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Original Paper

Unlocking Tef Potential: Assessing Yield-Limiting Nutrients Based on Topographic Position in Tehulederie District, Eastern Ethiopia.

Samuel Adissie Gedamu[1], Kassa Sisay[1], Adise Deg[1] and Sisay Dessale[1]*
1) Sirinka Agricultural Research Center, P.O. Box 74, Woldia
**) Corresponding Author: Sammy.ab1990@gmail.com*

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***Abstract*— Nutrient status of soils in Ethiopia varies among different landscapes, but fertilizer recommendations are broad and mostly N and P based. Fine-tuning fertilizer recommendations and crop yield variability within and between landscapes attracted research attention in Ethiopia and across the globe. A field study was conducted in 2021 in the Tehuledere district of the South Wollo Zone of the Amhara Region to identify major yield-limiting nutrients for tef across three different landscape positions in a catena slope of 0-5%, 5-15%, and >15%. Fertilizer rates of 80, 57,7,30,1 and 0.3 Kg/ha of N, P2O5, S, K20, Zn, and B respectively were evaluated. The randomized complete block design was used. Dunckun's multiple range tests was employed for comparison of treatment means for those which were statistically significant. Analysis indicated that micronutrients (Zn, B), potassium (K), and sulfur (S) did not significantly influence the yield, whereas N and P were critical limiting factors for yield. N and P exclusion led to significant yield losses, and their doubling of application to 150% of recommended rates highly enhanced tef grain yields across all slopes. This indicates the need for better management of N and P in tef production, while current emphasis on secondary and micronutrients may be unnecessary in the study region. Other research should be conducted to determine specific rates of N and P application at the study area and other similar agroecologies, further focusing on potential micronutrient deficiencies on hill slopes.**

Keywords*— Landscape position, Economic optimum, Fertilizer, Yields response

I. INTRODUCTION

Soil fertility heterogeneity in smallholder farming systems is a major factor that affects productivity and the suitability of crop and nutrient management recommendations for different locations at various spatial scales. Landscape as a factor for soil fertility status and how landscape positions could be used for fine-tuning fertilizer recommendations and crop yield variability within and between farms attracted research attention in Ethiopia and around the globe [1]. The attempt to understand soil variability and its potential effect on crop based on topography-related patterns [2].

The topography of most African agricultural landscapes comprising high-elevation hillslopes, midslopes, and foot slopes, which are appearing within short distances, requires differing agronomic management and various levels of inputs. The effect of the landscape position on soil nutrient status has been reported in Vietnam [3]. Thus, Soils can be more gravelly and thinner with rock outcrops close to hilltops, with more fertile soils in mid-slope positions and fertile, alluvial soils in the valleys. Given erosion risks, farmers' decisions in terms of input application and management are also in favor of foot slopes and midslopes.

Tef, Eragrostis tef (Zucc. Trotter), originated and diversified in Ethiopia [4] and is productivity has been ongoing since the time of Dokuchaev in early 1900, who divided soils as normal, transitional, and abnormal one of the major cereals grown for thousands of years. Ecologically, tef is adapted to diverse agroecological regions of Ethiopia and grows well under stress environments better than wheat, barley, and other cereals are known worldwide [5]. Because of this, it is said to be a "low-risk" crop for farmers. According to [6], the plant can be grown from sea level up to 2800 m.a.s.l under various rainfall conditions, temperatures, and soil regimes. However, for better performance, it requires an altitude of 1800- 2100 m.a.s.l, annual rainfall of 750-850 mm, and a temperature range of 10- 27 ° C. The crop plays a vital role in the country's overall food security, and it is the staple food for most Ethiopian people. Tef is the most expensive cereal in Ethiopia and is used as a cash crop for farmers. This is because of the high market prices for both its grain and straw. Today, tef received global attention as a health food because of its gluten-free nature, which renders it suitable for people suffering from gluten allergy known as celiac disease [7]. Teff plays an important role in supplying the population of the country with protein, carbohydrates, and minerals. Moreover, straw is an important cattle feed source. The national average mean grain yield tef will be found 1465 kg ha-1 for Ethiopia, 1513 kg ha-1 for North Shewa, and 1495 for Amhara Region [8] and mostly variable.

