Refining of recommended fertilizer rates for teff production systems in Takusa district, Northern Ethiopia

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Abstract

In Ethiopia, including Takusa district appropriate fertilizer management was the major problem accounted for low productivity of teff. Therefore, a field experiment was conducted with the objective of investigating the effect of nitrogen, phosphorus, potassium and sulfur levels on yield and related components of teff at Takusa district, Northern Ethiopia during the rainy seasons of 2014 and 2015. The treatments consisted of 8 rates of Nitrogen (0, 23,46, 69, 92,115, 138 and 161 kg ha^{-1} N), 6 rates of Phosphorus (0, 11, 22, 33, 44 and 55 kg ha^{-1} P), 6 rates of Potassium (0, 15, 30, 45, 60 and 75 kg ha^{-1} K) and 6 rates of sulfur (0, 10, 20, 30, 40 and 50 kg ha^{-1} S) arranged in randomized complete block design for each experiment. Other non-experimental elements (N, P, K, S, Zn and B) were applied to the same amount as basal fertilizer application. The result revealed that the effect of nitrogen fertilizer have significant effect on combined average value of plant height, panicle length, number of effective tiller per plant, above ground biomass and grain yield of teff. Besides, the effect of Phosphorus fertilizer have significant effect only on combined average value of above ground biomass and grain yield of teff. However, all a result, the maximum average biological grain yield of 1.89 ton ha^{-1} was harvested at 161 kg ha^{-1} N, and 1.74 ton ha^{-1} was harvested at 44 kg ha^{-1} P application. Finally, based on partial budget analysis, application of 69 kg ha^{-1} N and 22 kg ha^{-1} P are optimum rates for teff (Quncho variety) production. Therefore, it is indispensable to use this recommendation for Takusa area and similar agroecologies.

Key words: Nitrogen, phosphorus, potassium, quncho, sulfur,

Introduction

Teff [Eragrostis tef (Zucc.) Trotter] is a cereal crop resilient to adverse climatic and soil conditions, It grows with varying annual rainfall of 750-850 mm and temperatures between 10 and 27^oC (Seyfu, 1993). Interestingly, teff can thrive well in both waterlogged and drought conditions. It is occupying about 22.6% of the cultivated land from the total area of cereals (86.06%) with accounting 16% of the grain production in Ethiopia (CSA, 2012).

Despite its versatility in adapting to extreme environmental conditions, the productivity of teff is very low with the national average standing at 1.5 ton ha^{-1} (CSA, 2014). Which could be the result of a decline in the soil fertility due to high soil erosion and others, and unbalanced chemical fertilizer application. Currently a large portion of Ethiopian Institute of Agricultural Research (EIAR) resources is focused on testing crop yield response to N and P fertilizers, and regional tailoring of DAP and Urea fertilizer recommendations, as these were the priorities identified from the Murphy studies in the 1950s-60s (Gete *et al*., 2010) or more often, a single recommendation for all crops (100 kg DAP (18-46-0) and 100 kg Urea (46-0-0). This blanket recommendation often fails to take into consideration differences in resource endowment (soil type, labor capacity, climate risk) or make allowances for dramatic changes in input/output price ratio, thereby discouraging farmers from fertilizer application.

Moreover, the nutrients in the blanket recommendation are not well balanced agronomically and its continued use will gradually exhaust soil nutrient reserves. Therefore neither yields nor profits can be sustained using imbalanced application of fertilizers, as the practice results in accelerating deficiencies of other soil nutrients. This could explain, in part, the modest crop yield improvements observed over the last few decades in contrast to significant increases in fertilizer use and investment made in the country. Today, in addition to N and P, S, B and Zn deficiencies are widespread in Ethiopian soils, while some soils are also deficient in K, Cu, Mn and Fe (Ethio SIS, 2014). To overcome the constraint of low nutrient recovery and optimize fertilizer use, there is a need to replace such general and over-simplistic fertilizer recommendations with those that are rationally differentiated according to agro-ecological zones (soils and climate), crop types, nutrient uptake requirements and socio-economic circumstances of farmers. Better matching fertilizer application recommendations to local climate, soil, and management practices helps ensure that production can be intensified in a cost-effective and sustainable way and, thereby, enhance regional food security. The objective of this study was therefore to determine soil- crop specific optimum N, P, K and S fertilizer rates for teff.

