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Soil Test and Tissue Analysis Based Nitrogen and Phosphorus Fertilizer Applications on Teff [*Eragrostis tef* (Zucc.) Trotter] Cultivars in North Shewa Central Highlands, Ethiopia

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Abstract

Soil fertility studies and crop improvement have brought remarkable change in crop production particularly in teff in Ethiopia. Differences in soil status affect productivities of various cultivars in which their nutritional demand is different and increasing. This elucidates that fertilizer rate studies are dynamic and increasing time to time across crop cultivars. Fertilizer rate recommendations need to be specific soil and tissue test based and should be done repeatedly for any cultivar to maximize the inherent potential yield of the crop. Field experiment was laid out to test teff cultivars to a soil and tissue test based NP fertilizer applications. Soil samples were collected and subjected to a soil test in respective methods employed to determine the physicochemical property of a soil. High available P, medium organic carbon content moderately low total N content and pH of 7.57 were obtained from the experimental site. Plant tissue samples were collected from a 2 × 2 m^2 plot and subjected to analysis to determine tissue nitrogen and phosphorus contents. N application significantly increased the concentrations of nitrogen and phosphorus in shoot tissue and grain yield. However, application of P at different rates did not significantly affected any of the parameters. This might be due to unavailability of P for the plant due to fixation and hence examination must continue to identify real causes.

Keywords: Fertilizer application; Production; Soil test; Tef cultivars; Tissue analysis

Introduction

Soils of agricultural lands degrade in nutrition if poor management prevails in crop cultivation. Soils physico-chemical properties alter due to both fertilizer applications and removal of soil nutrients by crops. Adopting mechanisms of determining soil testing and tissue analysis required to identify the real needs of plants and the potential of a soil to provide nutrients to crops. Crops like teff which is a dominant and ancient to be cultivated by the Ethiopian farmers is gaining global attention. Fortunately, there is an increasing demand of the crop while its productivity is still low. Finding a way out to maximize teff grain yield will require a comprehensive study upon all growth requirements. Amongst soil nutrition plays great role but which might be easily amenable if identified.

Soil test based fertilizer recommendations could be designed for reducing such production constraints. Teff responds differently to rates of fertilizers depending on soil type and cultivars [1]. There are different blanket recommendations for various soil types of Ethiopia for teff cultivation. For heavy soils (Vertisols) and sandy clay loam soils (Andosols), 55/30 and 60/26 N/P kg/ha, respectively are recommended [2]. Nonetheless, N/P recommendation rates by the Ministry of Agriculture are 55/30, 30/40 and 40/35 N/P kg/ha for teff crop on Vertisols, Nitosols and Cambisols, respectively across the country [3]. However, 100 kg DAP/ha and 100 kg urea/ha were set by the Ministry of Agriculture and Rural Development later [4]. Generally, the recommended rate of fertilizer for teff is 25 to 40 kg N/ha and 30 to 40 kg P_2O_5/ha on light soils such as Nitosols, Luvisols and Cambisols, and 50-60 kg N/ha and 30-35 kg P_2O_5/ha for heavy soils such as Vertisols [5]. On the other hand, a study conducted at Hawassa and Areka using three teff varieties (Dabi, Dz-01-196 and Dz-01-354), representing early, intermediate and late maturing groups respectively, indicated that there was no need of applying urea on Nitosols and no fertilizer should be applied to teff grown on Fluvisols [6].

All the above considerations indicate that fertilizer recommendations are dynamic and change with time due to changes in soil nutrient status and environment. Those blanket recommendations brought generally, an increase in yield of improved cultivars ranging from 1700 to 2200 kg/ha [7]. Accordingly, the average national yield in the year 2010 reached 1200 kg/ha [8]. However, the recommendations do not work for all production aspects of various soil types of different regions. It is in fact possible to increase the yield potential of teff via optimizing nutrient supply to the soil. Determination of optimum fertilizer rates for specific soil types is vital for overcoming the problem that arose from the use of blanket fertilizer recommendations. Systematic studies should be conducted under varying conditions and in various regions to determine the fertilizer requirements of teff for optimizing yield. There for the objective of this study was to determine optimum rates of NP fertilizers on teff cultivars by employing soil test and plant tissue analysis.