Most of the Ethiopian soils contain low nutrient content due to erosion and the absence of nutrient recycling. In addition, most of the areas used for the production of grains, especially tef, wheat, and barley, fall under low-fertility soils [9]. The low availability of nitrogen and phosphorus has been demonstrated to be a major constraint to cereal production. Fertilizer usage plays a major role in the universal need to increase food production to meet the demands of the growing world population [10].

Generally, there is limited information on how landscape positions could be used for fine-tuning fertilizer recommendations and which nutrient is yield-limiting/deficient in the study area. In this study, we used teff as a test crop, which is becoming an increasingly important crop, to understand the factors affecting the crop response to a combination of fertilizers in the undulating setting of soils of the Ethiopian highlands across the catena.

The major objectives of the research were to quantify the effects of landscape positions on crop-nutrient responses and to determine the rate of the most yield-limiting nutrients (N and P) across the catena.

II. Materials And Methods

A. Description of the Study Area

The study was conducted in the Tehuledere district of the South Wollo Zone, located in the Amhara Region of Ethiopia. This area is characterized by undulating topography with elevation ranging from 1800 to 2800 meters above sea level, falling within the typical agroecological zone suitable for tef production. The region experiences a bimodal rainfall pattern with annual precipitation between 750-850 mm, and the dominant soil types are Vertisols and Cambisols, which are generally fertile but suffer from nutrient depletion due to erosion and continuous cultivation. Major crops grown in the area include tef, sorghum, and Maize, with smallholder farming being the predominant agricultural practice.

B. Experimental Design and Treatments

The experiment comprised of 80, 57,7,30,1 and 0.3 Kg/ha of N, P_2O_5, S, K20, Zn and B respectively. The experiment was conducted using a randomized complete block design (RCBD). The spacing was 1m and 0.5m between replications and plots, respectively, with plot sizes of 3 m by 3m. Zobel variety with 25 kg ha^{-1} seed rate was used. All nutrients other than nitrogen, which was applied 1/2 at planting and ½ at tillering, were applied at planting. Rides were made between plots and blocks to remove the cross-contamination of fertilizer from one plot and block to others.

C. Selecting a Template (Heading 2)

Composite surface soil samples (0-30 cm depth) were collected from each farm to determine the physicochemical properties of the soil. The soils were air-dried, ground, mixed thoroughly, and passed through a 2 mm sieve for most parameters except for OC and TN, which passed through a 0.5 mm sieve. The samples were then labeled and stored in sealed plastic bags for laboratory analysis of texture, pH, TN, OC/OM, CEC, and available phosphorous. Soil particle size distribution was determined by the hydrometer method [11]. Soil pH was measured with a digital pH meter potentiometrically in a supernatant suspension of 1:2.5 soils to distilled water [12]. Organic carbon (OC) was determined by the dichromate oxidation method [13]. Total N in the soil was measured by the micro kjeldhal method. Available P was also analyzed by the Olsen method [14] calorimetrically by the ascorbic acid-molybdate blue method [15].

D. Data Collection

Plant height: It was measured at physiological maturity from the ground level to the tips of the panicle from randomly selected 10 culms from the net plot area. The mean value from 10 culms was taken as plant height per plant.

Grain yield: This was measured by harvesting the crop from the net plot area. The grain moisture was adjusted to 12.5%.

E. Data Analysis

The collected data from the on-farm experiment were subjected to analyses of variance (ANOVA) on the selected parameters using SAS 9.1 statistical software. Wherever the treatment effect will be significant, mean separation was made using the DMRT test at 5% level of probability.

III. Results And Discussion

From Table 1, the pH range is moderately alkaline and it is conducive to crop production [16]. Total nitrogen is moderate and organic carbon is low according to [16]. As it is indicated in Table 1, available phosphorus is low on hill slopes [14]; [17]. This may be attributed to the leaching of cations and fixation with Al at the hill slope. According to [16], available phosphorus is medium at mid and foot slopes. It is also low in all states when we go deep to 60 cm. This may be low organic residues through depth. According to [18], B is medium in both depths (0-20 and 0-60) at the foot slope. But it is low in hill and mid slopes. This may be due to the leaching of b from hill slopes.