Materials and Methods

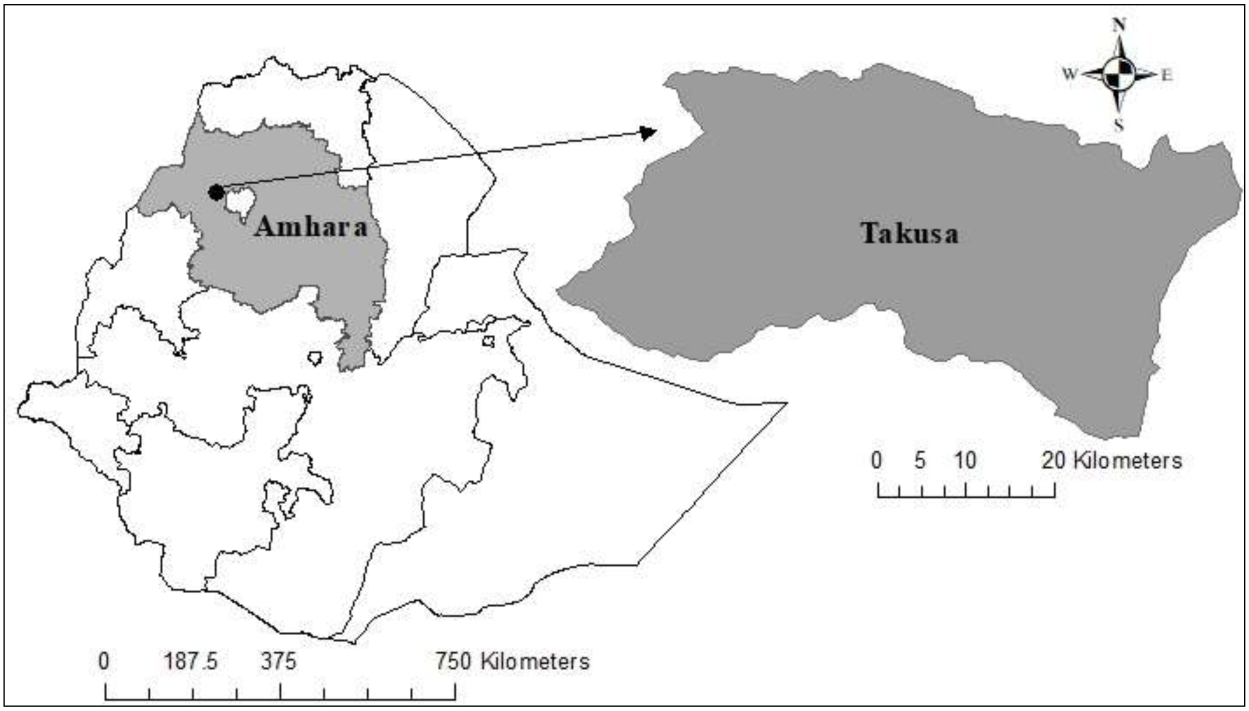
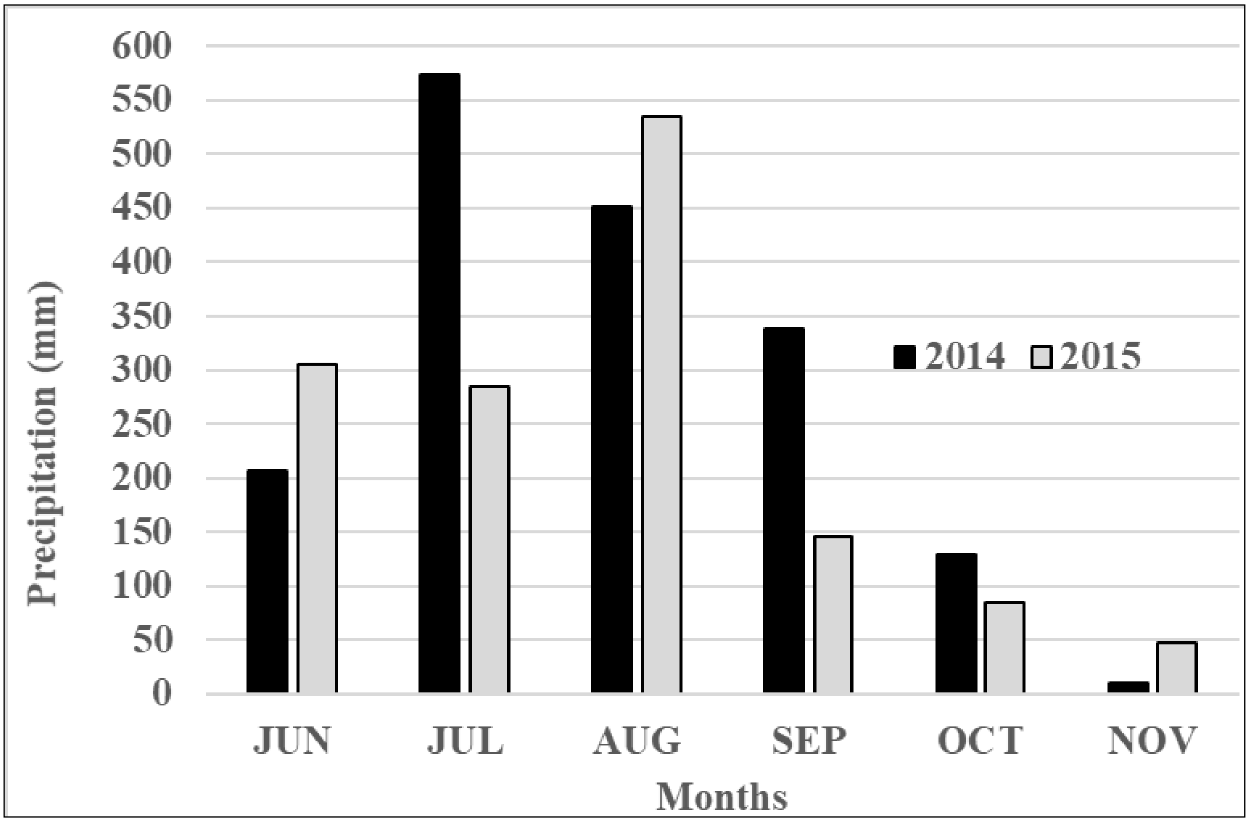


