

Application of NP Fertilizers for Better Production of Teff (*Eragrostis tef* (zucc.) trotter) on Different Types of Soils in Southern Ethiopia

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Abstract

Teff is one of the important crops grown in the southern region. Experiments were conducted at Bobicho research site (Hossana), Areka and Awassa on Profondic Luvisols, Haplic Alisols, and Vitric Andosols, respectively, to determine NP fertilizers requirement for teff production. Urea and triple super phosphate (TSP) were used as sources of N and P, respectively, at Hossana; whereas urea and diammonium phosphate (DAP) were used at Awassa and Areka as sources of N and P, respectively. Nitrogen was applied at rates of 0, 23, 46 and 69 kg/ha; whereas P was applied at 0, 10, 20, 30 and 40 kg/ha. Factorial randomized complete block design (RCBD) was used in three replications in all cases. Teff varieties DZ- 01- 354, DZ-01-196 and Dhabi, which are late, medium and early maturity groups, respectively, were used at Areka and Awassa; whereas another medium maturity group variety 'Ajora-1' was planted at Hossana. There was no response to any type of fertilizer irrespective of varieties variations for teff production at Awassa. At Areka, highly significant grain yield difference (up to 20 kg/ha) was obtained for P application, but there was no response to either N alone or its interaction with P. Additional grain yield of 394 kg/ha was obtained from application of the first 10 kg/ha P over the check. Highest value cost ratio (VCR) of 10.43 was obtained with application of 10 kg/ha P followed by 3.54 with 20 kg/ha P, after which the economic return declined sharply. Application of P up to 30 kg/ha highly significantly increased teff grain yield at Hossana. Both N and P, when applied separately, also significantly increased straw yield, but their interaction did not. Phosphorus application showed strong positive correlation with soil P, grain yield and straw yield of teff at Hossana. Highest VCR of 10.83 was obtained with the application of the first 10 kg/ha P. Value cost ratio continuously decreased with increasing levels of P up to 30 kg/ha resulting in positive economic return, where further increase of P level led to negative return. In general, on the basis of the results obtained, there is no need of applying any type of fertilizer for teff production at Awassa. Application of P up to 30 kg/ha is recommended for teff production at Hossana; whereas, only up to 20 kg/ha P is recommended at Areka.

Key words: Teff, N and P fertilizers

Background and Justification

Teff is the most important cereal crop serving millions of people as a staple food in Ethiopia. Doris (2002) reported that teff contains 11% protein and is an excellent source of essential amino acids, especially lysine, the amino acid that is most often deficient in grain foods. Teff contains more lysine than barley, millet, and wheat and slightly less than rice or oats. He further mentioned that teff is also an excellent source of fiber and iron, and has many times the amount of calcium, potassium and other essential minerals found in an equal amount of other grains. He also noted that teff is nearly gluten-free, and

is gaining popularity in the whole food and health food industry in the U.S. as an alternative grain for persons with gluten sensitivity. Teff may also have applications for persons with Celiac Disease. It contains 11% total carbohydrates, 24% dietary fiber, 10% thiamine, 2% riboflavin, 4% niacin, 8% calcium and 20% iron and is free from saturated fat, sugar and cholesterol (Purcell Mountain Farms, 2008). Gilbert (1997) indicated that teff straw from threshed grains is considered to be excellent forage, superior to straws from other cereal species. As cited by Gilbert (1997); Boe *et al.* (1986) and Eckhoff *et al.* (1993) reported that forage yields vary from 9.0 to 13.5 Mg/ha depending upon moisture levels during the growing season. Teff straw provides an excellent nutritional product in comparison to other animal feed and is also utilized to reinforce mud or plasters used in the construction of buildings (Doris, 2002).

Although teff is adapted to a wide range of environments and diverse agro climatic conditions, it performs excellently at an altitude of 1800-2100 m a s l, annual rainfall of 750-850 mm, growing season rainfall of 450-550 mm, and a temperature of 10 °C-27 °C (Seifu Ketema, 1993). It does well on clay loam and clay soils, which retain moisture during growing seasons. Teff is well suited on soils with a moderate fertility level and can tolerate a moderate water logged conditions (National Soil Service, 1994). It is also widely grown in Southern Region of Ethiopia, where early varieties like Dhabi and Bunigne are commonly produced during belg (March-June) rainy season, whereas medium to late varieties are dominantly produced during the main rain/meher (July-October) season.

