RESPONSES OF TEF [*Eragrostis tef (*Zucc.) Trotter] VARIETIES TO BLENDED NPSB FERTILIER RATES AT GELAN, CENTRAL ETHIOPIA

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Responses of Tef [*Eragrostis tef (*Zucc.) Trotter] Varieties to Blended NPSB Fertilizer Rates at Gelan, Central Ethiopia

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HARAMAYA UNIVERSITY POSTGRADUATE PROGRAM DIRECTORATE

We hereby certify that we have read and evaluated this thesis entitled **"Responses of Tef [***Eragrostis tef (*Zucc.) Trotter**] Varieties to Blended NPSB Fertilizer Rates at Gelan, Central Ethiopia**" prepared under our guidance by Teshome Girma. We recommend that it be submitted as fulfilling the thesis requirements.

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As members of the Board of Examiners of the M.Sc. thesis open defense examination, we certify that we have read and evaluated the thesis prepared by Teshome Girma and examined him. We recommend that the thesis be accepted as it fulfills the requirements for the Degree of Master of Science in Agriculture (Agronomy).

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DEDICATION

I dedicate this thesis to my father Mr. Girma Tesema and mother Mrs. Ejigayehu Heyi and my wife to Abonesh Eshetu for their affection and consistent care in the success of my life.

STATEMENT OF THE AUTHOR

First of all, I declare that this thesis is a result of my genuine work and that I have duly acknowledged all sources of materials I referred to for writing it. I submit this thesis to Haramaya University in partial fulfillment of the requirements for the Degree of Master of Science. The thesis is deposited at the library of the University to be made available to borrowers for reference. I solemnly declare that I have not so far submitted this thesis to any other institution anywhere for the award of any academic degree, diploma, or certificate.

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BIOGRAPHICAL SKETCH

The author was born on November 29,1986. at Dembi Kebele, Gelan town, Oromia especial Zone, Ethiopia. He attended his Elementary School Education at Dalota (1995-2002), and completed his junior high school at Bishoftu Model secondary school (2003-2004) and his senior secondary school at Bishoftu preparatory and Technical school (2005-2006). He successfully passed the Ethiopian School Leaving Certificate Examination (ESLCE) in 2006, and joined Haramaya University College of Agriculture in 2007 and graduated with BSc degree in Plant Sciences in July 2009.

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LIST OF ACRONYMS AND ABBREVIATIONS

ANOVA	Analysis of Variance
ATA	Agricultural Transformation Agency
AWARDO	Akaki Woreda Agricultural and Rural Developement Office
CEC	Cation Exchange Capacity
CIMMYT	Centro Internacional de Mejoramiento e Maiz Y Trigo (Spanish)
CSA	Central Statistical Agency
DAP	Di-ammonium Phosphate
DZARC	Debre Zeit Agricultural Research Center
Ethio SIS	Ethiopian Soil Information System
FAO	Food and Agricultural Organization
IAEA	International Atomic Energy Agency
LSD	Least Significant Difference
RCBD	Randomized Complete Block Design
SNNPR	South Nations, Nationalities and People Region

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ABSTRACT

Tef is the major crop grown in Ethiopia and the study area. However, its productivity is low mainly due to limited use of improved varieties and low soil fertility as result of intensive soil erosion and long history of cultivation. Therefore ,a field experiment was carried out on a farmer's field at Gelan Akaki district during the 2018 main cropping season (from July to November 2018) to assess the response of tef varieties to blended NPSB fertilizer rates and to identify the economically feasible rates of blended NPSB fertilizers for the tef varieties. The treatments consisted of factorial combinations of three varieties of tef (Qunch, Kora and Dagim) and five levels of blended NPSB (0, 50, 100, 150 and 200 kg ha^{-1}) fertilizer rates. The experiment was laid out in randomized complete block design in a factorial arrangement with three replications. All the plots were supplemented with 46 kg N ha^{-1} in the form of urea. Analysis of the results revealed that days of panicle emergence (DPE), days to physiological maturity (DPM), plant height (PH) and grain yield (GY) were highly significantly ($p<0.01$) affected by main effects of varieties and NPSB rates. On the other hand, panicle length (PL), harvest index (HI) and thousand kernels weight (TKW) were highly significant ($p<0.01$)affected only by the main effect of varieties while numbers of total tillers (TT) and productive tillers (PT) were highly significantly ($p<0.01$) affected only by NPSB fertilizer rates. The longest DPE (57.20 days) and DPM (94 days) were recorded for variety Dagim while the highest GY (3936 kg ha^{-1}), PL (44.29 cm), HI (29.63%) and TKW (0.2413 g) were recorded for variety Quncho. Similarly Kora the highest PH (114.0 cm), TT (956.1 m^{-2}) and PT (911.7 m^{-2}) were obtained at 200 kg NPSB ha^{-1} whereas the highest GY (3985 kg ha^{-1}) was obtained at 150 kg NPSB ha^{-1}. The interaction of varieties and NPSB rate was significant ($p<0.01$) on aboveground dry biomass (ABY), straw yield (SY) and lodging index (LI). The highest ABY (15926 kg ha^{-1}) and SY (11537 kg ha^{-1}) were obtained from combination of variety Quncho with 200 kg NPSB ha^{-1}. The result of economic analysis showed that application of 200 kg NPSB ha^{-1} for variety Quncho gave the highest economic benefit of 79531.67 Birr ha^{-1} with the marginal rate of return of 790%. Therefore, variety Quncho at 200 kg NPSB ha^{-1} supplemented with 46 kg N ha^{-1}can be tentatively recommended for production of tef in the study area

Keywords: Nitrogen, Partial budget analysis , Tef

1. INTRODUCTION

Tef [*Eragrostis tef* (Zucc.) Trotter] is an annual grass crop and important cereal harvested for grain in Ethiopia. Ethiopia is not only the origin of tef but it is also the center of diversity (Vavilov, 1951). Tef is adaptable to a wide range of ecological conditions in altitudes ranging from near sea level to 3000 m.a.s.l and even it can be grown in an environment unfavorable for most cereal, while the best performance occurs between 1100 and 2950 m.a.s.l in Ethiopia (Hailu and Seyfu, 2001).

In the country out of 7.6 million ha allocated for cereals, tef occupied 3.01 million hectares and the production was about 50.1 million ton annually (CSA, 2016/17). The Oromia regional state is ideal for tef production in Ethiopia. In the region, among the total land area of 4,792,014 hectares planted by cereals, tef covered 1,441,029 hectares, which is 30.1% of the production area covered by all cereals grown in the region. Among all the crops grown in the region, tef is the first major crop in area coverage (CSA, 2017). In Special Oromia Zone, tef is one of the major cereal crops produced for the purpose of both home consumption and market. In the Zone, out of the total land size of 57522 hectares planted by cereals, tef covered 35284 hectares, which is 61% of the production area covered by all cereals in 2016/17 cropping season (CSA, 2017). However, out of the total cereal grain production (114964 tons), tef accounted for 48% (55749 tons), and the average yield of tef in 2016/17 cropping season was only 1.6 t ha^{-1} which is also very low as compared with the yield potential of tef (CSA, 2017). Tef is primarily grown to prepare *injera*, *porridge* and some native *alcohols* drinks. The straw is used for animal feed. The nutritional value of tef grain is similar to the traditional cereals. Tef is considered to have an excellent amino acid composition, lysine levels higher than wheat or barley, and slightly less than rice or oats. Tef contains very little gluten and higher in several minerals, particularly iron than other cereal crops.

Tef is also grown on a limited basis for livestock forage in other parts of Africa, India, Australia, and South America. In the U.S., small acreages of tef are grown for grain production and sold to Ethiopian restaurants (Carlson, Idaho) or utilized as a late planted livestock forage (Wondimu and Mekbib, 2001)

Tef is a versatile cereal crop with respect to adaptation for the diverse agro-climatic and soil conditions (Deckers *et al.*, 2001). Inspite of the importance of in Ethiopia, its grain yield productivity level is generally low as compared to its attainable yield (Seyfu, 1997). The low productivity of tef could be due to a complex interaction among the environments, lack of appropriate management practices, biotic and abiotic stresses. Of these, low soil fertility is one of the major causes of temporal and spatial yield variability in tef (Brhan, 2012)

The unbalanced and un optimal fertilization of Ethiopian soils by applications of only di-ammonium phosphate (DAP) and urea (N and P containing fertilizers) for a long period of time has led to severe nutrient mining of the agricultural soils, particularly when the entire crop biomass (grain and stover) are removed from the land (Tekalign *et al.,* 2001). Studies showed that nutrients such as potassium (Astatke *et al.,* 2004); sulfur-S (Habtegebrial and Singh, 2006) and Zn (Bereket *et al.,* 2014) are also becoming tef yield limiting nutrients in different areas in addition to nitrogen (N) and phosphorus (P) nutrients. The deficiency of even one nutrient can reduce crop yield. Thus, application of fertilizers containing K, S, Zn and other essential nutrients should be considered to improve the productivity of tef.

Hence, the continuous use of DAP and urea should be complemented with the application of additional blended fertilizers, containing macro and micro nutrients. Other factors which affect the yield of tef are the variety, sowing method and soil quality and to the high competition for sunlight, moisture, and nutrients (Fufa *et al*., 2011). Additionally, the placement of the seed on the soil instead of in the soil leads to extremely poor crown and root development, lower tillering capacity and susceptibility to lodging and then lower yield (Berhe *et al.,* 2011, Fufa *et al*., 2011).

Since fertilizers were introduced to Ethiopia in 1960s through programs such as the Freedom from Hunger Campaign, virtually all fertilizers used in Ethiopia are limited to DAP and urea. However, recently completed research and soil tests through the Ethiopian Soil Information System Project revealed that Ethiopian soils are deficient in various other nutrients that are not provided by DAP and Urea (ATA, 2013a).

Furthermore, Ethiopia's crop yields have been constrained by a very limited set of imported fertilizers. However, there is little information on the impact of different types of fertilizers except nitrogen and phosphorous (46 kg N and 20 kg P per hectare) while, according to the soil fertility map made over 150 districts, most of Ethiopian soil lack about seven nutrients N, P, K, S, Cu, Zn and B (Ethio-SIS, 2014).