TABLE I. THE AVERAGE VALUE OF SOIL ANALYSIS RESULTS OF THE TESTING SITES AT EACH LANDSCAPE

Landscapes	pH20	Mehlich 3	Combustion	Combustion	Mehlich 3	Mehlich 3	Mehlich 3	Mehlich 3
		Al20	TN20	TC20	S20	AV. P20	Zn20	B20
		cmol/kg	%	%	ppm	ppm	ppm	ppm
Hill slope	7.42	11.54	0.15	0.92	2	3.92	0.3	0.27
Mid slope	7.57	11.06	0.16	0.95	2.85	8.95	0.88	0.25
Foot slope	7.9	10.5	0.18	1.22	2.82	9.01	0.64	0.4
	pH60	Al60	TN60	TC60	S60	AV. P60	Zn60	B60
Hill slope	7.29	11.52	0.15	0.86	2.38	3.25	0.17	0.25
Mid slope	7.54	10.64	0.16	1.01	2.77	6.45	0.64	0.28
Foot slope	7.65	10.3	0.18	1.15	3.79	3.73	0.75	0.36

Where TC = Organic carbon (%), TN = Total nitrogen (%), AV. P = Available phosphorus (mg kg^{-1}), The suffixes 20 and 60 are the soil depth up to 20 cm and 60 cm, respectively.

As indicated in Table 2, the application of micronutrients, Sulphur and K, didn't impose a significant yield difference compared to the recommended N and P. The only difference is the control and the percent reduction and increment in treatments. The application of 150% of all the fertilizers together with K gave a statistically significant biomass yield increase compared to the other treatments. On the contrary, 50% of all the fertilizers together with K and the control treatment gave statistically lower biomass yield. This is attributed to the low fertility status in the study district, which would give higher biomass yield if more fertilizer is added.

TABLE II. RESPONSE OF YIELD-RELATED PARAMETERS OF TEFF FOR DIFFERENT FERTILIZERS.

Fertilizers	Biomass (kg/ha)	Plant Height (cm)	Panicle length (cm)
150%(All+K)	9095.1 ^{a}	113.51 ^{a}	44.08 ^{a}
NPSB (All-Zn)	7593.7 ^{b}	112.05 ^{a}	43.83 ^{a}
NPZnB (All-S)	7586.8 ^{b}	113.36 ^{a}	44.92 ^{a}
NPSZnB (All)	7549.3 ^{b}	109.28 ^{a}	43.28 ^{a}
NPSZnB+K(All+k)	7532.6 ^{b}	114.37 ^{a}	44.35 ^{a}
NPSZn (All-B)	7472.9 ^{b}	111.3o ^{a}	43.59 ^{a}
NP (All-SZnB)	7054.9 ^{b}	113.15 ^{a}	44.48 ^{a}
50%(AllK)	5722.9 ^{c}	108.44 ^{a}	43.92 ^{a}
Control	2864.6 ^{d}	84.87 ^{b}	33.98 ^{b}
CV	26.3	14.2	12.2

From Figure (1-6), the grain yield of teff was significantly increased due to the application of different fertilizer types compared to the unfertilized fertilizer. In most cases, the lower yield was obtained from the unfertilized treatment and the 50% of the total fertilizer types. It is also observed the recommended N and P fertilizers alone are not statistically different from the application of all fertilizer types. In some rare cases there happened yield penalties due to the omission of some nutrients in hill slopes like the omission of Zn and S (Figure 2). This may be due to the leaching of micronutrients from the hill slopes. This result is compatible with the soil analysis result presented in Table (1) which shows the micronutrients were lower according to [18]. In all landscapes, the % increases to 150% bringing maximum teff grain yield. This is attributed that the most yield-limiting nutrients (N and P) are lower in the study area (Table 1). This result highlights the critical role of nitrogen (N) and phosphorus (P) as primary yield-limiting nutrients for tef production in the Tehuledere district. The findings align with recent research on soil fertility management in smallholder systems, emphasizing the need for landscape-specific fertilizer recommendations [19].

The significant yield response to N and P application (150% of recommended rates) supports earlier findings on widespread deficiencies of these nutrients in Ethiopian soils. The low available phosphorus (P) levels observed in hill slopes (Table 1) are consistent with recent studies indicating P fixation in high-pH soils [20].