According to CSA (1999), teff, covers the largest cultivated land as compared to cereals, pulses and oils, with average annual production of 1.87 million tones. Out of the estimated total cultivated land (8.216 million ha), it covered 31% in 1996/1997 (Doris, 2002), 32% in 1997/1998 (CSA 1999), and 25.84% in 2000/01 (CSA, 2002). From the figures above one can understand that, although the percentage of land under teff gradually decreases, the total area still continued to increase as a result of more and more new land is being cleared and put under cultivation each year.

Despite the large-scale production and various merits, teff production and productivity have been far below the potential. Currently the average national productivity is 0.92 t ha⁻¹, which is very low as compared to other small grain cereals grown in Ethiopia. This is because of many yield-limiting factors of which poor soil fertility being among the most important (Mwangi, 1995). Teff is produced in large plots, which is difficult to farmers to apply organic fertilizers to improve soil fertility. To feed the ever increasing population and generate income, continuous cultivation of land became a common practice in major teff producing areas, which eventually led to soil fertility decline and subsequent reduction of crop yields. Thus, as noted by Mwangi (1995) the use of inorganic fertilizer is critical to increase crop yield. Gruhn *et al.* (1995) suggested that, the levels of the fertilizer being used are very low and this must be increased to meet the demand for food with population growth. In many cases farmers are being forced to either not use or use low rates of fertilizer due to high fertilizer costs. Use of blanket recommendation rate irrespective of soil variations, however was found to be one of discouraging factors to farmers producing teff on relatively fertile soils. Thus, cost effective use of fertilizers on teff, which is low yielder and at the same time the most expensive grain crop in Ethiopia, is very crucial. Fertilizer recommendations are site, crop and soil specific; hence fertilizer rates should also be established for each site or crop and soil separately. These experiments were thus conducted with the objective to determine the economic optimum fertilizer rates for production of teff on different soils in southern Ethiopia.

The study sites and Characteristics of the soils

Bobicho(Hossana)

Bobicho research sub-center is found in Hadiya zone about 3 km northwest of *Hossana* town on gently sloping land (6% slopes). It is located on geographic coordination of 7° 34' 14.6" northern latitude and 37° 50' 06.1" eastern longitudes and an elevation of 2275 masl with tepid to cool sub-humid (SH₂) agro-ecology. The type of the soil is Profondic Luvisols, which is very deep (>150cm) and well-drained. The pH value of the surface soil varies from 4.23 to 5.4, and is rated as extremely to strongly acidic. When moist, it has dark brow (7.5 YR2.5/2) color, clay loam texture, and moderate medium sub angular blocky structure (Abaineh, 2003). The CEC (19.2 to 23 cmol (+)/kg soil) and base saturation (41 to 54%) of the soil are medium. He further reported that the organic matter and total nitrogen content ranges from 0.99-4.51% and 0.056-0.37%, respectively, which is rated as very low to high for both parameters. Available P content is low (0.12 to 4.62 mg kg⁻¹).

Areka

Areka research center is found in western part of Wolaita zone, Southern Ethiopia on a very gently undulating topography with a gradient of 0 - 10% slope and altitude ranging from 1730 to 1840 masl in and around the center. Its geographic extent is 7° 3' 26" to 7° 4' 24" northern latitude and from 37° 40' 52" to 37° 41' 30" eastern longitude. It receives mean annual rainfall of 1520 mm in a bi-modal pattern with extended rainy season from March to September (Abaineh and Ashenafi, 2003). The mean annual maximum temperature is 26°C, whereas the mean annual minimum is 14°C. The area is thus endowed to have 240 consecutive days of length of growing season (LGP) and with SH₂ agro-ecology. The soil of the center is Haplic Alisols, which is very deep (>150cm), very dark brown (10 YR2/1.5) to black (7.5 YR3/1) in color and clay loam to silt loam in texture. The pH_{H₂O} of surface soil is 4.7 and it increases to 6.0 in subsurface horizons. Abaineh (2003) reported that both the CEC (10 to 32 cmol_c kg⁻¹ soil) and base saturation (18 to 69%) of the soils are low to high, values decreasing with depth. The soil has got 0.3 to 9.7% organic carbon (OC), which is rated as low to medium. He further noted that available P (Olsen) content of the center's soil is <4.2 mg kg⁻¹, which is rated as low for most of the crops. Total nitrogen content varied from 0.01 to 0.53% and is rated as very low to medium.