Figure 1. Location map of the Takusa district

The experiment was conducted on farm under rain fed conditions in the 2014 and 2015 cropping seasons at Takusa district located at 12°I0' N and 37°01' E with an altitude of 1780 m a.s.l. (Figure 1). The dominant soil type of the district is vertisol. The area received an annual rain fall of 2051.22 mm, minimum temperature of 16.41° C and maximum temperature of 25.86° C during the year 2014. It also received an annual rain fall of 1560.51 mm, minimum temperature of 17.02° C and maximum temperature of 27.07° C in 2015. The area received the highest rainfall in july 2014 (572.83 mm) and august 2015 (535.25 mm) cropping seasons (Figure 2).

The trial considered four independent set of experiments in each site. Hence, at each location the different rates of N, P, K and S (but not as a factorial) with three replications having sufficiently large amounts of basal fertilizer application for the other three nutrients (Table 1) were considered. All fertilizer treatment combinations were laid out in Randomized Complete Block Design (RCBD) with three replications per site and also replicated across three farmers' fields. The plot size was 3m x3m with 1.5m in between blocks and 1m in between plots. Quncho variety was planted in rows at seed rates of 25 kg ha^{-1} and 20 cm space in between rows. Other agronomic practices were considered as recommended to the area. The collected data were analyzed using the SAS (2002) and Statistix (2013) statistical software. Analyses of variance (ANOVA) were performed to evaluate the effects of treatments (N, P, K and S rates),

Figure 2. Rainfall in 2014 and 2015 cropping season at Takusa district (Source:



https://power.larc.nasa.gov)

experimental sites, years, and their interactions on plant characteristics and yield parameters. Comparisons among treatment means were made using the LSD tests.

For economic analysis, the variable cost of fertilizer were taken at the time of planting and during other operations. Price of teff grain and straw were considered. Yield from experimental plots was adjusted downwards by 10% for management difference, to reflect the difference between the experimental yield and the yield that farmers could expect from the same treatment. Accordingly, the economic response of teff for fertilizer treatments were subjected to partial budget analysis using the procedures outlined by CIMMYT (1988). In this study, 100% return to the investments was used as reasonable minimum acceptable rate of return.

Table1. Treatment and basal fertilizer application rates

Nitrogen rates (N kg ha^{-1}) (Experiment1)	Basal application (kg ha^{-1})				
	P_2O_5	K_2O	S	Zn	B
0, 23,46, 69, 92,115, 138,161	69	80	30	5	1
Phosphorus rates (P kg ha^{-1}) (Experiment 2)	Basal application (kg ha^{-1})				
	N	K_2O	S	Zn	B
0,11,22,33,44,55	92	80	30	5	1
Potassium rates (K kg ha^{-1}) (Experiment 3)	Basal application (kg ha^{-1})				
	N	P_2O_5	S	Zn	B
0,15,30,45,60,75	92	69	30	5	1
Sulfur rates (S kg ha^{-1}) (Experiment 4)	Basal application (kg ha^{-1})				
	N	P_2O_5	K_2O	Zn	B
0,10,20,30,40, 50	92	69	80	5	1

Source: P=TSP, K= KCl, S= $CaSO_4$, Zn=$ZnSO_4$, B = Borax

Results and Discussions

Response of Teff to N

The two years combined analysis of variance (ANOVA) result showed that the effect of different N rates significantly affected plant height, panicle length, number of effective tiller per plant, above ground biomass and grain yield of teff (Appendix Table 1). In addition, the ANOVA result for each year indicated that there was significant plant height, above ground biomass and grain yield difference among the nitrogen fertilizer rates (Appendix Table 1).