Most research work focused on NP requirements of crops, limited information is available on various sources of fertilizers such as K, S, Zn and B and other micronutrients. Therefore, application of other sources of nutrients beyond urea and Diammonium Phosphate (DAP), especially those containing K, S, Zn and other micro-nutrients could increase crop productivity (CSA, 2017). This can be achieved by application of blended fertilizers, the mechanical mixture of two or more granular fertilizer materials containing N, P, K and other essential plant nutrients such as S, Zn, and B, recently known to Ethiopia. Application of balanced fertilizers could be the basis to produce more crop output from existing land under cultivation and nutrient needs of crops according to their physiological requirements and expected yields (Ryan, 2008).

Tef responds differently to fertilizer rates and types depending on soil type and cultivars (Melesse, 2007). Generally, the recommended rate of fertilizer for tef is 25-40 kg N ha^{-1} on light soils such as *Nitosols*, *Luvisols* and *Cambisols* and 50-60 kg N ha^{-1} for heavy soils such as *Vertisols* (Deckers *et al*., 2001). The average highest grain yield of 2.44 tons ha^{-1} was obtained when 46 kg ha^{-1} of N and 20 kg P ha^{-1} were used for tef (Fikiremariam *et al.*, 2014).

The local tef variety that is most often cultivated in the study area is known as *Sergegna*, has low yield potential. However, recently genetic improvement of the crop has resulted in the development of varieties that could yield as high as 3 tons ha^{-1}. Such a high yielding varieties have been released by Debre-Zeit Agricultural Research Centre and are being aggressively disseminated in different parts of Ethiopia twenty improved tef varieties (11 from crosses) have so far been released by DZARC. Moreover, to realize its optimum yield, appropriate fertilizer rates have to be used since this could vary according to soil type and weather conditions of the area and the varieties. In the Ada'a plains, where the varieties were developed, the recommended N and P rates are 46 kg N and 18.92 kg P ha^{-1} (AWARDO, 2018 unpublished). But, so far there is no work with respect to the optimum rates of NPSB to tef production in the study area.

Therefore, it is important that appropriate rates of blended NPSB fertilizer could have to be determine for the three recently released varieties Quncho, Kora and Dagim in the study area. Therefore, this study was undertaken with the objectives of determining the response of tef varieties to blended NPSB fertilizer rates tested and identifying the economically feasible rates of blended NPSB fertilizers for the varieties.

2. LITERATURE REVIEW

2.1. Origin of Tef

The fact that the genetic diversity for tef exists nowhere in the world except in Ethiopia, indicates that tef was originated and domesticated in Ethiopia. Vavilov (1951) identified Ethiopia as the centre of origin and diversity of tef. Tef is endemic to Ethiopia and its major diversity is found only in this country. As it is true with several other crops, the exact date and location for the domestication of tef is unknown. However, there is no doubt that it is a very ancient crop in Ethiopia, where domestication took place before Christ. According to Ingram and Doyle (2003), tef was introduced to Ethiopia well before the Semitic invasion of 1000 to 4000 BC. It was probably cultivated in Ethiopia even before the ancient introduction of emmer wheat and barley. According to Tadesse (1975), tef seeds found by Unger (1866) in the Pyramid of Dashur (3359 BC) and from the ancient Jewish town of Ramses in Egypt were probably *Eragrostis aegyptiaca* or *Eragrostis pilosa* and thus are not good evidence for the cultivation of tef in ancient Egypt.

2.2. Botany of Tef

Tef is a fine stemmed, tufted annual grass characterized by a large crown, many shoots, and a shallow fibrous root system. The plant germinates quickly and adapted to environments ranging from drought stress to waterlogged soil conditions. The inflorescence is an open panicle and produces small seeds. The florets consist of a lemma, three stamens, two stigma and two lodicules. Floret colors vary from white to dark brown. Plant height of tef varies from 25-135 cm depending on cultivar type and growing environments. The panicle length ranges from 11-63 cm and the spikelet numbers per panicle varies from 190-1410. Panicle types also vary from loose, lax, compact, multiple branching, multi-lateral and unilateral loose to compact forms. Maturity varies from 93–130 days. Grain colour ranges from pale white to ivory white and from very light tan to deep brown to reddish brown purple. Tef seed is very small, ranging from 1-1.7 mm long and 0.6–1 mm diameter with l000 seed weight averaging 0.3–0.4 g (Hesselbach and Westphal, 1976).

2.3. Importance of Tef

Tef has as much or even more food value than the major grains such as wheat, barley, and maize. This is probably because it is always eaten in the whole grain form. The germ and bran are consumed along with the endosperm (Demeke and Di Marcantonio, 2013).

In Ethiopia, tef is primarily grown for its grain that is used for preparing *injera* (leavened bread), which is a staple and very popular food in the national diet of most Ethiopians. It can also be used in many other food products, such as *kitta* (unleavened bread), *anebaberro* (double layered injera), porridge, gruel, and local alcoholic beverages, such as *tella* and *katikala* (Seyfu, 1997; Hailu and Seyfu, 2001). However, tef is not suitable for bread making as it lacks the necessary amount and quality of protein complex called "gluten" that can be formed into dough with the rheological properties required for the production of leavened bread in wheat.

According to Patricia and Lisette Van (2008), tef is rich in energy (353-367 K cal/100 g). Its fat content averages about 2.6%. The protein content is as good as or better than that of other cereals and it ranges from 8 to 15%, with average of 11%. The protein digestibility is probably high because the main protein fraction, albumin, glutline, and globulin are the most digestible types. The vitamin content seems to be about average for a cereal. The level of minerals is also good; (average ash content is 3%). Tef is reported rich in iron, calcium, potassium and phosphorus. The iron (0.011-0.033%) and calcium (0.1-0.15%) contents are especially notable (Patricia and Lisette Van, 2008).

Abay *et al.* (2011) reported that tef contains 11% protein and is an excellent source of essential amino acids, especially lysine, the amino acid that is most often deficient in other grain foods. It contains more lysine than barley, millet, and wheat and slightly less than rice or oats. It is also further mentioned that tef is 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. It is also noted that tef is nearly gluten-free, and is gaining popularity in the whole food and health food industry in the USA as an alternative grain for persons with gluten sensitivity or allergic effect.

Tef may also have benefits 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 (Abay *et al*., 2011).

Tef straw, besides being the most appreciated feed for cattle, is also used to reinforce mud used for plastering the walls of house and local grain storage facility called *gotera*. Tef grain, owing to its high mineral content, has been used in mixtures with soybean, chickpea and other grains in the baby food industry (Seyfu, 1997).

Furthermore, Seyfu (1997) reported that tef is predominantly grown in Ethiopia as a cereal crop and not as a forage crop. However, when grown as a cereal, farmers highly value the straw of tef and it is stored and used as a very important source of animal feed, especially during the dry season. Farmers feed tef straw preferentially to lactating cows and working oxen. Cattle prefer tef straw over other cereals' straw, and for this reason, its price is higher than that of the other cereals.

Seyfu (1991) described the reason as why Ethiopian farmers prefer to grow tef as: it can be grown in areas experiencing moisture stress; can be grown in waterlogged areas and withstands anaerobic conditions better than many other cereals, including maize, wheat and sorghum; it is suitable for use in multiple cropping systems such as double, relay and intercropping; its straw is a valuable feed during the dry season when there is an acute shortage; it is highly preferred by cattle over the straw of other cereals and demands high prices in the markets; it has acceptance in the national diet, and it has got high demand and high market value and hence enables farmers to earn more than with other crops; it is a reliable and low risk crop and farmers use it as a rescue crop; it is not attacked by weevils and other storage pests and therefore it is safely stored under local storage conditions which results in reduced post-harvest management costs; and compared with any other cereals growing in Ethiopia and it has fewer disease and pest problems (Seyfu, 1991).

2.4. Agro-Ecological Requirements of Tef

Tef is adapted to a wide range of environments and presently it is cultivated under diverse agro-climatic conditions (Minale *et al.,* 2005). Tef has a short growing season with rainfall needs of 450–550 mm, and temperature range of 10–27^{o}C (Roseberg *et al.,* 2005). Tef is day length sensitive and flowers best during 12 hours of daylight (Stallknecht, 1997). Tef can grow at under broad range of altitudes where many other crops cannot, and it can be grown from sea level to as high as 3000 meters above sea level (m.a.s.l) with maximum production occurring between 1800-2100 meters above sea level (Seyfu, 1997; Stallknecht, 1997).

Dry land areas with shortage of rainfall are well secured through the production of tef. Tef is a reliable cereal during unreliable rainfall, especially during the occurrence of unpredictable dry spells. This makes tef an important grain for drought-prone and food-insecure areas. Its production is currently expanding to include many drought-prone areas of the country (ATA, 2013b).

Tef is well adapted to a wide range of soil types. It has the ability to perform well in black soils and, in some cases, in low soil acidities. Tef is normally grown on soils of neutral pH, but it has been observed that it tolerates soil acidity below pH 5. Differences exist between cultivars for response to saline conditions. In addition, tef has the capacity to withstand waterlogged, rainy conditions, often better than other cereal grains except rice (ATA, 2013b).

2.5. Major Tef Producing Regions in Ethiopia

In Ethiopia, tef is mainly produced in vast areas of Amhara and Oromia regions, the total area covered by tef in 2016/17 cropping season in these regions were 1,137,844 ha (37.70%) and 1,441,030 ha (47.75%), respectively (CSA, 2017). With smaller quantities in the Tigray 168,509 ha^{-1} (5.58%), SNNP 246,099 ha^{-1} (8.15%) and Benishangul-gumuz 24,432 ha^{-1} (0.81%) regions produced. There are 19 major tef producing zones in the country. In the Amhara region, East Gojjam, West Gojjam, North Gonder, South Gonder, North Wollo, South Wollo, North Showa and Awi Zones are the major producers of tef. Within Oromia region the major tef producing zones include the East Showa, West Showa, South West Showa, North Showa, East Wollega, Horo Guduroo Wollega, Jimma, Illubabor and Arsi and in Tigray region the Central and South Tigray Zones are the major tef producing Zones (ATA, 2013b).

2.6. Tef Production Constraints in Ethiopia

Environmental stress is the most important factor which affects crop production. According to Cassman (1999) only about 10% of world arable land may be classified into non-stress category. About 20% of the land is limited by mineral stress, 26% by drought stress and 15% by freezing stress. Modifying the environment for proper crop growth means alleviation of environmental stresses through the current crop management practices (Arkin and Taylor, 1983). In semi-arid and arid areas, rainfall is inadequate, erratic, and non-uniform in distribution. Moreover, because of degradation and poor vegetation cover, soils in semi-arid and arid areas have low fertility with poor water holding capacity. In addition to the above-mentioned problems, weeds also compete with the food crops for the available moisture (Reddy and Kidane, 1991); besides, there are occasional outbreaks of pests and diseases.