Awassa

Awassa Agricultural Research Center is found in the central part of the Great Rift Valley (Southern Ethiopia), geographic extent that ranges from 07° 03' 19.1" to 07° 04' 00.2" north latitude and from 38° 31' 08" to 38° 31' 01.8" east longitude. It is located on an undulating topography with altitude ranging from 1695 to 1713 masl. It receives mean annual rainfall of about 948 mm. It has a bimodal rainfall pattern with extended rainy season from March to September. Its mean annual maximum and minimum temperatures are 27.3°C and 12.6°C, respectively. It is endowed with 200- 240 consecutive length of growing period (LGP) and a tepid to cool sub humid (SH₂) in agro-ecology.

According to Abaineh *et al.* (2006), the soil type of the farm is Vitric Andosols with 80-152 cm depth and its slope ranges from 0-2%. The soil is slightly acidic to neutral with the top soil (0-30 cm) pH values ranging between 6.4 and 6.9. Its total N content varied between 0.165 and 0.270%, which is rated as low to medium. It has got low organic carbon content (2.1- 3.0 %). The farm has very high available P (34.2- 164.6 mg kg⁻¹), which might have been accumulated as a result of continuous phosphatic fertilizer application for the last almost half a century by both the then Awassa Agro-

industry and lastly by the research center itself. That is why no response to P application had been recorded for different crops at the center (Kelsa, 1998, 1988a, b). Cation exchange capacity (CEC) of the soil is in the range of 17.4- 39.8 cmol(+) kg⁻¹ soil, which is medium to high and is highly base saturated (76- 96%).

The experiments were conducted on 4m x 4m plot size at Awassa and Areka, and on 3m x 4m plot size at Bobicho. Verification trials were conducted in the third years of the experiment on both farmers' fields and on the research sites using 10m x 10m plot size. Four levels of N (0, 23, 46, and 69 kg N ha⁻¹) and five levels of P (0, 10, 20, 30 and 40 kg P ha⁻¹) were applied in the form of Urea and TSP, respectively, at Bobicho. In Awassa and Areka, however three levels of urea (0, 50 and 100kg/ha) and five levels of DAP (0, 50, 100, 150 and 200 kg/ha) were used. All experiments were conducted in a factorial randomized complete block design in three replications. Urea was applied in a split: half of the suggested dose at planting and the remaining half at a month after planting when the soils were moist and all the weeds were removed. All doses of DAP and TSP were applied at planting. Medium maturing tef variety 'Ajora' was sown at Bobicho; whereas, late, medium and early maturing varieties 'DZ- 01- 354', 'DZ-01-196' and 'Dhabi', respectively, were sown at Areka and Awassa at a rate of 25 kg/ha seed.

Thirty surface soil samples (0-30 cm) were randomly (following zigzag way) collected and composited before planting. At harvest, eight surface soil samples were collected from every plot and composited for each plot. Soil analysis was done following the procedures in laboratory manual prepared by Sahlemedhin Sertso and Taye Bekele (2000). The soil samples were air dried and ground to pass 2 mm sieve and 0.5 mm sieve (for total N) before analysis. The pH of the soil was measured in 1:2.5 (soil: water) ratio. Organic carbon content of the soil was determined following the wet combustion method of Walkley and Black. Total nitrogen content of the soil was determined by wet-oxidation (wet digestion) procedure of Kjeldahl method. The available phosphorus content of the soil was determined by Bray II method as the experimental soil is acidic.