The combined analysis showed that maximum plant height (123.59 cm) was recorded at 138 kg ha^{-1} of N; while the lowest plant height (81.44 cm) was recorded in the control plots (no nitrogen fertilizer). The maximum number of effective tiller per plant was recorded at 161 kg ha^{-1} of N, but the maximum panicle length (cm) and biomass (ton ha^{-1}) was recorded at 138 kg ha^{-1} of N respectively; and the minimum was recorded in the control plots. Increase of grain yield was observed as the N fertilizers application increased. Application of 161 kg ha^{-1} N fertilizer resulted in the highest biological grain yield of teff, 1.89 ton ha^{-1}, with a yield advantage of 923.48 kg ha^{-1} over N unfertilized treatment (0.97 ton ha^{-1}) (Table 2). These results concurred with the study of Temesgen (2001) who observed a significant biomass and yield response to N on vertisols in the central highlands of Ethiopia.

Table 2. Effect of Nitrogen rates on the grain yield and yield components of teff at Takusa district.

Rates of N (kg ha^{-1})	Plant height (cm)	Panicle length (cm)	Number of effective tiller per plant	Above ground biomass (ton ha^{-1})	Grain yield (ton ha^{-1})
Year 2014					
0	81.53^{e}	34.56	1.69	2.69^{c}	1.06^{e}
23	101.24^{cde}	40.18	2.27	4.52^{b}	1.47^{d}
46	99.40^{de}	35.36	2.11	5.73^{b}	1.72^{c}
69	117.18^{bcd}	41.16	2.11	8.90^{a}	2.11^{b}
92	122.11^{bc}	42.29	2.07	8.43^{a}	2.01^{b}
115	119.62^{bcd}	40.76	2.27	8.35^{a}	2.09^{b}
138	148.18^{a}	43.11	2.73	9.80^{a}	2.00^{b}
161	124.27^{b}	42.20	2.76	8.71^{a}	2.41^{a}
LSD (0.05)	22.65	7.18	0.78	1.80	0.24
CV (%)	20.90	18.95	36.65	26.55	13.36
Year 2015					
0	81.36^{c}	32.10^{c}	1.47	3.04^{c}	0.87^{d}
23	89.96^{b}	35.63^{b}	1.48	3.46^{c}	0.99^{cd}
46	97.53^{ab}	37.86^{ab}	1.61	4.63^{b}	1.25^{ab}
69	99.43^{a}	39.06^{a}	1.61	5.29^{b}	1.34^{ab}
92	102.17^{a}	37.26^{ab}	1.74	4.65^{b}	1.15^{bc}
115	100.36^{a}	37.81^{ab}	1.62	6.43^{a}	1.43^{a}
138	99.00^{a}	36.9^{ab}	1.71	7.13^{a}	1.45^{a}
161	101.73^{a}	37.19^{ab}	1.66	6.61^{a}	1.36^{a}
LSD (0.05)	7.74	3.07	0.25	0.76	0.20
CV (%)	8.46	8.82	16.65	15.62	16.93
Combined					
0	81.44^{e}	33.33^{b}	1.58^{b}	2.87^{f}	0.97^{f}
23	95.60^{d}	37.91^{a}	1.87^{ab}	3.99^{e}	1.23^{e}
46	98.47^{cd}	36.61^{ab}	1.86^{ab}	5.18^{d}	1.49^{d}
69	108.31^{bc}	40.11^{a}	1.86^{ab}	7.09^{bc}	1.73^{bc}
92	112.14^{ab}	39.77^{a}	1.91^{ab}	6.54^{c}	1.58^{cd}
115	109.99^{bc}	39.28^{a}	1.94^{ab}	7.39^{bc}	1.76^{ab}
138	123.59^{a}	40.01^{a}	2.22^{a}	8.46^{a}	1.73^{bc}
161	113.00^{ab}	39.69^{a}	2.21^{a}	7.66^{ab}	1.89^{a}
LSD (0.05)	11.77	3.85	0.43	0.97	0.16
CV (%)	16.89	15.18	33.97	23.76	15.42

Response of Teff to phosphorus

The combined analysis of variance (ANOVA) result showed that the effect of different P rates significantly affected above ground biomass and grain yield of teff, however plant height, panicle length and number of effective tiller per plant didn't respond for applied P fertilizer (Appendix Table 2).

