic (pH 5.52) classes, indicating the possibility of Al toxicity and deficiency of certain plant nutrients. The exchangeable K of the soil before the application of the treatments ranged from 0.192 to 0.42 Cmol (+) kg^{-1}. All experimental soils had deficient to adequate K content. According to Landon (1991), available (Bray II extractable) soil P level of less than 10 mg kg^{-1} is rated as low, 11-31 mg kg^{-1} as medium and greater than 18 mg kg^{-1} is rated as high. Thus, most trial location had very low to medium available (Bray II extractable) P (Table 1). Following the rating of total N by Landon (1991), > 1% is rated as very high, 0.5 to 1% high, 0.2 to 0.5% medium, 0.1 to 0.2% low and < 0.1% as very low N status. The experimental soils qualify for very low total N. Similarly, the organic carbon (OC) content of the soil was also very low to low in accordance with Landon (1991), who categorized OC content as very low (< 2%), low (2- 4%), medium (4-10%), high (10-20%). The very low OC and low N content in the study area indicate low fertility status of the soil. This could be due to continuous cultivation and lack of incorporation of organic materials (Table1).

Table Chemical properties of some experimental soil samples prior to planting

Soil parameters	Nebar keshmando	Amba 14	Megel 33
pH_{H2O} (1:2.5)	5.2	4.8	4.3
CEC ($cmol_{(+)}$ kg^{-1})	29.0	17.2	25.9
OC (%)	2.5	1.7	2.1
Total N (%)	0.2	0.2	0.2
Available P (Bray II) (ppm)	3.4	3.4	3.2
K ($cmol_{(+)}$ kg^{-1})	0.4	0.2	0.3

Crop Phenology

Days to 50% emergence

Days to crop emergence was significantly ($P \leq 0.05$) affected by the main effect of N fertilizer rate, but not by the main effect of P fertilizer and their interaction (Table 2). Increasing the rate of N application from 0 to 92 kg ha^{-1} N hastened emergence of the crop by additional time of about 21% as compared to the number of days required by plants in the control treatment (Table 2). The acceleration of emergence of the crop in response to N application might be due to the possibility that N supply may have triggered faster germination because of its positive influence on the internal factors regulating the germination process such as increased contents of gibberellic acid in the seed (Taiz and Zeiger, 2006). A similar result was reported by Temesgen (2012). However, this finding is in contrast to Haftamu et al. (2009) and Mitiku (2008) who reported that increased application of N delayed crop emergence in tef.

Days to 50% heading

The analysis of variance over two years indicated that days to 50% heading in tef was significantly ($P \leq 0.05$) different due to the main effects of N and P application rates but not due to their interaction (Table 2). Nitrogen fertilized plots had faster heading than the plots not treated by fertilizer N (Table 2). The reason for accelerated heading of the crop by N fertilization could be due to the uptake of sufficient N by tef plants from the soil and also because of the uptake of N may have enhanced the uptake of other nutrients such as P and potassium which might speed up growth and development of plants. This is consistent with the suggestion of Temesgen (2012) that N supply promotes the uptake of other nutrients, enhancing growth and development. In contrast to the results of this study Legesse (2004) who found significantly prolonged number of days to heading in response to N application.

The number of days required to heading varied among P fertilizer rates. The control (0 P) treatment significantly delayed heading (96.7) while higher levels of P (10, 20 and 30 kg ha^{-1}), significantly enhanced heading (Table 2). The probable reason might be that applied P fertilizer played an essential role in plant growth and development. Assefa et al. (2016) also reported a similar result. The results of this study are inconsistent with those of Legesse (2004), Mitiku (2008), Haftamu et al. (2009) and Temesgen (2012) who reported non-significant differences in days to heading of tef plants in response to the application of P fertilizer. The heading of tef plants was accelerated as NP rate increased. This could be due to the fact that plots treated with the highest rates of nutrients encouraged early establishment, rapid growth and development of tef plants, which is in agreement with Tucker (1999).