Tef is harvested very close to the ground because of the high value of the straw, leaving the soil bare for about half a year after harvest and exposing the ground further. Therefore, the loss of soil organic matter and physical erosion are major problems in some tef growing areas. Inorganic fertilizers are able to overcome some, but not all, of these deficiencies. According to Seyfu (1991), tef is mostly grown on soils that are less fertile, have moisture deficit and mostly on waterlogged soils during the main rainy season, all of which limit the growth and yield of the crop. Moreover, the cultural broadcast sowing influences the availability of adequate space for each plant and consequently influences the uptake and utilization of resources such as nutrients. The low yield is due to low soil fertility status which is a result of continuous cropping, overgrazing, soil erosion, and complete removal of field crop residues without any soil amelioration activities and low or no input of fertilizers (Seyfu, 1993).

Soil fertility problems involving other major and micro nutrients are also important constraints in tef production. Furthermore, soil acidity is one of the major problems in various tef growing agro-ecologies of Ethiopia. The fertilizer use in the country is mainly subjective without being based on soil fertility data and using blanket rate of application. Abreha and Yesuf (2008) also stated that the fertilizer recommendations given to farmers are of general type without considering the crop need, soil nutrient dynamics and agro-ecological factors.

2.7. Tef Varieties in Ethiopia

Tef grown in Ethiopia is represented by either landrace selections or developed varieties adapted to specific geographic regions (Ebba, 1975; Seyfu, 1997). The improved varieties respond by far greater than the local ones. It was possible to increase yield by more than two folds using improved cultivars. Tef is also grown from selected plant introduction (PI) accessions. The largest number of tef accessions (3842) is housed at the Plant Genetic Resources Centre of Ethiopia (Seyfu, 1997).

Most of the Ethiopian farmers use traditional landraces of tef and these are distributed all over the country. Local cultivars such as GeaLamie, Dabi, ShewaGimira, Beten and Bunign, which are early maturing varieties (<85 days), are widely used in areas that have a short growing period due to low moisture stress or low temperature. The same varieties are also used in areas with adequate rainfall and where double cropping is practiced. In the highly productive and major tef producing regions of Gojam and Showa, and in other regions where environmental stress is not severe, the local cultivars such as Alba, Ada and Enatit are used. Modern varieties are used in many regions but in very small areas within each region. In the regions of Gojam and Showa, which are located in the central highlands of Ethiopia and are also the largest and major tef production areas in the country, modern varieties are used as well as traditional landraces and local cultivars (Seyfu, 1997). There are released varieties cultivated with higher yield potential. The response of tef cultivars for fertilizer applications depends on the rates applied. There is a remarkable yield increase by the application of fertilizers with the recommended rates to the released cultivars than the locals. However, all growth parameters of both released and local cultivars are highly influenced by fertilizer application.

2.8. General Soil Fertility Concept

Soil fertility refers to the ability of the soil to supply the nutrients needed by the plants. According to Kirkham (2005), study of soil fertility involves examining the forms in which plant nutrients occur in the soil, how these become available to the plant, and factors that influence their uptake. This, in turn, leads to a study of the measures that can be taken to improve soil fertility and crop yields by supplying nutrients to the soil-plant system. This is usually done by adding fertilizers, manures and amendments to the soil but sometimes by supplying nutrients directly to the plant parts by means of sprays.

A mineral element is considered essential to plant growth and development if the element is involved in plant metabolic functions and the plant cannot complete its life cycle without the element; if usually the plant exhibits a visual symptom indicating a deficiency in specific nutrient, it can be corrected or prevented by supplying that nutrient (Patricia and Lisette Van, 2008).

Fertilizer usage plays a major role in the universal need to increase food production to meet the demands of the growing world population. Fertilizer application results in marked crop yield increases, which for most crops can be more than 100%. The extent to which fertilizers are used still differs considerably between various regions of the world (Brhan, 2012).

The quantity of fertilizer nutrients required for optimum crop production depends on the inherent capacity of the soil to supply adequate levels of nutrients to growing plants, the yield potential of the crop variety grown, the availability and cost of fertilizers, and the climatic conditions prevailing during the crop growing season (Ghulam *et al*. ,2010; Refissa, 2012).

According to Ghulam *et al*. (2010), the importance of soil fertility and plant nutrition to health and survival of all life cannot be understood as human population continues to increase, human disturbance of earth's ecosystem to produce food and fiber will place greater demand on soils to supply essential nutrients. Therefore, it is critical that we increase our understanding of the chemical, biological and physical properties and relationships in the soil-plant-atmosphere continuum that control nutrient availability.

2.9. Role of Nitrogen, Phosphorus and Sulfur in Tef

2.9.1. Nitrogen

Plants require nitrogen in the largest amounts among the soil nutrients for growth and development. The quantity of nutrients required to optimize or sustain crop production depends on the inherent capacity of the soil to supply adequate levels of nutrients to the growing plants, the yield potential of the crops, the variety grown and the availability and cost of fertilizers. Among the macro nutrients, N is ranked first in limiting sustainable crop production (Tisdale *et al*., 2002).

Generally, N is involved in cell multiplication, giving rise to the increase in size and length of leaves and stems, especially the stalks of grains and grasses; increases in chlorophyll contents, giving the leaves their dark green color; plays a part in the manufacture of proteins in the plant and is part of many compounds in the plant, including certain types of basic acids and hormones; and improves the quality and quantity of dry matter protein in grain crops (Ortiz-Monasterio *et al.*, 1997).

An adequate supply of N is used properly in conjunction with other soil fertility inputs, can speed up the maturity of crops such as small grains (Tisdale *et al.*, 2002). The supply of N is related to carbohydrate utilization. When N supplies are insufficient, carbohydrates will be deposited in vegetative cells, causing them to thicken, whereas under adequate N supplies and favorable conditions for growth, proteins are formed from manufactured carbohydrates resulting in more protoplasm (Tisdale *et al.*, 2002). In green plant material, protein N is by far the largest N fraction and amounts about 80 to 85% of the total nitrogen. The nitrogen of nucleic acid and that of soluble amino N are about 10% and 5%, respectively, of the total N present in plant material. Nitrogen is also an essential constituent of various coenzymes. The protein content of vegetative plant organs as well as storage tissue may also be influenced by N supply (Mengel and Kirkby, 1996).

Nitrogen is essential for plant growth as it is a constituent of all proteins and nucleic acids. It is an integral component of many essential plant compounds such as amino acids which are building blocks of all protein including enzymes, nucleic acids and chlorophyll (Brady and Weil, 2002). Since nitrogen is present in many essential compounds, it is not surprising that growth without added nitrogen is slow in plants (Dobermana and Fairhurst, 2000). An optimum supply of nitrogen to the plant stimulates root growth and development as well as uptake of other nutrients. Nitrogen also promotes activities essential for carbohydrate utilization and its most important function in plant is promotion of rapid growth through increasing height, tiller number, size of leaves and length of roots (Brady and Weil, 2002).

According to many researchers, application of N fertilizer is known to increase plant height, number of tillers and spike length in cereal crops (De Datta and Patrick, 1986). However, excessive concentration of N resulting from further increase in applied N rates resulted in lodging of plants (Barnes, 1985). Yield increases due to application of optimum N largely accrue from increased number of spikelets per panicle. In cereal grain formation, grain weight and tillering are highly dependent on hormone activity (Dubey and Bisen, 1979). Nitrogen nutrition stimulates tillering probably due to the effect of nitrogen on cytokinin synthesis (Salisbury and Ross, 1992).

Excessive nitrogen supply causes higher photosynthetic activity, vigorous growth, weak stem resulting in crop lodging, dark green color, reduced productive tillers, reduced product quality, delayed in maturity, increase in susceptibility to insect pest and diseases and build-up of nitrate which is harmful to animals (Brady and Weil, 2002).

Nitrogen deficiency causes stunted plant growth, development of thin spindly stem, low protein and high sugar content (thickening of cells) and chlorosis as deficiency symptoms on older leaves which could progress to necrosis under severe conditions. Nitrogen deficient plants respond quickly to the addition of N fertilizers if applied in a timely manner and properly. However, adverse effects on annual plants caused by early-stage lack of N cannot usually be corrected by late application of N (IAEA, 2000).

Tef responds to N application with remarkable changes in all its yield and yield components. Studies on the response of tef to N fertilizer, by different authors showed that increased application resulted in increased production. Different studies in various environments and times reported that tef responds highly to higher N fertilizer rates. Temesgen (2001); Legesse (2004); Mitiku (2008); and Haftamu *et al.* (2009) noted that application of 69 kg N ha^{-1} was the best to obtain high total biomass yield, straw yield and grain yield. On the other hand, Mulugeta (2003) found that application of high rates of N fertilizer (90 kg N ha^{-1}) increased the number of fertile panicles of tef.

2.9.2. Phosphorus

Phosphorus is the second most essential element for crop production in order to achieve maximum yields. A good supply of P has been associated with increased root growth and a stiff stalk to resist lodging (Miller and Donhue, 1995). Phosphorus plays an important role in energy storage and transfer in crop plants. Although P is essential for photosynthesis and other physico-chemical processes in the plant, it is deficient in most agricultural soils or where fixation limits its availability (FAO, 2000). In cereal crops, good P nutrition strengthens structural tissues such as straw or stalks, thus, helping to prevent lodging (Brady and Weil, 2002). Thus, sustainable crop production is impossible without application of P fertilizers (Sanchez *et al.*, 1996). Contrary to this, the application of P had shown no significant effects on crop phenology, growth, lodging, and yield and yield components of tef on *Vertisols* (Legesse, 2004).

Adsorption of P in Ethiopian soils is highly associated with pH, organic matter and content of clay (Tekalign *et al*., 2002). In phosphate fertilization, fixation is a predicament but retention depends on types of clay, temperature, organic matter, P status of soil, and type of reaction. At pH lower than 5.5, the reaction results largely from the reaction with Fe, Al, and their hydrous oxides leading into low forms of available P while at higher pH greater than 7 high concentrations of Ca, Mg, and their carbonates cause precipitation of the added P (Mengel and Kirkby, 1996). Adsorption of these soils is also highly correlated with exchangeable and extractable forms of Fe and Al in which the role of Al is more important than that of Fe under acid or neutral conditions.