The maximum combined mean value of above ground biomass (6.86 ton ha^{-1}) was obtained from plots that was treated with 33 kg ha^{-1} P, which was statistically par from plots that was treated with 11, 22, 44 and 55 kg ha^{-1} P (Table 3). The lowest value for above ground biomass (5.65 ton ha^{-1}) was obtained from not P fertilized plots. The maximum combined mean value of grain yield (1.74 ton ha^{-1}) was obtained from plots that was treated with 44 kg ha^{-1} P, The lowest value for grain yield (1.36 ton ha^{-1}) was obtained from plots that received 11 kg ha^{-1} P, which was statistically par from plots that was not P fertilized (1.51 ton ha^{-1}) (Table 3). Consistent with these results, Temesgen (2012) reported significantly higher number of tillers, plant height, and panicle length in response to the application of high N rate in teff but not for P.

Table 3. Effect of Phosphorus rate on the grain yield and yield components of teff at Takusa

Rates of P (kg ha^{-1})	Plant height (cm)	Panicle length (cm)	Number of effective tiller per plant	Above ground biomass (ton ha^{-1})	Grain yield (ton ha^{-1})
Year 2014					
0	118.8	39.82	1.84	7.67	2.07^{a}
11	123.56	43.09	1.87	8.04	1.58^{b}
22	121.58	44.60	2.18	7.89	1.98^{a}
33	115.27	38.38	1.84	8.21	2.06^{a}
44	119.4	41.07	1.64	8.41	2.20^{a}
55	120.67	44.49	1.87	8.35	2.03^{a}
LSD (0.05)	9.78	5.36	0.50	1.10	0.33
CV (%)	8.52	13.36	27.7	14.19	17.47
Year 2015					
0	87.86^{c}	34.50	1.27^{b}	3.63^{b}	0.95^{b}
11	91.92^{bc}	35.64	1.31^{b}	4.73^{ab}	1.13^{ab}
22	101.58^{ab}	38.38	1.74^{a}	5.28^{a}	1.34^{a}
33	100.01^{ab}	38.19	1.67^{a}	5.50^{a}	1.26^{a}
44	101.74^{a}	38.12	1.70^{a}	5.20^{a}	1.29^{a}
55	100.74^{ab}	38.26	1.53^{ab}	5.01^{a}	1.22^{a}
LSD (0.05)	9.81	3.81	0.30	1.18	0.24
CV (%)	10.52	10.69	20.45	25.2	20.73
Combined					
0	103.33	37.16	1.56	5.65^{b}	1.51^{bc}
11	107.74	39.37	1.59	6.39^{ab}	1.36^{c}
22	111.58	41.49	1.96	6.58^{a}	1.66^{ab}
33	107.64	38.28	1.76	6.86^{a}	1.66^{ab}
44	110.57	39.59	1.67	6.80^{a}	1.74^{a}
55	110.71	41.37	1.70	6.68^{a}	1.63^{ab}
LSD (0.05)	6.70	3.19	0.30	0.80	0.20
CV (%)	9.28	12.12	26.65	18.48	18.68

Response of Teff to K

The two consecutive years of combined ANOVA result indicated that the different K fertilizer rates did not significantly affected plant height, panicle length, number of effective tillers per plant, above ground biomass and grain yield of teff (Appendix Table 3).

The combined mean value of grain yield obtained from plots that was not treated with K (1.75 ton ha^{-1}) was statistically par from plots that was treated with 15, 30, 45, 60 and 75 kg ha^{-1} K (Table 4). The result contradicts the research findings of Yohannes *et al*. (2019) who reported plant height, panicle length, number of effective tillers, dry matter and grain yield of teff increased significantly with applied K on vertisols of East Gojjam. On the other way, the present result contradicts the findings of Dagne (2016) and Fayera *et al*. (2014) whom recommended to include potassium in blended fertilizers.

Table 4. Effect of Potassium rate on the grain yield and yield components of teff (quncho variety) at Takusa area

Rates of K (kg ha^{-1})	Plant height (cm)	Panicle length (cm)	Number of effective tiller per plant	Above ground biomass (ton ha^{-1})	Grain yield (ton ha^{-1})
Year 2014					
0	114.36	38.13	1.89[a]	8.13	2.12
15	115.62	39.91	2.04[a]	7.77	2.12
30	140.07	39.82	1.64[ab]	7.99	2.14
45	115.82	39.02	1.44[b]	8.15	2.05
60	124.84	41.96	1.67[ab]	8.40	2.14
75	122.84	42.71	1.98[a]	8.32	2.24
LSD (0.05)	27.34	5.48	0.42	1.32	0.30
CV (%)	23.34	14.2	24.38	16.89	14.61
Year 2015					
0	100.37	39.33	1.61	5.70	1.39
15	97.08	38.97	1.62	5.25	1.29
30	95.96	36.44	1.86	5.59	1.31
45	96.49	36.43	1.60	5.43	1.28
60	100.96	39.17	1.98	5.97	1.38
75	93.78	35.98	1.70	5.69	1.30
LSD (0.05)	7.07	3.24	0.38	0.54	0.18
CV (%)	7.57	8.97	23.05	10.13	14.55
Combined					
0	107.36	38.73	1.75	6.92	1.75
15	106.35	39.44	1.83	6.51	1.70
30	118.01	38.13	1.75	6.79	1.72
45	106.16	37.73	1.52	6.79	1.67
60	112.90	40.56	1.82	7.18	1.76
75	108.31	39.34	1.84	7.01	1.77
LSD (0.05)	13.92	3.09	0.27	0.72	0.19
CV (%)	19.06	11.93	23.49	15.68	16.2