Teff yield data were statistically analyzed using the proc Glim function of SAS and means were compared using LSD at a probability level of 5 %. The economic value of applied fertilizer was analyzed using value cost ratio (the ratio between the value of the extra yield obtained by using fertilizer and the cost of the fertilizer applied) method taking only value cost ratio greater than 2 as economical. Current prices of commodities were considered for the economic analysis.

Results and Discussion

Soil properties as influenced by application of increasing levels of NP fertilizers

The analysis result of composite soil samples collected before planting indicated that soil of Bobicho was extremely acidic with pH value of 4.23. The soil pH on treatment plots was increased after harvest ranging from 4.60 to 5.40, which is still in a position to inhibit the availability of most plant nutrients. Like wise, organic matter content of the top soil (0 – 30 cm) also was slightly increased for post harvest samples, which might be attributed to decays of weeds and roots of the test crop and/or reduction of organic matter decomposition rate during the growing period of the crop. Total N content did not show much variation as compared to the before planting data (Table 1). This might be attributed to uptake by the crop during growing period. On all higher N dose treatments (46 and 69 kg N ha⁻¹), the crop was lodged indicating that it took up excessive N. Soil test N was very highly correlated with organic matter content ($r=0.87^{***}$) (Table 4).

The available P content of the soil with no P treatments was reduced from the initial value. The soil P content increased only in the treatments with highest P application (40 kg P ha⁻¹). However, the increment is small (1.5 mg kg⁻¹), which might be attributed to P uptake by the crop and fixation as the

soil is strongly acidic. According to Pushparajah (1997), who classified available P as low ($< 11 \text{ mg kg}^{-1}$), medium ($11\text{-}20 \text{ mg kg}^{-1}$), high ($20\text{-}30 \text{ mg kg}^{-1}$), and very high ($> 30 \text{ mg kg}^{-1}$), both before planting and after harvest, available P values are rated as low indicating phosphorus is deficient in the soil of the experimental site. The available P was very highly correlated with applied P ($r=0.67^{***}$).

Yield and yield components of teff as influenced by application of increasing levels of NP fertilizers

The result of the experiment conducted at Bobicho indicated that, though statistically not significant, teff grain yield was slightly increased with application of 23 kg/ha N, which gave 386 kg/ha yield advantage over the control. The grain yield gradually decreased with additional use of N. On the other hand, the use of 10 kg/ha P alone increased teff grain yield from 788 to 1377 kg/ha with a 75% yield increment. Phosphorus influenced teff grain yield very highly significantly ($P < 0.0001$) and the mean maximum of 1571 kg/ha was obtained from application of 30 kg/ha P. Though the maximum yield of 1606 kg/ha was obtained with the use of 23/30 kg/ha N/P, no significant response was recorded from the interaction of N and P (Table 2).

Teff straw yield was also very highly significantly ($P < 0.0001$) influenced by application of N and P fertilizers, but not by their interactions. Straw yield increased from 5167 – 6958 kg/ha when N levels increased from 0 - 46 kg/ha, but declined with further N addition. Mean yield continuously increased with increased levels of P from 0 to 30 kg/ha, but it was declined with further P application (Table 3). The maximum teff grain and straw yields were obtained with the application of 30 kg/ha P. Phosphorus was highly correlated with grain yield ($r=0.23^{**}$) and straw yield ($r=0.3^{**}$). There was also positive correlation between grain and straw yields ($r=0.95^{***}$) (Table 4). Taking the values of both grain and straw yields into account, gross benefit increased from birr 16,250 to 25,082, with corresponding DAP rates from 0 – 150 kg/ha. Value cost ratios of 10.83, 4.51 and 3.87 were obtained with the use of 50, 100 and 150 kg/ha DAP, respectively. However, the gross benefit was declined and the corresponding VCR became negative when the amount of DAP was increased to 200 kg/ha (Table 5) suggesting that the amount of DAP should not exceed 150 kg/ha for teff production on Profondic Luvisols of Bobicho

The findings of the experiment conducted on Haplic Alisols of Areka indicated that there was no variation among the different maturity groups of tef varieties in response to fertilizer application. Yield of all the three tested teff varieties were not influenced by the application of nitrogen; whereas, it was highly significantly influenced by the application of P. For the first 10 kg/ha P applied in the form of DAP, an additional mean grain yield of 394 kg/ha as compared to the control was obtained. But thereafter, mean grain yield was increased at a decreasing rate despite that the use of 100 kg/ha DAP gave statistically significantly higher yield than 50 kg/ha (Table 6).