Days to 90% physiological maturity

Days to 90% physiological maturity was not significantly different due to the application of N fertilizer, which is in line with the finding of Temesgen (2012). In contrast, data presented in table 2 indicated that days to 90 % physiological maturity was significantly ($P \leq 0.05$) affected by phosphorus rates. The shortest days (91.2) to physiological maturity were obtained from the application of 30 kg P ha^{-1} and the longest days (96.7) from the control. This was also supported by Brady and Weil (2002) who showed that phosphorus application could possibly shorten maturity date since it promotes rapid cell division. The probable reason might be that phosphorus promotes maturity of plants. Onasanya *et al.* (2009)

showed that phosphorus plays an important part in many physiological processes that occur within a developing and maturing plants. It is involved in enzymatic reactions in the plant and hastens the maturity, thus counteracting the effect of excess nitrogen application to the soil. However, the delay of physiological maturity may be due to insufficient amount of essential elements under unfertilized treatment.

Growth Parameters

Panicle length

Panicle length was significantly ($P \leq 0.05$) affected by the main effects of N and P fertilizer application, but not by their interaction (Table 2). Significant differences were observed among N fertilizer application rates in panicle length. The longest (39.9 cm) panicle length was obtained from the application of 69 kg N ha^{-1} while the shortest (31.6 cm) was recorded from the control (0 N). Increasing N from 0 to 69 kg N ha^{-1} increased panicle length by about 26.3%, compared to the control. Panicle length is one of the most important traits influencing yield. In many findings, the effect of high N application on tef yield was attributed to the major role played by panicle length on grain yield. Longer panicles bear more number of spickletes that contain higher number of grains, higher total biomass and straw yield. This is consistent with the findings of Temesgen (2012); Haftamu et al. (2009); Mitiku (2008); Legesse (2004) and Mulugeta (2000), who reported that panicle length exhibited positive and highly significant correlation with plant height and grain yield. In all findings including the aforementioned ones, increased application of N caused increased panicle length and hence crops with higher panicle length produced significantly higher total biomass yield, grain yield and straw yield than those with shorter panicles. A similar study by Channabasavanna and Setty (1994) also revealed increased yield of cereal crops due to increased yield attributes such as panicle length as a result of successive increases in N application.

Application of P fertilizer also significantly affected panicle length. The highest panicle length (39.6 cm) was recorded from the application of 20 kg P ha^{-1} while the shortest was obtained from the control treatment **(**Table 2**).** The increase in panicle length with increasing P rate could be due to sufficient uptake of P by plants, which encourages plant growth. Phosphorus is the main element involved in energy transfer for cellular metabolism in addition to its structural role (Wiedenhoeft, 2006). The result was in agreement with the findings of Giday (2014). Higher panicle length may have also positive contribution to the grain and straw yields since it has a positive correlation to grain yield. In line with this result, Asefa (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.

Table 2. The main effects of N and P fertilizer rates on phenology of tef in Assosa and Bambasi Districts 2012-2013

Treatments	Days to 50% emergency	Days to 50% heading	Days to 90% physiological maturity	Panicle length(cm)
Nitrogen (kg ha^{-1})				
0	4.6^{a}	50.2^{a}	90.3	31.6^{c}
23	4.4^{ab}	47.1^{b}	92.0	37.8^{b}
46	3.9^{bc}	46.7^{b}	91.6	38.1^{ab}
69	3.8^{c}	47.4^{b}	92.4	39.9^{a}
92	3.8^{c}	46.5^{b}	92.4	38.8^{ab}
LSD (5%)	0.25	1.03	Ns	1.03
Phosphorus (kg ha^{-1})				
0	4.2	51.7^{a}	96.7^{a}	32.4^{b}
10	4.3	47.2^{b}	92.8^{b}	38.2^{a}
20	3.9	46.1^{bc}	91.4^{b}	39.6^{a}
30	4.0	45.3^{c}	91.2^{b}	38.9a
LSD (5%)	Ns	0.92	1.83	0.92
CV (%)	25.7	9.2	9.4	11.8