Many sandy soils which are low in humus content, for instance, have low available P. Soils which are prone to strong phosphate fixation and adsorption to sesquioxides and clay minerals often require extremely high phosphate fertilizer application in order to alleviate the effects of fixation. In these strongly phosphate fixing soils, pH correction is also recommended since phosphate adsorption is especially high at low pH levels (Tisdale *et al*., 2002). Phosphorous has a lower mobility than any other nutrients and does not remain in a free state for long in which case it is slowly available to plants hence, the uptake of fertilizer P depends much on root growth and morphology of the crop being considered. Most of the P present in soils is in unavailable forms and added soluble forms of P are quickly fixed by many soils (Parnes, 1990). Plants absorb P in the form of $HPO4^{-2}$ and $H_2PO_4^-$ depending on the pH of the growing medium although there is no efficient mechanism in the soil to retain $H_2PO_4^-$ and HPO_4^{-2} ions in large quantities as exchangeable anions (Barker and David, 2007).

According to Legesse (2004), the total P uptake was significantly increased as applied P rate increased but this increase was not at all reflected in an increase in growth, yield and yield components. The same author reported that total P uptake was increased significantly due to the application of N, and maximum P uptake by tef was recorded. Therefore, in order to get optimum yield, 20 kg P ha^{-1} amount of P application was needed to satisfy the fixing ability of the soil and increased yield (Legesse, 2004).

Phosphorus application did not significantly affect panicle and grain weight, panicle length, plant height, harvest index, biomass, grain and straw yield of tef (Legesse, 2004). Grain P content also showed inconsistent trend with the increase in the application rate of P while the straw P remained almost the same (Legesse, 2004).

Phosphorus fertilizer trial on tef according to the finding of Alemayehu *et al.* (2006) indicated that the highest grain yield was obtained with the highest P fertilizer rate (34 kg P_5 ha^{-1}) in most localities of *Vertisols* and the highest grain yield in most localities of *Nitosols* were obtained at 26 kg P ha^{-1} with interaction of 100 and 60 kg N ha^{-1}, respectively. Similarly, phosphate fertilizer effect on most of the agronomic parameters of tef was discussed. Mehreteab (2008) reported that days to heading and maturity were significantly reduced as the level of phosphate fertilizer increased. However, panicle length, plant height, number of nodes, number of effective tillers, lodging index, biomass yield, grain yield and harvest index increased with an increased level of phosphate fertilizer and the optimum grain yield was obtained by applying phosphate fertilizer rate of 20 kg P $ha^{-1.}$

According to the finding of Alemayehu (2014), grain yield and yield related parameters of tef increased with increasing P rate except for days to flowering and maturity, and grain filling period. Grain yield increased from 84 to 218 g/m^2, total biomass 586 to 1016 g/m^2, harvest index 0.14 to 0.22%, panicle weight 0.49 to 0.73 g/m^2, and seed weight 0.25 to 0.38 g/m^2 when P rate was increased from 0 to 9 g/m^2 P_2O_5. In addition, increasing P rate from 0 to 9 g/m^2 P_2O_5 reduced days to flowering and maturity by 14 and 13 days, respectively.

2.9.3. Sulfur

Sulfur (S) is as important as nitrogen (Brady and Weil, 2002). Most crop growers are concerned about applying enough N to non-legume crops, but do not realize that sulfur is key to N use. As a result, adequate supply of S is needed in order for plants to use N. This is because both N and S are building blocks in protein and a deficiency of either results in shortages of chlorophyll, Rubisco (the enzyme which changes CO_2 into sugar), and nitrate reductase (an enzyme which converts plant nitrate into ammonia) (Brady and Weil, 2002).

Crop responses to applied sulfur have been reported in a wide range of soils in many parts of the world (Fageria, 2009). Sulfur (S) is required in similar amount as that of phosphorus and constitutes 0.2 to 0.5% dry matter accumulation in crop tissue (Ali *et al.*, 2008). It is required for the synthesis of S containing amino acids such as cystine, cysteine and methionine. Sulfur is also involved in carbohydrate metabolism of the crop plants (Balasubramaniyan and Palaniappan, 2004). Some of the most important functions of S include its role in specialized peptides, such as glutathione and thioredoxins, in redox reactions, and the role of disulfide bond (S-S) formation in the stabilization of protein structure (Inal *et al.*, 2003). Sulfur does not affect only nitrogen utilization and grain quality, but it also plays an important part in the formation of the baking quality (Ryant and Hrivna, 2004). It is absorbed by plants as SO_4^{2-} ion.

Sulfur can be limiting for plant growth in intensive farming system, after a rainy winter, mainly on sandy soils (Mathot *et al*., 2008). Sulfur deficiency has been reported in almost all cereal crops in various countries. The main reasons for sulfur deficiency are low organic matter content of the soil; low mineralization rate of organic matter due to unfavorable soil environment; depletion of soil reserves due to intensive cultivation, use of high yielding cultivars that remove greater amounts of S from soil, and the application of sulfur free fertilizers; declining S reserves in soil due to accelerated rate of soil erosion; use of high rates of nitrogen and potassium fertilizers, which require high rate of S; the decreased use of S-containing pesticides and fungicides and depletion of S from soils by volatilization and leaching (Fageria, 2009).

Sulfur deficiency is characterized by stunted growth, reduced plant height, tillers and spikelets, delayed maturity, and general yellowing of plants. Sulfur deficient plants have also less resistance under stress condition (Doberman and Fairhurst, 2000). Yellowed plants are also characteristic of nitrogen deficiency. However, unlike nitrogen deficiency which begins in the older leaves and progresses up on the plant, sulfur deficiency symptoms begin in the young, upper leaves first. Sulfur deficiencies are often misdiagnosed as nitrogen problems, leaving growers to wonder why their nitrogen applications are ineffective. In many crops, an acute sulfur deficiency causes the entire plant to turn yellow. In crops like maize and small grains, however, yellow stripes that run parallel to the leaf blade are common. Sulfur deficiency is most frequently observed on very sandy soils with low organic matter content during seasons of excessive rainfall. Generally the deficiency of S has pronounced retarding effect on plant growth and is characterized by uniformly chlorotic plants which are stunted, thin stemmed and spindly (Brady and Weil, 2002). Without adequate sulphur, crops cannot reach their full potential in terms of yield (Jarvan *et al.,* 2012); the most important role in such an increase of grain yield was performed by the number of grains per ear as one of the yield components. Addition of S to a calcareous soil may result in a decline in soil pH and consequently may increase availability of micronutrients like B (Nadian *et al*., 2010).

According to Habtegebrial and Singh (2006) found that combined N and S fertilization increased the dry matter and grain yields of tef on average by 1.7 and 0.3 kg ha^{-1}, compared with the control and S fertilization increased the nitrogen use efficiency of the tef crop by 36%. Reproductive growth of wheat appears to be more sensitive to sulphur deficiency than vegetative growth, with decreased grain size under sulfur-limiting conditions. Similarly, Jarvan *et al.* (2012) reported that when sulfur is added at the rate of 10 kg ha^{-1} to nitrogen, the cysteine and methionine contents increased by 8.1 and 15.1%, respectively. Similarly, addition of 100 kg N ha^{-1} with 10 kg S ha^{-1} to winter wheat gave yield of 5.88 t ha^{-1} while it gave 5.73 t ha^{-1} when 100 kg N ha^{-1} with 6 kg S ha^{-1} (Jarvan *et al*., 2012).

2.10. Role of Boron in Small Cereals

The micronutrients or trace elements are iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), molybdenum (Mo), chlorine (Cl) and boron (B) (Fageria, 2009). They are part and parcel of the key substances in plant growth and are comparable with the vitamins in human nutrition. Being taken up in minute amounts, their range of optimal supply is very small (FAO, 2000). Their plant availability depends primarily on the soil reaction.

Boron (B) is an essential micronutrient for plants and plant requirements for this nutrient are lower than the requirements for all other micronutrients except molybdenum and copper. It is the only non-metal among the micronutrients and also the only micronutrient present over a wide pH range as a neutral molecule rather than an ion (Epstein and Bloom, 2005).

Boron is an essential element for better utilization of macro-nutrients by plants and there by greater translocation of photo-assimilates from source to sink during growth period (Ali *et al.,* 2013). Boron is also involved in the transport of sugars across cell membranes and in synthesis of cell wall material. It influences transportation through the control of sugar and starch formation (Singh *et al.,* 2015).

Boron-deficiency symptoms first become evident on the younger leaves, which change color and become hardened, malformed, and necrotic (Dursun *et al.,* 2010). Deficiency of boron can also cause reduction in crop yield and inferior crop quality (Singh *et al.*, 2015). Its deficiency results in low grain set, poor seed quality and interferes rapidly with cell division, cell membrane permeability and often results in phenolic compounds accumulating in plant tissue (Shorrocks, 1997). Even the cereals (like wheat and rice) with small B requirement can suffer from impaired seed set due to B shortage at a critical growth stage (Shorrocks, 1997). Boron is involved in N and P metabolism, and in plants poorly supplied with B, NO_3^-, N accumulated in the roots, leaves and stems, showing that NO_3^- reduction and amino acid synthesis were inhibited. Boron is mainly associated with cell wall pectin and physical characteristics of the growing cell wall were altered under B deficiency (Brown and Hu, 1997). Boron uptake by plants is controlled by the B level in the soil solution rather than the total B content in the soil (Fageria and Barbosa Filho, 2006).

Plants absorb boron in the form of H_3BO_3, and it moves to plant root mainly by mass flow and diffusion. Uptake of B in crop plants is mainly determined by yield level. Variation in B uptake was about 99% in rice and 97% in dry bean with increasing plant age. This variation in boron is not efficiently remobilized in many plant species, and that is why B deficiency occurs in young parts of the plant and toxicity in mature parts of plants (Fageria and Barbosa Filho, 2006). The decrease in B uptake at harvest was associated with translocation of this element to grain. In B-deficient soils, use of appropriate source is fundamental to improve crop yields and B use efficiency. Principal B carriers are boric acid, borax, or sodium tetra-borate that are commonly used fertilizers for correcting B deficiency in crop plants. Boron fertilizers can be applied as broadcast, band, or foliar (Fageria, 2009).