The net economic benefit obtained from the sales of both grain and straw was progressively increased when DAP up to 100 kg/ha. The highest VCR (10.43) was obtained with the application of 50 kg/ha DAP followed by 3.54 with the application of 100 kg/ha DAP. The VCR was fallen below 1.0 with additional application of DAP suggesting that the fertilizer rate for teff production on Haplic Alisols of Areka should not exceed 100 kg/ha DAP (Table 7).

There was no response of all the three tef varieties to the application of both fertilizers (DAP and urea) at Awassa (Table 8). The finding was verified both on farm (10mx10m plot size) and station (in large scale). As a result, it was concluded that there is no need of applying any type of fertilizer for teff production at Awassa irrespective of varietal differences (Kelsa, 1998). This indicates that the soil is not deficient in N and P. An experiment conducted on NP requirement of sunflower also indicated that the soil was not deficient in these nutrients (Kelsa Kena, 1988a).

Conclusion and Recommendations

Teff production is widely practiced in Ethiopia on different soils, which respond differently to the use of fertilizers. Application of organic fertilizers on crops like teff, which are grown in large acreage, is also a difficult area of intervention. Thus wise use of inorganic fertilizers supported by economic feasibility is of paramount importance. Straw yield has also considerably contributed to the economic benefit of fertilizer use for teff production on different soils.

Accordingly, on Profondic Luvisols of Bobicho, around Hossana, teff grain yield was highly significantly increased due to P fertilizer application, whereas the straw yield was highly significantly increased with the use of both N and P fertilizers. The economic analysis result, taking the values of both teff grain and straw yields into consideration, indicated that gross benefit was considerably increased for the use of DAP at rates ranging from 50 to 150 kg/ha. Thus, application of 50 to 150 kg/ha is recommended depending on the availability of the fertilizer and affordability of the farmer.

On Haplic Alisols of Areka, there was no response to N application for teff production. However, both grain and straw yields were highly significantly increased due to application of P. The gross benefit was considerably increased with application DAP until the level of 100 kg/ha, but increased at a decreasing rate with further increase of DAP. The VCR varied between 10.43 and 3.54, for the use of DAP at 50 to 100 kg/ha, respectively. Consequently, application of 50 to 100 kg/ha DAP is recommended for teff production on Haplic Alisols of Areka.

For tef yield was not influenced by application of fertilizers, no fertilizer use is recommended for teff production on Vitric Andosols of Awassa irrespective of variations in variety.

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Table 1. Selected soil chemical properties as influenced by application of NP fertilizers at Bobicho Research Site, Hossana

N/P (kg ha ⁻¹)	Soil pH (H ₂ O)	OC (%)	OM (%)	Av. P, Olsen (mg kg ⁻¹)	Total N (%)
0/0	4.89	1.2	2.07	1.0	0.16
0/10	4.60	1.16	2.00	1.5	0.16
0/20	4.80	1.25	2.33	1.5	0.16
0/30	5.04	1.41	2.43	1.5	0.18
0/40	4.91	1.14	1.97	2.5	0.16
23/0	4.71	1.56	2.69	1.0	0.19
23/10	4.80	1.50	2.59	0.5	0.19
23/20	4.90	1.21	2.09	1.0	0.21
23/30	4.86	0.60	1.03	1.0	0.11
23/40	4.81	1.02	1.76	3.0	0.15
46/0	4.74	1.80	3.10	0.5	0.22
46/10	4.73	1.20	2.07	1.5	0.16
46/20	5.40	1.30	2.24	1.0	0.16
46/30	5.10	1.37	2.19	1.0	0.17
46/40	4.95	0.94	1.62	1.5	0.14
69/0	4.88	1.00	1.72	1.0	0.15
69/10	4.73	1.01	1.74	1.0	0.15
69/20	4.86	1.30	2.24	1.5	0.17
69/30	4.77	1.16	2.00	1.0	0.16
60/40	4.7	1.19	2.05	3.0	0.16
Composite (0/0)	4.23	0.62	1.07	1.5	0.18