The higher fertility in foot slopes (Table 1) aligns with findings from [21], which highlighted sediment deposition as a key factor in soil nutrient accumulation. The slight yield penalty from Zn omission on hill slopes (Figure 2) suggests localized micronutrient deficiencies, corroborating studies [22] on micronutrient leaching in erosive landscapes.

The superior performance of 150% N/P rates underscores the inadequacy of blanket fertilizer recommendations, echoing recent calls for precision nutrient management [23]. The lack of sulfur (S) response contrasts with findings [24] in other tef-growing areas, emphasizing the need for localized trials.

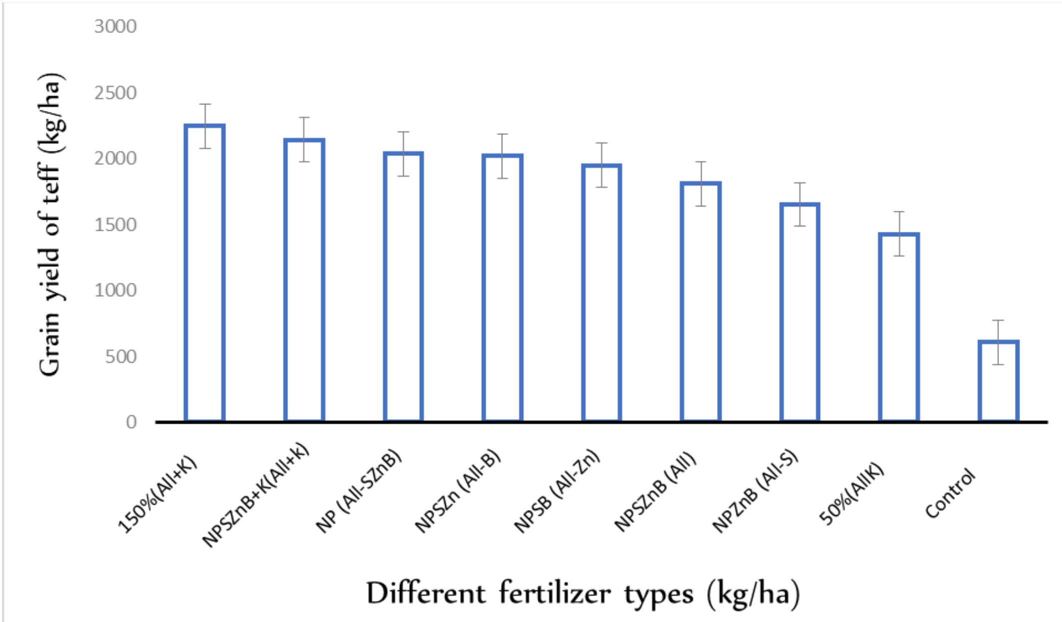

Fig. 1. Effect of different fertilizer types on teff grain yield at hill slope

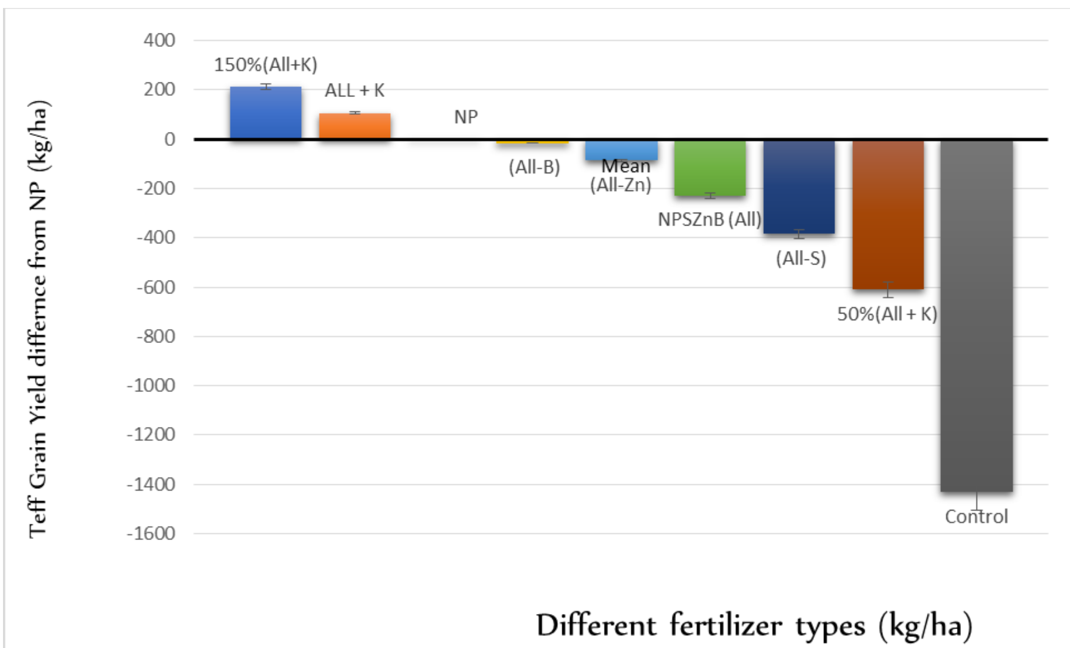

Fig. 2. Grain yield difference of teff from the NP at hill slope

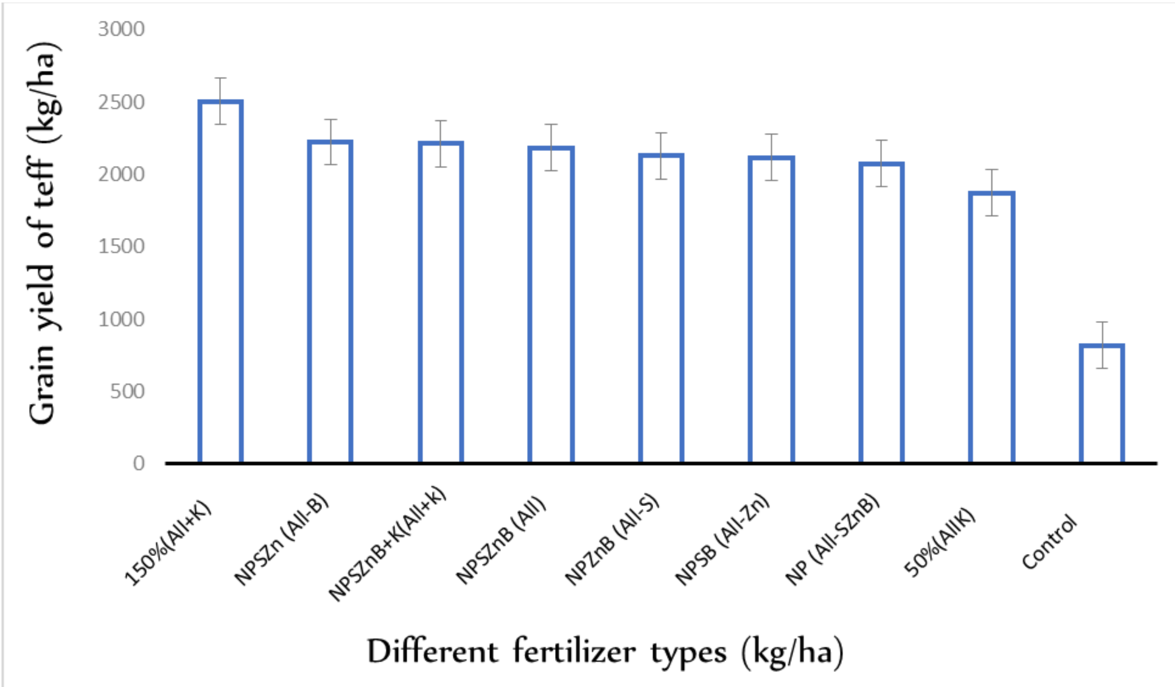

Fig. 3. Effect of different fertilizer types on teff grain yield at mid-slope

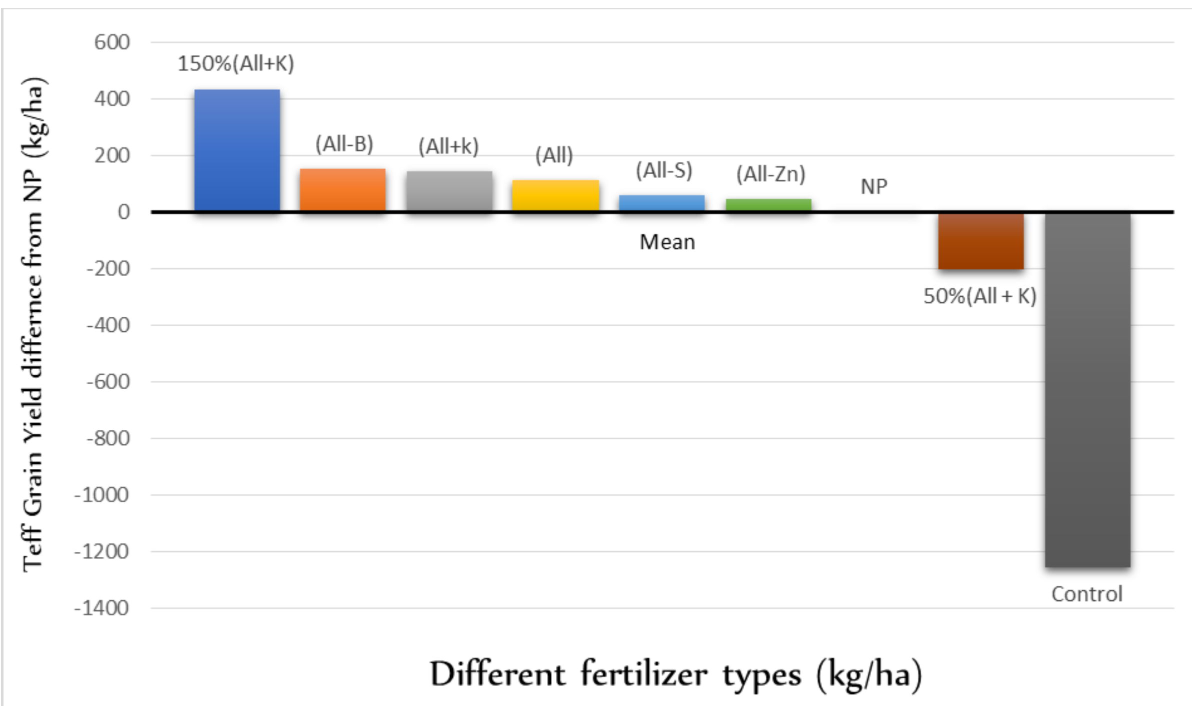

Fig. 4. Grain yield difference of teff from the NP at mid-slope

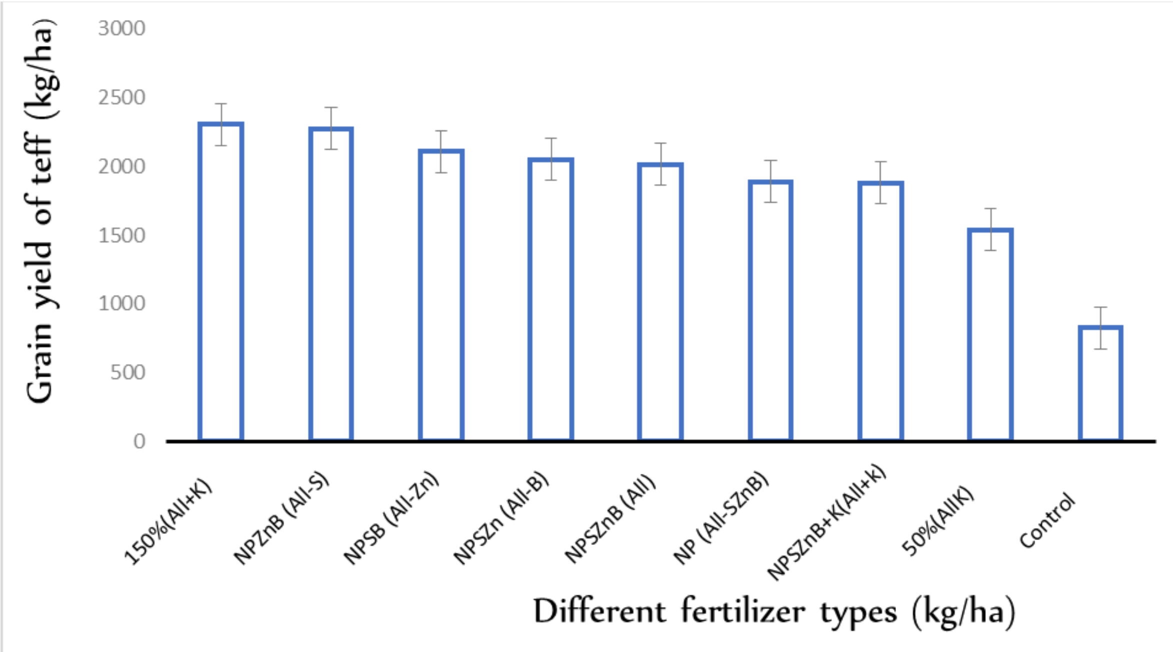