Response of Teff to S

Like K fertilizer application, combined ANOVA result indicated that the different S fertilizer rates did not significantly affected plant height, panicle length, number of effective tiller, above ground biomass and grain yield of teff (Appendix Table 4).

The combined mean value of grain yield obtained from plots that was not treated with S (1.67 ton ha^{-1}) was statistically par from plots that was treated with 10, 20, 30, 40 and 50 kg ha^{-1} S

(Table 5). In contrast to the present result, Habtegebrial and Singh, (2006) were reported that the grain yield of teff was improved with S fertilization which is a 33% increase, compared with those treatments without S at Tigray national regional state, Ethiopia.

Table 5. Effect of Sulfur rate on the grain yield and yield components of teff (quncho variety) at Takusa

Rates of S (kg ha^{-1})	Plant height (cm)	Panicle length (cm)	Number of effective tiller per plant	Above ground biomass (ton ha^{-1})	Grain yield (ton ha^{-1})
Year 2014					
0	115.73	41.22	1.92	7.47	1.91
10	121.71	39.80	2.20	8.12	1.99
20	120.64	39.89	1.76	7.56	1.98
30	117.36	36.98	1.62	7.90	2.00
40	116.36	39.51	1.80	7.82	2.07
50	120.51	42.51	2.09	8.31	2.05
LSD (0.05)	10.04	5.53	0.59	1.04	0.28
CV (%)	8.83	14.43	30.9	13.81	14.47
Year 2015					
0	94.98	36.18	1.78	5.52	1.43
10	98.19	38.42	1.68	4.97	1.31
20	98.36	38.64	1.74	5.49	1.36
30	96.69	37.32	1.77	5.51	1.42
40	103.68	36.68	1.89	5.78	1.50
50	107.54	36.84	1.82	5.73	1.45
LSD (0.05)	14.63	3.68	0.33	0.53	0.16
CV (%)	15.29	10.3	19.26	9.98	11.48
Combined					
0	105.36	38.70	1.84	6.49	1.67
10	109.95	39.11	1.94	6.54	1.65
20	109.50	39.27	1.75	6.53	1.67
30	107.02	37.15	1.69	6.70	1.71
40	110.02	38.09	1.84	6.80	1.79
50	114.03	39.68	1.96	7.02	1.75
LSD (0.05)	8.89	3.23	0.33	0.57	0.15
CV (%)	12.24	12.56	26.05	12.92	13.59

Economic Analysis

The result of this trial encourages to recommend N and P fertilizers, but the need of K and S fertilizers are rejected through statistical evidences. Morover, the partial budget analysis of the present experiment showed that the maximum net benefit of 15734.75 ETB ha^{-1} and marginal rate of return (MRR) of 561.74% were obtained from application of 69 kg ha^{-1} N. The maximum net benefit of 14761.80 ETB ha^{-1} with MRR value of 79.86% (which is below 100%) were obtained from application of 44 kg ha^{-1} P, but the second large and un-dominated net benefit of 14291.40 ETB ha^{-1} with the MRR value of 280.79% was obtained from application of 22 kg ha^{-1} P. Therefore, for every 1.0 ETB invested in N application farmers can expect to recover their 1.0 ETB, and obtain an additional 5.6 ETB; and for every 1.0 ETB invested in P application farmers can expect to recover their 1.0 ETB and obtain an additional 2.8 ETB in teff production at Takusa area.