Materials and Methods

Description of the study area

The experiment was conducted in Menz keya district on a farmer's field during the main cropping season under rain fed. Menz Keya district is located at 312 km far from Addis Ababa, to the North-Eastern direction in North Shewa at altitude that ranges from 1400 to 2960 meter above sea level (masl). The site of the experiment was located around a village called Zemero. It is located at an altitude of 2791 metres above sea level and at 10.136°North and at 39.263°East in North Shewa Zone. The main rainy season is from mid-June to mid-September and the small rainy season is from March to May. The area receives mean annual rainfall of 1000 mm with mean minimum and maximum annual temperature of 10 and 25°C, respectively. The agro-ecology of the area is 20% low land, 42% midland and 38% highland [9]. The major soil types of the study area were observed as Veritsols, Nitosols and Alluvial soils. The soil of the site was clay textured with pH of 7.57, low N content, medium organic content, high available P and high CEC (Table 1). The experimental site was under legume cultivation during the previous growing season.

Farmers of the area practice mixed farming; cultivate crops such as wheat, barley, teff, fabba bean, lentil field pea, chick pea and grass pea and rear animals in every fragmented plot of land that allows the land no time to rest. The land is continuously exploited and is poor in fertility and particularly very low in organic matter as crop residues are not left in the fields after harvest basically for straw utilization.

Experimental materials

Teff cultivars selected for the study were 'Quncho' (DZ-cr-387), which was developed and released by Debrezeit Agricultural Research Centre in 2006 and 'Sergegna', a local cultivar adapted and grown in the area. 'Quncho' is a high yielding white-seeded cultivar adapted to a wide range of altitudes. 'Sergegna' is a cultivar with mixed white and brown seeds of local origin. Fertilizer materials used as sources of N and P, were Urea (46% N), and TSP (46% P_2O_5) respectively.

Treatments and experimental design

The treatments consisted of two teff cultivars ('Quncho' and 'Sergegna'), three rates of N (0, 46 and 92 kg N ha^{-1}), and three rates of P (0, 50, and 100 P_2O_5 ha^{-1}). The experiment was laid out as a randomized complete block design in a factorial arrangement and replicated three times. According to the stipulations of the design, each treatment was assigned randomly to the respective experimental units within a block. A plot size of 3 m by 2 m was used to sow teff seeds manually by broadcasting. The blocks were separated by a meter open space to work properly in between the blocks while the plots within a block were separated by a 0.5 m open space for the same purpose.

Land preparation and sowing

Land preparation was done according to the local practice. Thus, the land was ploughed five times using oxen before planting and the last ploughing was done following the local practice before sowing to make it ready for compaction and to bury early emerging weeds. After well levelling and compacting seedbeds, seeds were broadcasted at the rate of 25 kg ha^{-1}.

Methods and time of fertilizer application

Sowing of the teff seeds was done by broadcasting. N at the specified rates was applied in three splits in the form of urea ($1/4^{th}$ at the time of sowing $1/2^{nd}$ at mid-tillering (30 days after sowing), and $1/4^{th}$ at anthesis (60 days after sowing). Urea was applied by broadcasting. Application of phosphorus at the specified rates was done by broadcasting the TSP granules all once at sowing.

Soil sampling and analysis

Soil analysis of the experimental land was done. Soil samples were taken in a zig-zag pattern randomly before sowing. Twenty soil samples were taken from the entire experimental field using an augur to the depth of 30 cm from the top soil layer. The soil samples were composited into a bucket. The soil was broken into small crumbs and thoroughly mixed. From this mixture, a sample weighing 1 kg was filled into a plastic bag. The sample was replicated three times and prepared for determining physico-chemical characteristics. The soil was air-dried and sieved through a 2 mm sieve. Soil pH was determined from the filtered suspension of 1:2.5 soils to water ratio using a glass electrode attached to a digital pH meter (potentiometer) [10]. Texture of the soil was determined by sedimentation method.

The soil samples were analyzed for total N, available P, CEC, soil pH, and organic carbon contents. Organic carbon was determined by the method of Walkley and Black [11]. Total N was determined using Kjeldhal method [12]. Available P was determined by extraction with 0.5 M $NaHCO_3$ according to the methods of Olsen and Dean [13].