Means in a column with same letter are not significantly different at 5% probability level. Ns=not significant

Plant height

The analysis of variance showed that plant height was significantly affected ($P \leq 0.05$) by the interaction of N and P fertilizer application. Plant height generally increased with the increase in the rate of NP fertilizer application (Table 3). In line with this, Rashid et al. (2007) indicated that plant height was linearly increased with increasing levels of NP fertilization. The maximum plant height (104.1 cm) was obtained from application of 23kg N ha^{-1} and 10 kg P ha^{-1}, while the lowest (77.3 cm) from the control treatment (Table 3). The increase in plant height was not consistent with the increase in NP rates. The plant heights obtained from all NP fertilized plots were significantly higher than unfertilized plots. This is because the applications of NP fertilizers have great roles in plant growth. Many studies revealed significant influence of N on plant height as it plays a vital role in vegetative growth of plants. A similar result was reported by Haftom et al. (2009) showing that a tef plant with higher plant height was found by applying a high amount of N fertilizer. This may be attributed to the fact that N usually favours vegetative growth of tef, resulting in higher stature of the plants with greater panicle length. Legesse (2004) also reported that high N application resulted in tef plants with significantly taller plants due to direct effect of N on vegetative growth of plants. This result is in line with the report of Wakene et al. (2014) who stated that plant height of barely increased with increasing rates of NP from 0/0 to 69/30 kg ha^{-1}.

Table 3. Plant height (cm) of tef as affected by N*P interaction at Assosa Zone, 2012 - 2013

Nitrogen (kg ha^{-1})	Phosphorus (kg ha^{-1})				
	0	10	20	30	Mean
0	77.3^{h}	89.4^{cdef}	88.9^{defg}	86.3^{fgh}	85.5
23	79.3^{h}	104.1^{a}	95^{bcde}	97.6^{abcd}	94.0
46	80.1^{gh}	95.5^{abcd}	99.2^{ab}	100.3^{ab}	93.8
69	79.5^{h}	94.4^{bcde}	99.0^{ab}	98.1^{abc}	92.8
92	82.4^{fgh}	97.6^{abcd}	96.9^{abcd}	101.1^{ab}	94.5
Mean	79.7	96.2	95.8	96.7	
LSD (5%) N*P = 4.52			CV (%) =10.43		

Straw yield

Straw yield was significantly (P≤0.05) affected by the main effect of N and P application as well as their interaction. Generally, the combined application of N and P resulted in increased straw yields (Table 4). Thus, the application of 46 kg N ha^{-1} and 10 kg P ha^{-1} resulted in the highest (3135.4 kg ha^{-1}) straw yield, with the yield increment of 129% compared to the control. I contrast the lowest (1396.4 kg ha^{-1}) straw yield was recorded from the control treatment (unfertilized plot). Consistent with this finding, Melesse (2007) reported that wheat cultivars produced higher straw yields in response to the combined application of higher rates of N and P. The increased straw yield might be due to the effect of high N application on the production of effective large numbers of tillers, increased plant height, and panicle length. Temesgen (2012), Haftamu et al. (2009) and Mitiku (2008) who indicated that the highest straw yield was obtained in response to the application of higher rates of N application, which enhanced the production of significantly longer panicle sizes and taller plants, and as a result greater biomass yield, reported similar results.