Table 2. Mean teff grain yield (kg/ha) as influenced by NP fertilizer use on Profondic Luvisols of Bobicho

N levels (kg ha ⁻¹)	P levels (kg ha ⁻¹)					N mean
	0	10	20	30	40	
0	788	1377	1336	1563	1582	1329
23	1174	1245	1546	1606	1606	1440
46	1058	1400	1366	1585	1562	1403
69	976	1287	1577	1501	1440	1370
P mean	999	1329	1461	1571	1557	1386
	N	P	N*P			
LSD, 5 % :	NS	131.76	NS			
CV (%) :	16.56					

Table 3. Mean teff straw yield (kg/ha) as influenced by NP application on Profondic Luvisols of Bobicho

N levels (kg ha ⁻¹)	P levels (kg ha ⁻¹)					N mean
	0	10	20	30	40	
0	5167	7750	7708	8833	9083	7708
23	6417	7708	9000	9625	9750	8505
46	6958	8083	8875	9125	9083	8434
69	6500	8208	9167	9875	8750	8514
P mean	6260	7940	8693	9372	9177	8290
	N	P	N*P			
LSD, 5 % :	598.21	597.62	NS			
CV (%) :	14.05					

Table 4. Correlations among fertilizers, crop and soil parameters

	Nap	Pap	Year	N soil	P soil	OM	pH	Gy	By
Nap	1	0	0	-0.11	-0.08	-0.11	0.27	0.02	0.07
Pap		1	0	-0.4	0.67***	-0.43	0.28	0.23**	0.30**
Year			1	0	0	0	0	-0.87***	-0.85***
N soil				1	-0.33	0.87***	-0.09	-0.30	-0.015
P soil					1	-0.28	-0.19	0.15	-0.02

OM	1	-0.06	-0.36	-.22
pH		1	0.30	0.14
Gy			1	0.37
By				1

Nap - applied N, Pap - applied P, N soil - soil test N, P soil - soil test P, OM - organic matter, Gy - grain yield, By - biomass yield

** Significant at p=0.001, *** significant at p=0.0001

Table 5. Economic Analysis for teff production at Hossana using VCR as an indicator

DAP (kg/ha)	Fertilizer Cost, (Birr)	Benefit (Birr) from sales of		Gross benefit (Birr)	VCR
		Grain	Straw		
0	0	9990	6260	16250	-
50	460	13290	7940	21230	10.83
100	920	14610	8693	23303	4.51
150	1380	15710	9372	25082	3.87
200	1840	15570	9177	24747	(0.73)

Table 6. DAP and Urea fertilizers effect on mean tef grain yield (kg/ha) on Haplic Alisols of Areka

Urea, kg/ha	DAP kg/ha					N Mean
	0	50	100	150	200	
0	708	1081	1178	1238	1222	1085
50	659	1059	1230	1228	1288	1093
100	753	1159	1194	1231	1224	1112
P Mean	706c	1100b	1201a	1232a	1245a	1097

Means in a column with different letters are significantly different (P<0.05).

Significance:

P- **

N- NS

Interaction- NS

CV= 16.47%

Table 7. Economic Analysis for teff production at Areka using Value Cost Ratio as an indicator

DAP, Kg/ha	Fertilizer Cost	Benefit (Birr) from sales of		Gross Benefit	VCR
		Grain	Straw		
0	0	7060	2535	9595	-
50	460	11000	3392	14392	10.43
100	920	12010	4011	16021	3.54
150	1380	12320	4134	16454	0.94
200	1840	12450	4279	16729	0.60

Table 8. Response in grain yield of teff (kg/ha) to NP fertilizers (kg/ha) on Vitric Andosols of Awassa

Urea, kg/ha	DAP, kg/ha					Urea Mean
	0	50	100	150	200	
0	1005	1003	918	994	1007	985
50	962	935	994	1033	1007	986
100	952	1010	1022	988	952	985
DAP Mean	973	983	978	1005	989	

Significance:

P- NS
 N- NS
 Interaction- NS

CV= 15.73%

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