Plant sampling and tissue analysis

Just at anthesis, the whole aboveground portion of the plant was moved at the surface of the soil from an area of 0.12 × 0.12 m in each plot as determined by throwing a quadrat. The plant shoots were oven dried at 65°C till a constant weight was attained. The dried samples were ground to pass through a 40-mesh screen. The dried and ground shoot of the plant was ashed at the temperature of 480°C. The ashed plant material was treated with a solution of 1 volume of nitric acid (HNO_3) diluted in 3 volume of distilled water. P content in the plant tissue was determined from the extract calorimetrically by Vanadomolybdate method [14]. N was determined by modified Kjeldhal method as described by Jackson [12]. Nitrogen and phosphorus concentrations in shoot tissue were determined in the laboratory and expressed in mg N or P per gram shoot dry matter at Jijelaboglass private limited company.

Data analysis

The data were subjected to analysis of variance (ANOVA) following the appropriate procedures of RCBD as stated by Gomez and Gomez [15] for a factorial experiment. ANOVA was computed with the help of SAS computer software programme. Means of significant treatment effects were separated using the Least Significant Difference (LSD) test at 5% level of significance [16].

Results and Discussion

Selected physical and chemical properties of the soil of the experimental site

The results of analysis of the top 0-30 cm depth soil of the experimental site is indicated in Table 1. The results of the laboratory analysis for some physical and chemical properties of the experimental soil indicated that the soil was clay loam in texture with pH (H_2O) of 7.57; the organic carbon content of the soil amounts to 1.26% (organic matter 2.98%); the soil had contents of total N amounting to 0.12%, available P (Olsen) of 19.64 mg kg soil^{-1} and CEC of 55.80 c mol kg soil^{-1} (Table 1).

% Clay	% Silt	% Sand	Soil Class	TN (%)	Av. P (mg/kg)	OC (%)	pH	CEC (c mol/kg)
51	39	10	Clay	0.12	19.64	1.26	7.57	55.8
NB: TN: Total N; Av. P: Available P; OC: Organic Carbon; CEC: Cation Exchange Capacity								

Table 1: Physico-chemical properties of the experimental soil to the depth of 0-30 cm.

Sahlemedhin [17] classified total N content of 0.1 to 0.2% as low and organic matter content of 3-5% as high and more than 5% as very high. The author also described CEC by sodium acetate at pH 8.2 or ammonium acetate at pH 7 with values between 25 and 40 c mol kg soil^{-1} as high to medium and satisfactory for agricultural production with the use of fertilizers and CEC>40 c mol kg^{-1} as very high. This showed that the content of organic matter in the experimental soil was medium and total N content was low. Mengel and Kirkby [18] stated that the critical available P content in the soil according to the analytic method of Olsen [19] for optimum plant growth lay near 20 mg kg soil^{-1}. This showed that the available P content of the experimental soil (19.64 mg kg soil^{-1}) was just near sufficiency for plant growth. These classifications of soil nutrient status were consistent also with those of Landon [20] and Roy et al. [21]. Therefore, with this consideration, the total N content of the experimental soil was in the lower range and CEC was very high. The pH of the soil was near neutral and suitable for plant growth [22]. The relatively medium to sufficient available P might have occurred due to the continuous intensive P fertilizer application. However, the actual response of crops to P application might depend on many other factors such as availability of other nutrients in the soil such as N and potassium as well as moisture [18].

Concentrations of nitrogen and phosphorus in shoot tissue of teff

The results of the concentrations of N and P in the shoot tissue of teff as analyzed from samples collected from each treatment just before anthesis are summarized in Table 2. The main effects of N application and cultivars significantly (P<0.05) affected the concentrations of N in teff shoot tissue. However, the main effect of P as well as all interactions did not affect this parameter of the plant. The main effect of N also significantly affected the concentrations of P in teff shoot tissue. All other treatments were non-significantly affected the concentrations of P teff shoot tissue (Table 2).

Source of Variation	Mean squares			
	Parameters			
	Df	TN%	T %	Grain yield (kg ha^{-1})
Rep	2	0.067	0.0085	1760.9
Cultivars(C)	1	0.097	0.00016	707083.80**
N rate	2	0.196**	0.1572**	964162.40**
P rate	2	0.027	0.00155	16104.9
C × N rate	2	0.011	0.000045	207439.20**
C × P rate	2	0.0045	0.0012	17776.2
N x P rate	4	0.037	0.0033	12560.5
C x N x P	4	0.012	0.00036	77695.8
Error	34	0.015	0.003	31643.4
CV%		7.4	22.79	10.1
NB: * and ** significant at 5% and 1% probability levels, respectively. df=degree of freedom, TN=Total Nitrogen Tissue Content and TP=Total Phosphorus Tissue Content.				