Table 4. Straw yield (kg ha^{-1}) of tef as affected by N*P interaction at Assosa Zone, 2012 – 2013

Nitrogen (kg ha^{-1})	Phosphorus (kg ha^{-1})				
	0	10	20	30	Mean
0	1396.4^{i}	2106.4^{ef}	2266.2^{de}	2294.6^{de}	2015.8
23	1863.7^{fgh}	2869.1^{ab}	2604.3^{bcd}	2748.5^{abc}	2521.4
46	1716.8^{fghi}	3135.4^{a}	2505.4^{bcd}	2468.1^{cde}	2456.4
69	1597.9^{hi}	2286.4^{de}	2436.5^{cde}	2468.7^{cde}	2197.4
92	1708.6^{ghi}	2600.4^{bcd}	2367.2^{cde}	2089.0^{efg}	2191.3
Mean	1656.7	2599.54	2435.9	2413.8	
N *P , LSD(5%)=201.1			CV (%) =18.75		

Grain yield

Grain yield is the result of many complex morphological and physiological processes occurring during the growth and development of crops (Khan et al., 2008). The analysis of variance showed that grain yield of tef was significantly

($P \leq 0.05$) influenced by the main effect of N and P fertilizer rate as well as by the interaction of N and P rates (Table 5).

The maximum grain yield (1681.1 kg ha^{-1}) was obtained from application of 46 kg N ha^{-1} and 10 kg P ha^{-1} while the minimum grain yield of tef was recorded from the unfertilized plots. Grain yield significantly increased ($P \leq 0.05$) from 708.6 to 1681.1 kg ha^{-1} with the increase in the levels of N/P from the control (0/0 N/P) to 46 kg N ha^{-1} along with 10 kg P ha^{-1}, but decreased with further increase in applied N and P fertilizer. The magnitude of increase in grain yield due to application of 46 kg N ha^{-1} and 10 kg P ha^{-1} was higher by 137 % than the control. This might be due to the uptake of balanced amounts of nitrogen by plants throughout the major growth stages; enhanced synchrony of the demand of the nutrient for uptake by the plant and its availability in the root zone in sufficient amounts. Temesgen (2001) reported that application of different levels of N significantly affected grain yield of tef on farmer's field. In this experiment, the reduction in grain yield with higher N and P levels beyond 46 kg N and 10 kg P ha^{-1} might be mainly related to the reductions observed in the yield components and thereby decreased grain yield. Consistent with this suggestion, Reinke *et al.* (1994) indicated that where the grain yield response is negative, yield reduction is primarily caused by a reduction in the proportion of the number of filled spikelets per panicle. Singh et al. (1995) also reported a decrease in grain yield of rice with application of high doses of N fertilizer.

Table 5. Grain yield (kg ha^{-1}) of tef as affected by N*P interaction at Assosa Zone, 2012- 2013.

Nitrogen (kg ha^{-1})	Phosphorus (kg ha^{-1})				
	0	10	20	30	Mean
0	708.6^{h}	1005.8^{de}	1257.2^{bc}	1179.4^{cd}	1037.8
23	812.6^{gh}	1220.2^{bcd}	1316.0^{b}	1212.0^{bcd}	1140.2
46	832.6^{fgh}	1681.1^{a}	1142.0^{cd}	1312.0^{b}	1241.9
69	966.1^{efg}	1039.0^{de}	1015.8^{ef}	1105.3^{cde}	1031.6
92	921.3^{efg}	1079.6^{de}	1042.4^{de}	947.5^{efg}	997.8
Mean	848.2	1205.1	1154.7	1151.2	
N *P , LSD(5%)= 99.8			CV (%) =18.53		

Linear relationships among Tef agronomic parameters

Linear relationships among tef agronomic parameters are presented in table 6. Grain yield of tef was significant and positively correlated with plant height ($r=0.55^{**}$), panicle length ($r=0.49^{**}$) and straw yield ($r=0.78^{**}$). This indicates that grain yield significantly increases with the increase in plant height, panicle length, and straw yield. On the other hand, grain yield was negatively correlated with days to heading($r=-0.16^{*}$) and maturity($r=-0.39^{**}$) which was in line with the report of Getachew (2004) on bread wheat. Straw yield had significant and positive correlation with plant height ($r = 0.59^{**}$) and panicle length ($r=0.46^{**}$), but negatively correlated with days to heading ($r=-0.25^{**}$) and maturity ($r=-0.32^{**}$).