Fig. 5. Effect of different fertilizer types on teff grain yield at foot slope

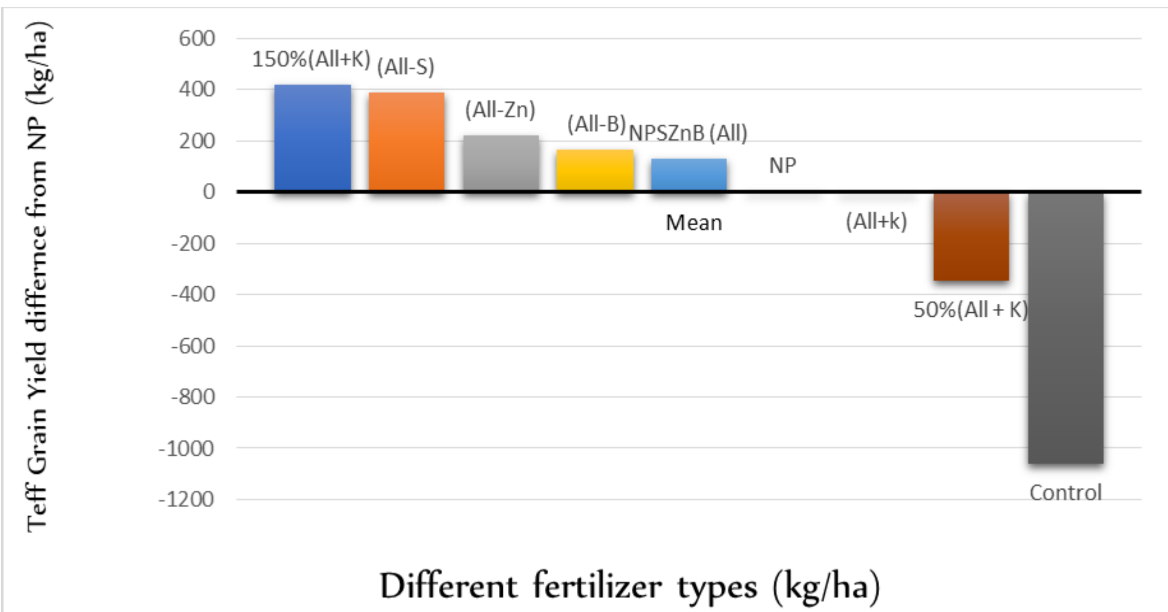

Fig. 6. Grain yield difference of teff from the NP at the foot slope

Conclusion And Recommendation

Nitrogen and phosphorus impose significant yield differences compared to the control. Micronutrients, potassium, and sulfur didn't yet bring a yield difference. As it is expressed in Figures, (Figure 1,3, and 5, the teff grain yield was higher in 150% of all the landscapes. Other than nitrogen, phosphorus yield was not greatly affected at the lower and medium strata. At the top strata, it was seen that there was a response for the application of some micronutrients.

Therefore, the application of nitrogen and phosphorus while increasing their amount will be feasible in the study area. Determination of optimum nitrogen and phosphorus should be done in the Tehulederie district and similar agroecology. In some cases, especially on hill slopes, some nutrients in addition to N and P may be limited and follow-up for the deficiency symptoms and further experimentation should be conducted.

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