Boron is unevenly distributed within plants and highest levels are found in reproductive structures such as anthers, stigma and ovaries. Boron requirements vary with plant type: in monocotyledons species, leaf content ranges from 1 to 6 mg kg^{-1}; in most dicotyledons from 20 to 70 mg kg^{-1}; and in dicotyledons with latex systems from 80 to 100 mg kg^{-1}. Crops such as sugar beet, celery, apple, pear and grape have higher B requirement (Benton, 2003).

The behavior of boron in soil and plant is uniquely different to other trace elements and naturally high soil reserves or over-application of boron fertilizer can rapidly lead to toxicity in cereals and other sensitive crops (James, 1997). When plants are exposed to boron toxicity, it will cause reduction of leaf area, formation of chlorotic and necrotic patches in older leaves, delay of development and inhibition of plant growth (Nable *et al.*,1997).

According to Debnath *et al.* (2014), wheat cultivar “Shatabdi” was grown successfully for obtaining maximum yield with 120 kg N ha^{-1} and 2 kg B ha^{-1} individually or in combination along with recommended rates of TSP and gypsum fertilizers. Muhmood *et al.* (2014) reported that application of 2 kg B ha^{-1} along with recommended doses of chemical fertilizer gave 11% more grain yield of wheat than with the sole application of N, P and K fertilizers.

3. MATERIALS AND METHODS

3.1. Description of Experimental Site

The experiment was conducted at Gelan, Akaki district, Central Ethiopia, during 2018 main cropping seasons. The site of the experiment is located at latitude of 8^{o} 44′ N, longitude of 38^{o} 58′ E and at an altitude of 1860 meters above sea level in Central Ethiopia.

The main rainy season (*Meher*) in the area is from mid-June to mid-September. According to the weather record from Debre Zeit Meteorology Station, the average annual rainfall, and annual mean minimum and maximum temperatures of the area based on the last 10 years (2009-2018) records were 850 mm, and 8.5 ^{o}C and 22.0 ^{o}C, respectively (Appendix Tables 1. 2. and 3). The total rainfall of the study area during the growing season was 700 mm and was suitable for maximum tef production throughout the growth stages and the minimum and maximum mean temperatures were 12.0 ^{o}C and 21.5 ^{o}C, respectively (Appendix Tables 1, 2 and 3).

The major soil type of the study area is *Pellic Vertisols* and major crops grown in the area are tef, wheat, chickpea, and lentil. The area has been under cultivation for long periods of time and so are the crops. Almost all farmers practice crop-dominated mixed crop-livestock farming system in every fragmented plots of land that allow the land no time to rest (AWARDO, 2018, unpublished)

3.2.Description of Experimental Materials

3.2.1. Planting materials

The tef varieties named ‘Quncho’ (DZ-Cr-387 RIL355), ‘Kora' (DZ-Cr-438 RIL133B) and 'Dagim' (DZ-Cr-438(RIL-91A) which were developed and released by Debre Zeit Agricultural Research Center (DZARC) in 2006, 2014, and 2015, respectively were used for the experiment.

Quncho is a high yielding cultivar adapted to a wide range of altitudes. Dagim is white seeded, high yielding tef variety with grain yield advantage of 7.31% and 8.14% over the standard check (Quncho) and local check, respectively, as well as Kora is white seeded high yielding variety resulting from a simple cross and released as an alternative variety to

Quncho. The seeds of tef varieties were obtained from Debre Zeit Agricultural Research Center.

3.2.2. Fertilizer Materials

Blended NPSB (18.9% N, 16.2% P, 6.95% S and 0.1% B) and N in the form of Urea (46% N) were used as sources of nutrient elements.

3.3. Soil Sampling and Analysis

Surface soil samples (0-30 cm depth) were collected randomly by Auger sampler in a *zigzag* pattern before sowing of the crop from the entire experimental field and composited into one sample. From this mixture, a sample weighing 1.0 kg was taken. Air dried soil sample was grinded with a wooden pestle and mortar under shading. Before analysis, the sample was sieved through a 2-mm sieve mesh. The soil analysis was done for soil textural class, soil pH, organic carbon, total N, available P, CEC, available S and B. The soil analyses was done at Horticoop Ethiopia (Horticulture) PLC Soil and Water Analysis Laboratory at Debre Zeit town.

Soil textural Class was determined by Bouyoucos Hydrometer Method (Bouyoucos, 1962).Soil pH was determined in 1:2.5 soil: water ratio using a glass electrode attached to a digital pH meter (Walkley and Balck, 1934). Organic carbon was estimated by the wet digestion method (Walkley and Balck, 1934) after air-dried soil was grinded to pass a 0.2 mm sieve

To determine the cation exchange capacity (cmol kg^{-1} soil), the soil sample was leached using 1 M ammonium acetate, washed with ethanol and the adsorbed ammonium was replaced by sodium (Na). Then, the CEC was determined titrimetrically by distillation of ammonia that was displaced by Na (Sahlemedhin and Taye, 2000). Total nitrogen (%) was determined using the Kjeldhal method (Jackson, 1973). Available phosphorus (ppm) was determined by Olsen method (Olsen *et al*., 1954). Available sulfur (meq/l SO_4^{-2}) and boron were determined using Mehlich-3.

3.4. Treatments and Experimental Design

The treatments consisted of factorial combinations of three tef varieties (Quncho, Kora and Dagim) and five levels of blended NPSB (0, 50, 100, 150 and 200 kg ha^{-1}) fertilizer rates with uniform rate of urea (46 kg N ha^{-1}).

Table 1.Fertilizer compositions of experimental treatments

No.	Treatments		Total composition of the nutrients in the treatment (kg ha^{-1})			
	Blended NPSB rate (kg ha^{-1})	Nitrogen rate (kg ha^{-1})	N	P	S	B
1	0	46	46	0	0	0
2	0	46	46	0	0	0
3	0	46	46	0	0	0
4	50	46	55.45	8.1	3.48	0.05
5	50	46	55.45	8.1	3.48	0.05
6	50	46	55.45	8.1	3.48	0.05
7	100	46	64.9	16.2	6.95	0.1
8	100	46	64.9	16.2	6.95	0.1
9	100	46	64.9	16.2	6.95	0.1
10	150	46	74.35	24.3	10.43	0.15
11	150	46	74.5	24.3	10.43	0.15
12	150	46	74.35	24.3	10.43	0.15
13	200	46	83.8	32.4	13.3	0.2
14	200	46	83.8	32.4	13.3	0.2
15	200	46	83.8	32.4	13.3	0.2

The experiment was laid out in randomized complete block design (RCBD) with three replications.

3.5. Experimental Procedure

The experimental field was prepared according to the local practice. Thus, the land was ploughed two times using oxen before planting and the third ploughing was done before sowing to make it ready for compaction and to bury early emerging weeds. In accordance with the specifications of the design, a field layout was prepared. The size of each experimental plot was 2.4 m x 2.4 m (5.76 m^2). The blocks were separated by 1.0 m wide open spaces, whereas the plots within a block were 0.5 m apart from each other. After the layout, the plots were leveled manually, and each treatment was assigned randomly to the experimental plots within a block.

The tef varieties were drilled uniformly at the rate of 5.0 kg ha^{-1} in rows of 20 cm apart on the 21th of July 2018. Thus, there were 12 rows in each plot. The entire blended NPSB fertilizer was applied as per the treatments at a full dose at sowing, whereas N was applied in two splits (½ at sowing and ½ at tillering about 30 days after sowing) in the form of urea. The outermost two rows from each side of a plot and 0.1 m on both ends of each row were considered as border and were not included for recording the data. Thus, the net plot size was 2 m x 2.2 m (4.4 m^2). Harvesting was done on the 20th of November 2018 when the senescence of the leaves took place as well as the grains came out free from the glumes when pressed between the forefinger and thumb. The harvested total biomass yield was sun dried until constant weight. The total dry matter was weighed by using field balance. Threshing and winnowing were done manually by hand on a mat. After threshing, the grain yield was weighed using sensitive digital balance. All other cultural practices were uniformly applied to each of the plots as per the recommendations for the test location.

3.6. Data Collected

3.6.1. Phenological data

Days to 50% panicle emergence: was determined as the number of days from sowing to the time when 50% of the plants started to emerge the tip of panicles through visual observation.

Days to 90% physiological maturity: was determined as the number of days from sowing to the time when 90% of the plants reached physiological maturity based on visual observation. It was indicated by senescence (turning to light yellow) of the leaves and vegetative parts as well as free threshing of grain from the glumes when pressed between the forefinger and thumb.

3.6.2. Growth parameters

Plant height: was measured at physiological maturity from the ground level to the tip of panicle by hand meter from ten randomly pre-tagged plants in each net plot and then averaged on plant basis

Panicle length: is the length of the panicle from the node where the first panicle branches emerged to the tip of the panicle by hand meter which was determined from an average of ten pre-tagged plants per net plot.

3.6.3. Yield components and yield

Total tillers: The numbers of tillers (both effective and non-effective tillers) were determined at maturity by counting all the tillers in 0.5 m length from two rows of net plot area at physiological maturity and then converted to m^2.

Number of productive tillers: The numbers of tillers bearing panicle were determined by counting the tillers from an area of 0.5 m length from two rows of net plot at maturity and then converted to m^2.

Biomass yield: At harvest maturity, the total aboveground dry biomass was weighted after sun drying until constant weight from the net plot area and then expressed in kg ha^{-1}.

Grain yield: was weighted after harvesting and threshing the crop from the net plot area and the yield was expressed in kg ha^{-1}then the weight was adjusted to 12.5% moisture content.

Thousand kernels weight: The weight of 1000 kernels from the bulk of threshed yield was determined by carefully counting the small grains by hand and weighing them using a sensitive balance

Straw yield: After threshing and measuring the grain yield, the straw yield was determined by subtracting the grain yield from the total aboveground biomass yield.

Harvest index: Harvest index was calculated by dividing grain yield by the total aboveground dry biomass yield and multiplied by 100.

Lodging index (%): The degree of lodging was assessed just before the time of harvest by visual observation based on the scales of 1-5 where 1 (0-15^o) indicates no lodging, 2 (15-30^o) indicate 25% lodging, 3 (30-45^o) 50% indicate lodging, 4 (45-60^o) indicate 75% lodging and 5 (60-90^o) indicate 100% lodging (Donald, 2004). The scales were determined by the angle of inclination of the main stem from the vertical line to the base of the stem by visual observation. Each plot was divided based on the displacement of the aerial stem in to all scales by visual observation. Each scale was multiplied by the corresponding percent given for each scale and average of the scales represents the lodging percentage of that plot. Data recorded on lodging percentage were transformed by arcsine transformation method to normalize the error mean square as described by Gomez and Gomez (1984).