Table 2: Mean squares of analysis of variance for total nitrogen and phosphorus tissue content and grain yield of teff.

'Quncho' teff had significantly (P<0.05) higher N concentration in shoot tissue, than the 'Sergegna' cultivar, in which 5.3% mean difference was obtained. This might be due the higher N uptake efficiency of the cultivar.

Increasing N application from 0 to 46 kg ha^{-1} significantly increased the concentration of the nutrient in shoot tissue as compared to the control treatment. Further increasing the N application rate from 0 to 92 kg ha^{-1} increased significantly the concentration of the nutrient in shoot tissue. Maximum concentration of the nutrient in shoot tissue (1.75%) was recorded due to the application of 92 N kg ha^{-1} while the minimum (1.54%) was recorded due to the application of 0 kg N ha^{-1} in which 14% mean difference was observed (Table 3). This indicates that increased availability of the nutrients in the soil due to the fertilizer application led to increased uptake and accumulation of the nutrient in shoot tissue of the plants.

Increased N application also significantly (P<0.05) affected the concentration of P in shoot tissue (Table 3). The increase in N application to 92 kg ha^{-1} resulted in significant difference in the concentration of P in the shoot tissue of the plant over the control with a mean difference of 23.81%. 46 and 92 kg N ha^{-1} fertilized treatments were in statistical parity.

Similar to the results of the current study, Legesse [23] found that both N and P content increased due to increased N application in teff. Tekalign et al. [24], Doyle and Holford [25] and Tilahun et al. [26] reported significant increases in grain N uptake in teff, barley and wheat respectively, as N application increased. Getachew and Tekalign [27] also indicated significant and linearly increase of N uptake in barley grains while Mitiku [28] reported significant increase of N content in teff straw with an increase in N application. The author also noted that application of the highest N (90 kg ha^{-1}) gave the highest straw N content while the lowest was obtained in the unfertilized treatment.

The critical concentration of a nutrient in plant tissues is the value in a particular plant part sampled at a given growth stage below which plant growth and yield are suppressed by 5 to 10% [29]. For optimum growth with maximum potential yield reductions of 10%, sufficient concentrations of N and P in the shoot of most plants generally amount to 2-5% and 0.2-0.5%, respectively [30-32]. Roy et al. [21] also described that the concentration of N in shoot tissue of cereals for optimum growth ranges between 3 to 5% and that of P ranges between 0.2 to 0.5%. The results of this experiment show that the concentrations of N at the maximum grain yield of the teff varieties nearly corresponded with the ranges indicated above. Thus, consistent with the above suggestions, the maximum grain yield (1959.8 kg ha^{-1}) was recorded at the highest application of N (92 kg ha^{-1}) which led to the attainment of tissue N (1.75%) and P (0.26%) concentrations that reached the sufficiency level (Table 3).

Treatments	N (%)	P (%)	Grain yield (kg ha^{-1})
		Cultivar	
Quncho	1.7a	0.24	1857.20a
Sergegna	1.6b	0.241	1728.30b
LSD (0.05)	0.067	NS	98.4
		N (kg ha-1)	
0	1.54c	0.21b	1525.60c
46	1.63b	0.25a	1892.70b
92	1.75a	0.26a	1959.80a
LSD (0.05)	0.08	0.0369	120.5
		P (kg ha-1)	
0	1.665	0.24	1809.4
46	1.66	0.23	1813.2
92	1.655	0.248	1755.6
	NS	NS	NS
CV%	7.4	22.79	10.1
NB: Means followed by the same letter with in a column are non-significantly different at 5% probability. Ns: Non-significant at 5% probability			

Table 3: Effects of cultivar, N and P rates on plant N and P tissue concentrations and grain yield of teff.