Table 6. The partial budget analysis

Fertilizer rate (kg ha^{-1})	Adjusted yield (ton ha^{-1})	Straw (ton ha^{-1})	Total Revenue (ETB ha^{-1})	Production costs (ETB ha^{-1})	total costs (ETB ha^{-1})	Gross field benefit (ETB ha^{-1})	Net benefit (ETB ha^{-1})	Total costs that vary (ETB ha^{-1})	D	Marginal cost (ETB ha^{-1})	Marginal net benefit (ETB ha^{-1})	MRR (%)
Nitrogen												
0	0.92	1.95	12953.75	6629	6629	6324.75	6324.75	0				
23	1.17	2.82	16601.25	6629	7204	9972.25	9397.25	575		575.0	3072.5	534.35
46	1.42	3.76	20283.75	6629	7779	13654.75	12504.75	1150		575.0	3107.5	540.43
69	1.64	5.45	24088.75	6629	8354	17459.75	15734.75	1725		575.0	3230.0	561.74
92	1.50	5.04	22032.50	6629	8929	15403.50	13103.50	2300	D			
115	1.67	5.72	24595.00	6629	9504	17966.00	15091.00	2875	D			
138	1.64	6.82	24773.75	6629	10079	18144.75	14694.75	3450	D			
161	1.80	5.86	26273.75	6629	10654	19644.75	15619.75	4025	D			
Phosphorus												
0	1.43	4.22	20756.25	8121.5	8122	12634.75	12634.75	0				
11	1.29	5.10	19345.00	8121.5	8416	11223.50	10928.70	295	D			
22	1.58	5.00	23002.50	8121.5	8711	14881.00	14291.40	590		590	1656.6	280.79
33	1.58	5.28	23142.50	8121.5	9006	15021.00	14136.60	884	D			
44	1.65	5.15	24062.50	8121.5	9301	15941.00	14761.80	1179		589	470.4	79.86
55	1.55	5.13	22696.25	8121.5	9596	14574.75	13100.75	1474	D			

Conclusion and Recommendation

A field experiment was conducted with the obejective of refining the current fertilizer rate and to check whether additional nutreints such as K and S would be important for teff production in Takusa district. The result revealed that the two major macro nutreints are most necessary to apply as fertilizer sources in the studz areas. Hence, maximum average biological grain yield (1.89 ton ha^{-1}) was harvested by applying 161 kg ha^{-1} N application. Similarly, application of 44 kg ha^{-1} P gave a grain yield of 1.74 ton ha^{-1}. Howver, application of K and S fertilizers did not provided significant biomasss and grain field on teff crop in the study sites. Therefore, based on partial budget analysis of the present finding, its is possible to recommend for Takusa district and othe similar agro-ecologies two types of major nutrients namely N and P with a rate 69 kg ha^{-1} N and 22 kg ha^{-1} P respectively for teff production.

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Appendix

Appendix Table 1. Combined mean squares for teff yield and yield components by Nitrogen treatment in 2014, 2015 and over the two years

Source of variation	Df	Plant height (cm)	Panicle length (cm)	Number of effective tiller per plant	Above ground biomass (ton ha^{-1})	Grain yield (ton ha^{-1})
Year 2014						
Site	2	300.43	111.882	11.805	18.0061	1.53354**
Rep	2	551.36	47.922	4.5717**	2.1059	0.18033
N	7	3613.73**	93.714	1.1273	57.0967**	1.63006**
Site*N	14	385.46	23.063	0.6552	2.2302	0.04596
Error	46	569.6	57.286	0.6801	3.5944	0.06166
Year 2015						
Site	2	4376.49**	908.555**	0.72792**	5.1035**	2.29636**
Rep	2	3.55	8.39	0.10792	1.2898	0.06968
N	7	466**	39.856**	0.08808	19.9716**	0.4001**
Site*N	14	102.74	14.369	0.16522*	2.0317**	0.09239*
Error	46	66.61	10.497	0.07212	0.6478	0.04355
Combined						
Year	1	11342.3**	374.423**	14.6306**	142.168**	14.0938**
Site	2	1402*	823.476**	9.014**	12.804**	3.2941**
Rep	2	319.9	24.484	1.7502*	0.667	0.0144
N	7	3038**	100.25**	0.7689*	68.422**	1.7188**
Site*N	14	210.4	15.142	0.2625	2.083	0.0693
year *N	7	1041.8**	33.319	0.4465	8.65**	0.3152**
year *Site*N	16	652.5*	44.125	0.9281*	3.195	0.1275**
Error	94	316.3	33.848	0.4304	2.133	0.0568

**, ** =significant at 0.05 and 0.01 levels respectively*

Appendix Table2. Combined means squares for teff yield and yield components by Phosphorus treatment in 2014, 2015 and over the two years