3.7. Statistical Data Analysis

Data collected were subjected to analysis of variance (ANOVA) using GenStat release 18th ed. software (GenStat, 2016). Means of significant treatment effects were separated using the Fisher's protected Least Significant Difference (LSD) test at 5% level of significance.

3.8. Partial Economic Analysis

An economic analysis was done using partial budget procedure described by CIMMYT (1988). Labour costs involved for application of blended NPSB rates were recorded and used for analysis. The current (November to December, 2018) price of grain and straw yield of tef were valued at an average open market price at *Bishoftu* town which were 25.0 ETB kg^{-1} and 0.5 ETB kg^{-1}, respectively. The net returns (benefits) and other economic analysis were based on the formula developed by CIMMYT (1988) and given as follows:

Unadjusted grain and straw yield (UGY and USY) (kg ha^{-1}):are the average grain and straw yield of each treatment.

Adjusted grain and straw yield (AGY and ASY) (kg ha^{-1}): are the average grain and straw yield adjusted downward by a 10% to reflect the difference between the experimental yield and yield of farmers.

Gross field benefit (GFB) (ETB ha^{-1}): was computed by multiplying field/farm gate price that farmers receive for the crop when they sell it as adjusted yield. GFB = AGY(ASY) × field/farm gate price for the crop.

Total variable cost (TVC) (ETB ha^{-1}): was calculated by summing up the costs that vary, including the cost of blended NPSB fertilizer (10.50 ETB kg^{-1}) at the time planting (July 21, 2018), and labour cost for application of fertilizers (4 persons ha^{-1}, each 80 ETB day^{-1}). The costs of other inputs and production practices such as labour cost for land preparation, planting, weeding, harvesting and threshing were considered the same for all treatments or plots.

Net benefit (NB) (ETB ha^{-1}): was calculated by subtracting the total variable costs (TVC) from gross field benefits (GFB) for each treatment as NB = GFB – TVC

Marginal rate of return (MRR) (%): was calculated by dividing change in net benefit (ΔNB) by change in total variable cost (ΔTVC) as $\mathrm{MRR} = \frac{\Delta \mathrm{NB}}{\Delta \mathrm{TVC}} \times 100$

The dominance analysis procedure as described in CIMMYT (1988) was used to select potentially profitable treatments from the range that was tested. The discarded and selected treatments using the technique were referred to as dominated and non dominated treatments, respectively.

Identification of a candidate recommendation was from among the non-dominated treatments. That is the treatment which gave the highest net return and a marginal rate of return greater than the minimum acceptable to farmers (100%) was considered for the recommendation.

4. RESULTS AND DISCUSSION

4.1. Soil Physico-Chemical Properties

The results of the pre-sowing composite soil sample laboratory analyses indicated that the particle size distribution of the soil of the experimental site was 65% clay, 16% silt and 19% sand (Table 2). Thus, the texture of the soil was clay according to soil textural triangles

The pH of the soil was 7.30 (Table 2) which was almost neutral (Tekalign, 1991). This value falls in the pH range that is very conducive for tef production as optimum soil pH for tef production from 6-7.5 (Seyfu, 1993).

The CEC of the site was 57.02 cmol kg^{-1} soil (Table 2). According to Landon (1991), top soils having CEC greater than 40 cmol kg^{-1} soil are rated as very high. Thus, the soil of the study area has very high CEC, which is an indication of good agricultural soil. Usually, soil cation exchange capacity describes the potential fertility of soils and indicates the soil texture, organic matter content and the dominant types of clay minerals present. In general, soils high in CEC contents are considered as agriculturally fertile (Tegbaru, 2014)

The organic carbon content (OC) of the experimental field was 0.97% (Table 2) which is low according to the rating of Tekalign (1991), who rated soils having OC value in the range of 0.5-1.5% as low. This indicates the low potential of the soil to supply nitrogen to plants through mineralization of organic carbon. The low amount of soil organic carbon might be due to complete removal of crop residues, and less aeration due to soil compaction of sub-soils. Most cultivated soils of Ethiopia are poor in organic matter content due to low amount of organic materials applied to the soil

The total nitrogen was 0.08% (Table 2) which was low according to the classification of Tekalign (1991). The low nitrogen content might be due to the loss of nitrogen from the soil system easily through leaching, denitrification, volatilization, crop removal, soil erosion and runoff as the land is continuously cultivated.

Olsen *et al.* (1954) classified soil P availability of <3 ppm very low, 4-7 ppm low, 8-11 ppm medium, 12-20 ppm high >20 ppm very high. Therefore, the experimental soil has high P content of 14.69 ppm.

The analysis for available sulfur and boron indicated that the experimental soil had value of 14.69 ppm of available sulfur which is rated low and < 0.0004 of available B which is rating as very low according to Ethio-SIS (2014).

Table 2. Soil physical and chemical properties of the experimental site before sowing of tef

Soil properties	Values	Ratings	References
A. Physical properties			
Clay (%)	65		
Silt (%)	16		
Sand (%)	19		
Textural class	Clay		
B. Chemical Properties			
pH (1:2.5 H_2O)	7.30	Neutral	Tekalign (1991)
Organic carbon (%)	0.97	Low	Tekalign (1991)
Total nitrogen (%)	0.08	Low	Tekalign (1991)
Available P (ppm)	14.69	High	Olsen *et al.*(1954)
CEC (meq/100 g soil)	57.02	Very high	Landon *et al.* (1991)
Available sulfur (ppm)	14.69	Low	Ethio-SIS (2014)
Available boron (ppm)	0.0004	Very low	Ethio-SIS (2014)

4.2. Phenological Traits

4.2.1. Days to panicle emergence

The main effect of varieties and blended NPSB rates were highly significant ($p<0.01$) on the days to panicle emergence of tef (Appendix Table 4). However, the interaction effect of the two factors was not significant (Appendix Table 4).

The longest days to 50% panicle emergence (57.20 days) was recorded from the variety Dagim while the lowest (54.87 days) was recorded from variety Kora (Table 3). The shortest days to 50% panicle emergence of Kora varieties might be due to the variety have short life span for growth and development.

This result was also in agreement with Kebebew *et al.* (2017) who reported that varieties Dagim and Kora took 59 days and 46 days, respectively, to 50% panicle emergence

With regards to the NPSB effect, the longest days to 50% panicle emergence (59.11 days) was obtained from the unfertilized plots while the shortest days to 50% panicle emergence (53.89 days) was obtained with the application of 200 kg NPSB ha^{-1}.

The hastened panicle emergence as a result longest rates of blended NPSB fertilizers could be due to early establishment, rapid growth, and development of the crop. The application of N hastened the days to heading possibly because the tef plants were able to take up sufficient N from the soil and also because uptake of N may have enhanced the uptake of other nutrients such as P which might speed up growth and development of the crop. This result is consistent with the result of Temesgen (2001) who reported that N supply promotes the uptake of other nutrients, enhancing growth and development of tef.

This result was also in agreement with that of Sate (2012) who found that N and P_2O_5 at the rates of 64/46 kg ha^{-1} significantly reduced days to heading of tef over the control. Similarly, Getahun *et al.* (2018) reported that the heading of tef plants was accelerated as NP rate increased from zero to 69 kg N ha^{-1} and 13 kg P ha^{-1} fertilizer applications.

4.2.2. Days to physiological maturity

The main effect of varieties and blended NPSB rates were highly significant ($p<0.01$) on the days to physiological maturity of tef (Appendix Table 4). However, the interaction effect of the two factors was not significant (Appendix Table 4).

The longest days to physiological maturity of tef (94.00 days) was recorded for variety Dagim which was statistically at par with Kuncho while the shortest days to maturity (90.07 days)was recorded for variety Kora (Table.3.). The shortest days to physiological maturity of tef might be due to Kora varieties are short life span than Dagim varieties..

This result was also in agreement with Solomon *et al.* (2017) who reported that varieties Dagim and Kora took 114 days and 106 days, respectively. to physiological maturity of tef

The longest days to physiological maturity of tef (97.22 days) was obtained from the unfertilized plots while the shortest days to physiological maturity (89.89 days) was obtained with the application of 200 kg NPSB ha^{-1} fertilizers.

The enhanced maturity with the application of the highest blended fertilizer could be due to the presence of balanced nutrients in the blended fertilizer. Normally, crops treated with N show better vegetative growth and that treated with P fertilizer exhibit good root development to reach physiological maturity in time. Brady and Weil (2002) described that phosphorus application could possibly shorten maturity date since it promotes rapid cell division. Onasanya *et al*. (2009) showed that phosphorus plays an important role in many physiological processes that occur within a developing and maturing plants. It is involved in enzymatic reactions in the plant and hastens the maturity of plants. However, the delay of physiological maturity in unfertilized plots may be due to insufficient amount of essential elements.

In line with our result, Tilahun *et al*. (2013) reported that increasing of P_2O_5 from 50 kg ha^{-1}to 100 kg ha^{-1} with increasing compost rate from 0 to 7.5 t ha^{-1} showed reduction in days to maturity of rice. Similarly, Getahun *et al.* (2018) reported that the shortest days (91) to physiological maturity of tef were obtained from the application of 69 kg N ha^{-1} and 30 kg P_2O_5 ha^{-1} and the longest days (97) from the control. On the other hands Seifu (2018) reported that the longest value for days to 90% physiological maturity of tef (106 days) was recorded for the un-fertilized (control) plots while the shortest physiological maturity (95 days) was recorded, with the application of 150 kg NPSB ha^{-1}and 69 kg N fertilizers

Table.3.Mean number of days to 50% panicle emergence (DPE) and maturity (DM) of tef as influenced by the main effects of varieties and blended NPSB fertilizer rates

Treatment	DPE (days)	DM (days)
Varieties		
Quncho	56.27 ^{a}	93.07^{a}
Kora	54.87 ^{b}	90.07 ^{b}
Dagm	57.20 ^{a}	94.00 ^{a}
LSD (0.05)	1.25	1.80
Blended NPSB (kg ha^{-1}) fertilizer rates		
0	59.11^{a}	97.22^{a}
50	56.67^{b}	93.56^{b}
100	56.22^{b}	92.22^{bc}
150	54.67^{bc}	90.67^{bc}
200	53.89 ^{c}	89.89^{c}
LSD (0.05)	1.62	2.32
CV (%)	3.0	3.8

Where, LSD (0.05) = Least Significant Difference at 5% level; CV= coefficient of variation. Means in column followed by the same letters are not significantly different at 5% level of significance.