Grain yield as affected by NP fertilizers and cultivars

Grain yield was significantly influenced by the main effect of cultivar and N application. Cultivar and N application also interacted to significantly ($P<0.01$) influence grain yield. However, the main effect of P as well as other interactions did not influence the grain yield. In response to the increased levels of N application, the yield of 'Quncho' cultivar increased significantly and linearly up to the highest level of N application (92 kg N ha^{-1}). However, the yield of the 'Sergegna' cultivar increased only up to the rate of 46 kg N ha^{-1}, after which it tended to decline though not significantly. At the level of 0 kg N ha^{-1}, the yield of 'Sergegna' tended to surpass that of 'Quncho' although the difference between the yields of the two cultivars was not statistically significant. On the other hand, when the rate of N was increased to 46 kg N ha^{-1}, the yield of 'Quncho' surpassed that of 'Sergegna', but the difference between the yields of the two cultivars was not statistically significant. However, at 92 kg N ha^{-1}, the yield of 'Quncho' was significantly higher than that of 'Sergegna', which remained statistically the same with its yield obtained at 46 kg N ha^{-1}. The yield of 'Quncho' that was recorded at the highest level of N application was higher than the yield of 'Sergegna' obtained at the same level of N application additionally by about 19%. However, the yield of 'Quncho' at the level of 92 kg N ha^{-1} was greater than the yield of the same cultivar as well as that of 'Sergegna' obtained at nil application of N incrementally by about 43 and 36%, in the order cited here (Table 3).

The results of this study revealed that the potentially maximum yield of 'Quncho' was not realized since the yield continued significantly increasing up to the highest level of N application. Therefore, there is a possibility that significantly higher yields could have been obtained if higher rates of the N fertilizer were applied. This indicates that the cultivar is highly productive under high N input. In contrast, the 'Sergegna' cultivar attained optimum yield already at 46 kg N ha^{-1}, indicating its low yielding potential. However, under low input of N fertilizer, both cultivars have equal grain yielding potential. But in terms of biomass production, 'Quncho' is still preferable under low N supply.

Studies on response of various teff cultivars to N application by Mulugeta [33], Legesse [23], Mitiku [28] and Haftamu et al. [34] found that N application significantly increased grain yield. Increased grain yield due to increased N application was also reported for different cereal crops. For instance, Mekonn and Gobeze [35] reported high yield of barley in response to increased N application. Mulugeta [33] and Gobeze also found similar results in rice and finger millet respectively.

The minimal or no response of P application in terms of grain as well as many plant parameters in this study might indicate that P was not a limiting factor for the production of teff at the study site. This is confirmed by the relatively sufficient or near sufficient amounts of available P found in the soil (19.64 mg P kg $soil^{-1}$) as shown by the result of the soil analysis before sowing (Table 1). That soil test value amounting to 19.64 is considered high and sufficient for plant growth and development, according to the method of Olsen [19], was stated by Landon [20], Mengel and Kirkby [18] and Roy et al. [21].

In line with the present finding, Legesse [23] also reported non-significant differences in grain yield due to application of P and its interaction with N application on this type of soil. For other cereals such as sorghum, certain findings showed that there was no substantial yield difference among the P rates at Sirinka [36]. Research conducted at Debre-Zeit, indicated that, there was no response of teff to applied P under unimproved drainage conditions. In contrast to these results, similar experiments conducted under improved drainage conditions revealed significant increases in teff grain and straw yield in response to different rates of P fertilizer even though the yield obtained followed inconsistent trend [37,38].

Conclusion

In conclusion, Soil fertility studies and crop improvement have brought remarkable change in crop production particularly in teff. Differences in soil status affect productivities of various cultivars in which their nutritional demand is different and increasing. This elucidates that fertilizer rate studies are dynamic and increasing time to time. Fertilizer rate recommendations need to be soil test based and should be done repeatedly for any cultivar to maximize the inherent potential yield of the crop.

Surface soil (0-30 cm) samples were collected before sowing from 20 random spots in a zigzag pattern to make a composite soil sample of the experimental site. Total N, available P, soil pH, soil texture, organic carbon content and CEC of the soil samples were determined using standard laboratory procedures at Jijelaboglass private limited company.

The teff cultivars tested under this study required high N application to produce high grain and straw yield but minimal effect of P application was observed on this specific soil type. Therefore, the results of this finding might be very helpful to use as an alternate practice to improve teff yield in the region. Introduction of the highly disseminating 'Quncho' teff with its full package of management to the area and use of mineral N and P fertilizers with proper management practices for the local cultivar can significantly enhance productivity of the crop. The highly positive response of the crop to increased N application could give an indication to producers to use higher rates of N application (> 92 kg N ha^{-1}) in three splits especially for the improved cultivar 'Quncho' to obtain even higher grain yield that was obtained in this experiment. However, to come to a conclusive recommendation, multi-location trials should be conducted over seasons on different soil types in the study area using including higher rates of N and considerable rates of P fertilizers.

Conflict of Interest

There is no conflict of interest.

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