This indicates that straw yield significantly increases with the increase in plant height and panicle length. Bekalu and Arega (2016) who reported that grain and straw yields of tef were significantly and positively correlated with plant height and panicle length, but negatively with days to heading and maturity, reported similar results.

Table 6. Linear relationships among tef agronomic parameters

	Days to emergence	Days to heading	Days to maturity	Plant height	Panicle length	Straw yield	Grain yield
Days to emergence	1						
Days to heading	0.25^{ns}	1					
Days to maturity	0.02^{ns}	-0.10^{ns}	1				
Plant height	0.01^{ns}	-0.22^{ns}	-0.52^{ns}	1			
Panicle length	-0.19^{**}	-0.36^{**}	-0.36^{**}	0.66^{**}	1		
Straw yield	-0.05^{ns}	-0.25^{**}	-0.32^{**}	0.59^{**}	0.46^{**}	1	
Grain yield	0.01^{ns}	-0.16^{*}	-0.39^{**}	0.55^{**}	0.49^{**}	0.78^{**}	1

- *ns=non significant,* & **=significant at probability of 5 & 1%, respectively.*

Effects of NP fertilizer on economic feasibility of tef production

The higher net return EB 19043.8 Birr ha^{-1} with marginal rate of return of 1221% was obtained with application of 46/23 kg N P_2O_5 ha^{-1}. Thus, planting tef with application of 46 kg N ha^{-1} combined with 23 kg P_2O_5 ha^{-1} resulted in 79.9 % surplus income from grain sale compared to adopting national blanket fertilizer recommendation (46 kg N ha^{-1} combined with 46 kg P_2O_5 ha^{-1}) recommended by Ministry of Agriculture (Tables7). Thus, 46 kg N ha^{-1} combined with 23 kg P_2O_5 ha^{-1} fertilizer rate application are the most economical feasible to tef growers compared to the other levels .

Table 7. Effects of NP fertilizer rates application on economic feasibility of tef production of at Assosa

N (kg ha^{-1})	P_2O_5 (kg ha^{-1})	AGYT (kg ha^{-1})	TVC (Birr)	Revenue (Birr)	Net benefit (Birr)	Value to cost ratio	Marginal rate of return (%)
0	0	637.7	9885	2085	7800	3.7	
23	0	731.3	11336	2777.5	8558.3	3.1	110
0	23	905.2	14031	3022.5	11008.4	3.6	1000
46	0	749.3	11615	3470	8144.8^D	2.3	
23	23	1098.2	17022	3715	13306.8	3.6	332
0	46	1131.5	17538	3960	13577.9	3.4	111
69	0	869.5	13477	4162.5	9314.6^D	2.2	
46	23	1513	23451	4407.5	19043.8	4.3	1221
23	46	1184.4	18358	4652.5	13705.7^D	2.9	
92	0	829.2	12852	4855	7997.1^D	1.6	
0	69	1061.5	16453	4897.5	11555.1^D	2.4	
69	23	935.1	14494	5100	9394.1^D	1.8	
46	46	1027.8	15931	5345	10585.9^D	2	
23	69	1090.8	16907	5590	11317.4^D	2	
92	23	971.6	15060	5792.5	9967.9^D	2	
69	46	914.2	14170	6037.5	8132.9^D	1.3	
46	69	1180.8	18302	6282.5	12019.9^D	1.9	
92	46	937.8	14536	6730	8505.9^D	1.4	
69	69	994.8	15419	6975	8443.9^D	1.2	
92	69	852.8	13218	7667.5	6250.1^D	0.9	

** Price of Urea =13.85 Birr/kg, TSP=18.75 Birr/kg, DAP=14.35 Birr/kg, Price of tef=15.50 Birr/kg and price of tef for seed=20 Birr/kg, AGYT= Adjusted grain yield of tef and D=Dominated*

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