4.3. Growth Parameters

4.3.1. Plant height

The main effect of varieties and blended NPSB rates were significant ($p<0.01$) on plant height of tef (Appendix Table). However, the interaction effect of the two factors was not significant (Appendix Table 4).

The highest plant height (111.8cm) was recorded for variety Kora while the shortest plant height (106.7cm) was recorded for variety Dagim (Table 4).This is because the genotype characteristic of the varieties. Similarly, Solomon *et al.* (2017)reported higher plant height for variety Kora (102.5 cm) than variety Dagim (95.6 cm).

The highest plant height (114.0 cm) was recorded at the highest NPSB rate of 200 kg ha^{-1} and it was statistically at par with NPSB rate of 150 and 100 kg ha^{-1} while the shortest plant height (106.4 cm) was recorded for the control (Table.4). This increment in plant height with the increased rate of NPSB may be due to N in the blended fertilizers plays vital role in cell division, elongation, and vegetative growth of plants (Marschner, 1995).

This result was in agreement with the findings of Legesse (2004) who reported that high N application (69 kg N ha^{-1}) resulted in tef plants with significantly taller plants (94 cm) as compared to control (82 cm) due to direct effect of N on vegetative growth of plants. Similarly, Okubay *et al.* (2014) reported the maximum plant height (112.33 cm) from the application of the highest rate (69 kg N ha^{-1}) whereas the lowest plant height was obtained from the control plot of the tef crop. This result is also in line with the report of Wakene *et al*. (2014) who stated that plant height of barley was increased with increasing rates of N from 0 to 69 kg ha^{-1}.

4.3.2. Panicle length

The main effect of varieties showed highly significant ($p<0.01$) effect on panicle length but the main effect of blended fertilizer rates and the interaction effect of the two factors were not significant (Appendix Table 4).

The highest panicle length (44.29 cm) was recorded for variety Kora while the shortest panicle length (42.77 cm) was recorded for variety Dagim (Table 4). This is might be due to the highest plant height for variety Kora which also gives highest panicle length. This result is also in line with the report of Kebebew *et al*. (2017) who reported higher panicle length for variety Kora (37.3 cm) than for variety Dagim (35.5 cm).

Table 4. Mean plant height and panicle length of tef as influenced by the main effects of varieties and blended NPSB fertilizer rates

Treatment	Plant height (cm)	Panicle length (cm)
Varieties		
Quncho	110.7^{a}	43.11^{b}
Kora	111.8^{a}	44.29^{a}
Dagm	106.7^{b}	42.77^{b}
LSD (0.05)	3.78	0.93
Blended NPSB (kg ha^{-1}) fertilizer rates		
0	106.4^{b}	42.63
50	107.0^{b}	43.34
100	110.3^{ab}	43.31
150	110.8^{ab}	43.62
200	114.0^{a}	44.04
LSD (0.05)	4.87	NS
CV (%)	4.0	2.9

Where, LSD (0.05) = Least Significant Difference at 5% level; CV= coefficient of variation; NS= non-significant. Means in column followed by the same letters are not significantly different at 5% level of significance.

4.4. Yield Components and Yield

4.4.1. Number of total tillers

The main effect of blended fertilizer rate was highly significant ($p<0.01$) on the number of total tillers, but the main effect of varieties and the interaction effect of the two factors were not significant (Appendix Table 5).

The highest number of total tillers (956.1 m^{-2}) was obtained with the application of blended fertilizer 200 kg NPSB ha^{-1} and it was statistically at par with 150 and 100 kg NPSB ha^{-1}while the lowest number of total tillers (583.3 m^{-2}) was obtained from the unfertilized plots (Table 5). The highest number of tillers at the highest rates of NPSB might be due to the rapid conversion of synthesized carbohydrates into protein and consequently the increase in number and size of growing cells, ultimately resulting in increased number of tillers. Moreover, improvement in total number of tillers with NPSB application might be due to the role of P found in NPSB in developing radical and seminal roots during seedling establishment (Cook and Veseth, 1991).

This result is in agreement with that of Seifu (2018) who reported that the highest number of total tillers (1295 m^{-2}) was obtained with the application of blended fertilizer 150 kg

NPSB ha^{-1}, while the lowest number of total tillers (890 m^{-2}) was obtained from the unfertilized plots

This result is in contrary to the finding of Shiferaw (2012) who reported no significant difference on total tillers number of tef as the rate of P_2O_5 was increased from zero to 46 kg ha^{-1}. Wakene *et al.* (2014) also reported no significant differences between application of 46 and 69 P_2O_5 kg ha^{-1} in total tillers of barley. Similarly, Esayas (2015) reported no significant differences in the numbers of total tillers per plant among different blended fertilizers (NPSZnB) in durum wheat.

4.4.2. Number of productive tillers

The main effect of blended fertilizer rate was highly significant ($p<0.01$) on the number of productive tiller,s but the main effect of varieties and the interaction effect of the two factors were not significant (Appendix Table 5).

The highest number of productive tillers (911.7 m^{-2}) was obtained with the application of blended fertilizer 200 kg NPSB ha^{-1}, while the lowest number of productive tillers (537.2 m^{-2}) was obtained from the control plots (Table 5). The highest number of productive tillers at the highest NPSB rate might be due to sufficient amount of growth and development of plants owing to the availability of sufficient and balanced supply of essential elements under blended NPSB fertilizer condition. Furthermore, the maximum number of productive tillers may be due to the presence of nitrogen in the NPSB promotes several activities essential for carbohydrate utilization and its most important function in plant promotion of rapid growth through increasing vegetative growth and hence productive number of tillers

In agreement with this result, Fayera *et al*. (2014) found that the highest productive tillers of tef (26 tillers per plant) under the application of 200 kg ha^{-1} NPKSZnB blended (14 N, 21 P_2O_5, 15 K_2O, 6.5 S, 1.3 Zn and 0.5 B) + 23 kg N ha^{-1}fertilizer.

4.4.3. Thousand kernels weight

The main effect of varieties was highly significant ($p<0.01$) on thousand kernels weight of tef but the main effect of blended NPSB fertilizer rates and the interaction effect of the two factors were not significant (Appendix Table 5).

The highest thousand kernels weight (0.24 g) was obtained for variety Quncho while the lowest thousand kernels weight (0.22 g) was obtained for variety Kora (Table 5).

Thousand seed weight is an important yield determining component and reported to be a genetic character that is influenced the least by environmental factors (Ashraf *et al.*,1999)

Table 5. Means of total tillers (TT), productive tillers (PT) and thousand kernels weight (TKW) of tef as influenced by the main effects of varieties and blended NPSB fertilizer rates

Treatment	TT (m^{-2})	PT (m^{-2})	TKW(g)
Varieties			
Quncho	806.0	748.3	0.241^{a}
Kora	682.0	632.7	0.218^{b}
Dagim	796.3	739.0	0.232^{a}
LSD (0.05)	NS	NS	0.012
Blended NPSB (kg ha^{-1}) fertilizer rates			
0	583.3^{b}	537.2^{b}	0.233
50	675.0^{b}	611.7^{b}	0.217
100	794.4^{ab}	730.0^{ab}	0.237
150	798.3^{ab}	742.8^{ab}	0.229
200	956.1^{a}	911.7^{a}	0.237
LSD (0.05)	193.3	191.7	NS
CV (%)	26.3	28.1	7.2

Where, LSD (0.05) = Least Significant Difference at 5% level; CV= coefficient of variation; NS= non-significant. Means in column followed by the same letters are not significantly different at 5% level of significance.

4.4.4. Aboveground biomass yield

The main effects of varieties and blended NPSB fertilizer rates were significant ($p<0.01$) on aboveground biomass yield of tef (Appendix Table 5). Moreover, the interaction effect the two factors on aboveground biomass yield was also significant ($P<0.05$) (Appendix Table 5).

The highest aboveground biomass yield (15926 kg ha^{-1}.) was recorded from the combination of variety Quncho with 200 kg NPSB ha^{-1} fertilizer rates, while the lowest aboveground biomass yield (11574 kg ha^{-1}) was recorded from the combination of Quncho with control which was statistically at par with the combination of Kora and Dagim varieties with control fertilizers with mean aboveground biomass yields of 11852 and 12037 kg ha^{-1}, respectively (Table 6). The increase in aboveground dry biomass at the highest rates of NPSB might have resulted from improved root growth and increased uptake of nutrients favoring better growth of the crop due to synergetic effect of the four nutrients (NPSB) which resulted from high nutrients particularly N and P might be used for the plants to capture ample solar radiation, which may result in the corresponding increment of photosynthetic rate.

This result was in agreement with the findings of Fissehaye *et al*. (2009) who reported a significant increase in total dry biomass of tef (3720 kg ha^{-1}) as a result of application of 69 kg N ha^{-1} and 46 kg P_2O_5 ha^{-1}. Similarly, Wakene *et al*. (2014) stated that supply of P_2O_5 at rate of 69 kg ha^{-1} in barely was found to be adequate to produce maximum aboveground dry biomass.

Table 6. Mean aboveground biomass of tef as affected by the interaction of varieties and blended NPSB fertilizer rates

	Blended NPSB (kg ha^{-1}) fertilizer rates				
Varieties	0	50	100	150	200
Quncho	11574^{c}	12778^{bc}	12870^{bc}	13611^{b}	15926^{a}
Kora	11852^{c}	14167^{b}	13241^{bc}	13426^{bc}	13981^{b}
Dagim	12037^{c}	11667^{c}	12963^{bc}	14167^{b}	13056^{bc}
LSD (0.05)	1473.58				
CV (%)	6.7				

Where, LSD= Least Significant Difference at 5% level; CV= Coefficient of Variation. Means in columns and rows followed by the same letters are not significantly different at 5% level of significance

4.4.5. Straw yield

The main effects of varieties and blended NPSB fertilizer rates were highly significant ($p<0.01$) on straw yield of tef (Appendix Table 6). Moreover, the interaction effect the two factors on straw yield of tef was significant ($p<0.05$) (Appendix Table 6).