Source of variation	Df	Plant height (cm)	Panicle length (cm)	Number of effective tiller per plant	Above ground biomass (ton ha^{-1})	Grain yield (ton ha^{-1})
Year 2014						
Site	2	298.282	92.0541	6.04741**	82.7793**	2.36914**
Rep	2	33.087	8.3163	1.17852*	1.4245	0.18001
P	5	71.443	59.0816	0.2643	0.719	0.3961*
Site*P	10	138.441	25.6674	0.15674	1.8412	0.15431
Error	34	104.249	31.3445	0.2695	1.3196	0.12039
Year 2015						
Site	2	658.032**	304.711**	0.02574	3.55767	0.55337**
Rep	2	67.869	27.146	0.12963	1.10312	0.1668
P	5	315.692*	25.267	0.37896**	4.02504*	0.17611*
Site*P	10	57.472	8.787	0.11396	0.70558	0.03005
Error	34	104.817	15.789	0.09885	1.51765	0.06181
Combined						
Year	1	13752.1**	603.028**	3.06704**	277.858**	16.6852**
Site	2	754.4**	362.126**	3.08694**	35.669**	1.9513**
Rep	2	97.6	32.622	0.34111	0.361	0.346*
P	5	167.9	51.935	0.37822	3.559*	0.3416**
Site*P	10	120.8	18.89	0.15017	1.512	0.0764
year *P	5	219.2	32.414	0.26504	1.185	0.2312*
year *Site*P	12	96.3	18.743	0.59815**	9.307**	0.253**
Error	70	101.6	22.975	0.20654	1.44	0.0886

*, ** =significant at 0.05 and 0.01 levels respectively

Appendix Table 3. Mean squares for teff yield and yield components for six Potassium rates (K) at three sites, 2014 and 2015.

Source of variation	Df	Plant height (cm)	Panicle length (cm)	Number of effective tiller per plant	Above ground biomass (ton ha^{-1})	Grain yield (ton ha^{-1})
Year 2014						
Site	2	361.17	5.3719	0.50667	94.1989**	5.83061**
Rep	2	652.39	3.1763	0.04667	2.2617	0.44321*
K	5	849.75	27.4519	0.47644*	0.4677	0.03264
Site*K	10	1118.87	22.4074	0.21778	1.7403	0.09634
Error	34	814.3	32.7041	0.18784	1.8849	0.09714
Year 2015						
Site	2	25.4585	47.1669*	0.46167	8.03003**	1.39092**
Rep	2	93.1746	4.8802	0.00722	0.92041	0.10898
K	5	67.6363	22.622	0.21722	0.5511	0.02063
Site*K	10	46.9594	12.8951	0.18922	0.30013	0.04252
Error	34	54.4072	11.4486	0.15859	0.32243	0.03705
Combined						
Year	1	16635.9**	174.041**	0.0675	171.588**	17.7471**
Site	2	268.1	34.021	0.14083	24.315**	3.4338**
Rep	2	166	1.671	0.01194	0.159	0.0892
K	5	397.3	18.679	0.25883	0.943	0.0275
Site*K	10	693.7	24.768	0.2235	0.637	0.0489
year *K	5	520.1	31.395	0.43483*	0.075	0.0258
year *Site*K	12	413.2	11.865	0.29083	14.155**	0.7063**
Error	70	438.5	21.628	0.16947	1.159	0.0784

*, ** =significant at 0.05 and 0.01 levels respectively

Appendix Table 4. Mean squares for teff yield and yield components for six Sulfur rates (S) at three sites, 2014 and 2015.

Source of variation	Df	Plant height (cm)	Panicle length (cm)	Number of effective tiller per plant	Above ground biomass (ton ha^{-1})	Grain yield (ton ha^{-1})
Year 2014						
Site	2	727.15**	119.825*	0.73461	19.9432**	0.40361*
Rep	2	240.927	21.379	0.6235	1.5911	0.02336
S	5	58.015	31.002	0.42092	0.9137	0.02912
Site*S	10	104.583	22.901	0.39419	0.6974	0.06641
Error	34	109.917	33.302	0.34363	1.1797	0.08381
Year 2015						
Site	2	404.712	98.8119**	1.47241**	11.2732**	0.45772**
Rep	2	469.054	3.3557	0.01907	0.3027	0.03218
S	5	202.611	8.8336	0.04596	0.7422	0.03941
Site*S	10	319.792	13.8323	0.03796	0.2585	0.03435
Error	34	233.29	14.8103	0.11751	0.3012	0.02625
Combined						
Year	1	9556.04**	187.757**	0.35611	150.781**	9.35745**
Site	2	993.85**	201.818**	1.49549**	0.659	0.30623**
Rep	2	279.24	16.8	0.40771	0.97	0.04621
S	5	158.67	15.151	0.18864	0.74	0.04922
Site*S	10	294.44	25.402	0.25923	0.31	0.0486
year *S	5	101.96	24.684	0.27778	0.916	0.01931
year *Site*S	12	131.28	12.246	0.27935	5.631**	0.13598**
Error	70	179.01	23.596	0.22905	0.746	0.05373

*, ** =significant at 0.05 and 0.01 levels respectively