The highest straw yield (11537 kg ha^{-1}) was recorded from the combination of variety Quncho with 200 kg NPSB ha^{-1} fertilizer rates, while the lowest straw yield (8002 kg ha^{-1}) was recorded from the combination of variety Quncho with control (Table 7). The significant increase in straw yield in response to the highest rate of application of NPSB might be attributed to the synergic roles of the nutrients in enhancing growth and development of the crop. The high N application produced higher numbers of tillers, increased plant height, and panicle length that might have resulted in increased straw production.

Similar results were found by Temesgen (2001); Legesse (2004); Mitiku (2008); and Okubay *et al.* (2014) who indicated the highest straw yield (3136-9652 kg ha^{-1}) of tef was obtained in response to the application of higher rates of N application (46-69 kg N ha^{-1}) and attributed this to the production of significantly higher number of tillers, longer panicles and taller plants that enhanced greater biomass yield.

Table 7. Mean straw yield (kg ha^{-1}) of tef as influenced by the interaction of varieties and blended NPSB fertilizer rates

Varieties	Blended NPSB (kg ha^{-1}) fertilizer rates				
	0	50	100	150	200
Quncho	8002^{c}	8969^{bc}	8911^{bc}	9631^{bc}	11537^{a}
Kora	8724^{c}	10469^{ab}	9609^{bc}	9581^{abc}	10413^{ab}
Dagim	8444^{c}	8030^{c}	9439^{bc}	10037^{b}	9294^{bc}
LSD (0.05)	1265.99				
CV (%)	8.0				

Where, LSD (0.05) = Least Significant Difference at 5% level; CV= coefficient of variation. Means in columns and rows followed by the same letters are not significantly different at 5% level of significance.

4.4.6. Grain yield

The main effects of varieties and blended NPSB fertilizer rates were highly significant ($p<0.01$) on grain yield of tef while the interaction effect of the two factors was not significant (Appendix Table 6).

The highest grain yield (3936 kg ha^{-1}) was recorded from variety Quncho but it was statically on par with variety Dagim while the lowest grain yield (3574 kg ha^{-1}) was recorded from variety Kora (Table 8).This is because variety Kora was with more vegetative growth habit. This result was also in agreement with Kebebew *et al.* (2017) who reported that variety Quncho gave higher grain yield (2653.0 kg ha^{-1}) than variety Kora (2634 kg ha^{-1}).

As the application rate of blended NPSB fertilizer increased from 0 to 150 kg ha^{-1}, there was an increase in mean grain yield (Table 8). The highest grain yield (3985 kg ha^{-1}) of tef was obtained at the rate of 150 kg NPSB ha^{-1} fertilizer application and it was statistically at par with all the rates of NPSB except the control which had the lowest grain yield of 3422 kg ha^{-1}

The highest grain yield at the higher NPSB rates might have resulted from improved root growth and increased uptake of balanced and sufficient nutrients and better growth favored due to synergetic effect of the nutrients which enhanced yield components and yield, but at highest 200 kg ha^{-1} fertilizer the yield is low due to high vegetative growth. The application of P is reported to be of secondary importance and is recommended at minimum levels of application except in highly weathered soils that fix considerable amount of applied P (Tekalign *et al.,* 2002).

In agreement with this result, Bereket *et al.* (2014) reported that increasing P rate from 20 to 29.7 kg P ha^{-1} increased grain yield of bread wheat by about 6.8%. Similarly, Jarvan *et al*. (2012) reported that the addition of 100 kg N ha^{-1} with 10 kg S ha^{-1} to winter wheat gave yield of 5.88 t ha^{-1} while it gave 5.73 t ha^{-1} when 100 kg N ha^{-1} with 6 kg ha^{-1} S. On the other hand, Brhan (2012) reported that treatments that received blended fertilizers (69 kg N ha^{-1} + 20 kg P ha^{-1} + 22 kg S ha^{-1} + 0.3 kg Zn ha^{-1}) under row planting of tef gave grain yield of 4155 kg ha^{-1} and increased 30% and 178% over treatments that receive urea and DAP under row planting and control plots, respectively. Similarly, Seifu (2018) reported that the highest grain yield (3228 kg ha^{-1}) of tef was obtained at the highest rate of blended (150 kg NPSB ha^{-1}) fertilizer application, while the lowest grain yield of 2503 kg ha^{-1} was recorded from non-treated (control) plot.

4.4.7. Harvest index

The main effect of varieties was highly significant ($p<0.01$) on harvest index but not the blended fertilizer rate and the interaction effect of the two factors (Appendix Table.6).

The highest harvest index of 29.63% was recorded for variety Quncho while the lowest harvest index of 26.87% was recorded for variety Kora (Table 8).This is because due to Kora variety has more biomass than Quncho. Generally, harvest index (HI) indicates the balance between the productive parts of the plant and the reserves, which form the economic yield. Higher harvest index indicates the presence of good partitioning of biological yield to economical yield.

Table 8. Means of grain yield (GY) and harvest index (HI) of tef as influenced by the main effects of varieties and blended NPSB fertilizer rates

Treatment	GY (kg ha $^{-1}$)	HI(%)
Varieties		
Quncho	3936^{a}	29.63^{a}
Kora	3574^{b}	26.87^{b}
Dagim	3734^{ab}	29.32^{a}
LSD (0.05)	223.456	1.55
Blended NPSB (kg ha^{-1}) fertilizer rates		
0	3422^{b}	28.93
50	3724^{ab}	29.18
100	3705^{ab}	28.50
150	3985^{a}	29.10
200	3906^{a}	27.34
LSD (0.05)	288.48	NS
CV (%)	8.0	7.2

Where, LSD (0.05) = Least Significant Difference at 5% level; CV= coefficient of variation; NS= non-significant. Means in column followed by the same letters are not significantly different at 5% level of significance.

4.4.8. Lodging index

Lodging index was highly significant ($p<0.01$) influenced by the main effects of varieties and blended NPSB fertilizer rates as well as the interaction effect of two factors (Appendix Table.6).

The highest lodging (45%) was recorded from the combination of variety Kora with the highest blended fertilizer rate (200 kg NPSB ha^{-1}), while the lowest lodging index (15.33%) was recorded from the combination of Dagim varieties with control fertilizer (Table 9). The highest lodging for variety Kora might be due to tall plant height than the other varieties and high rate of total nitrogen 83.8 kg N ha^{-1} in 200 kg NPSB ha^{-1} of blended fertilization, that enhanced fast vegetative growth, plant height and succulent stem elongation of tef and the wind prevailed in the study area the lodging on control plot is due to the nature of crop.

This result was in line with the findings of Shiferaw (2012) who reported highest lodging of tef (74%) at N/P_2O_5 rate of 64/46 kg ha^{-1}. Likewise, Fayera *et al.* (2014) reported the highest lodging percentage (79.74%) of tef with the highest rate of NPK (138 kg N ha^{-1} combined with 55 kg P ha^{-1} and 0 kg K_2O ha^{-1}) application.

Table 9. Mean lodging index (%) of tef as influenced by the interaction of blended NPSB and N fertilizer rates

Varieties	Blended NPSB (kg ha^{-1}) fertilizer rates				
	0	50	100	150	200
Quncho	16.00^{d}	17.67^{d}	24.00^{cd}	21.00^{cd}	32.67^{b}
Kora	19.67^{d}	22.00^{cd}	32.33^{b}	33.00^{b}	45.00^{a}
Dagim	15.33^{d}	20.00^{d}	23.67^{cd}	26.67^{c}	26.67^{c}
LSD (0.05)	6.22				
CV (%)	14.8				

Where, LSD (0.05) = Least Significant Difference at 5% level; CV= coefficient of variation. Means in columns and rows followed by the same letters are not significantly different at 5% level of significance.

4.5. Partial Budget Analysis

As indicated in Table 10, the highest net benefit of 79531.67 Birr ha^{-1} with marginal rate of return (MRR) of 790.28% was obtained with application of 200 kg blended NPSB ha^{-1} fertilizer rates for variety Quncho while the lowest net benefit of 65473.33 Birr ha^{-1} was obtained for the control treatment of NPSB fertilizer rates on variety Quncho. Thus, applications of 200 kg of blended NPSB ha^{-1} for variety Quncho is economically beneficial as compared to the other treatments in the study area because the highest net benefit and the marginal rate of return was above the minimum level (100%).

In line with thus result, Seifu (2018) indicated that the estimated net income for in organic fertilizer is attractive as compared to growing tef without application of in organic fertilizer.

Table 10. Summary of partial budget analysis of the effects of varieties and blended NPSB fertilizer rates on tef

Treatments		Adjusted grain yield (kg ha^{-1})	Adjusted straw yield (kg ha^{-1})	Total revenue (ETB ha^{-1})	Total variable cost (ETB ha^{-1})	Net benefit (ETB ha^{-1})	Marginal rate of return (%)
Varieties	NPSB (kg ha^{-1})						
Quncho	0.00	3190.00	7226.67	67413.33	1940.00	65473.33	0.00
Kora	0.00	2815.00	7851.67	60225.83	1940.00	58285.83	D
Dagim	0.00	3233.33	7600.00	68466.67	1940.00	66526.67	D
Quncho	50.00	3428.33	8071.67	72602.50	2860.00	69742.50	349.55
Kora	50.00	3328.33	9421.67	71277.50	2860.00	68417.50	D
Dagim	50.00	3298.33	7201.67	69567.50	2860.00	66707.50	D
Quncho	100.00	3563.33	8020.00	75276.67	3460.00	71816.67	851.53
Kora	100.00	3268.33	8648.33	69690.83	3460.00	66230.83	D
Dagim	100.00	3171.67	8495.00	67680.83	3460.00	64220.83	D
Quncho	150.00	3581.67	8668.33	75967.50	4060.00	71907.50	1281.11
Kora	150.00	3460.00	8623.33	73511.67	4060.00	69451.67	D
Dagim	150.00	3716.67	9033.33	78850.00	4060.00	74790.00	D
Quncho	200.00	3950.00	10383.33	84191.67	4660.00	79531.67	790.28
Kora	200.00	3211.67	9371.67	68919.17	4660.00	64259.17	D
Dagim	200.00	3385.00	8365.00	71882.50	4660.00	67222.50	D

Where, D = dominated treatments.ETB ha^{-1} = Ethiopian Birr per hectare; Market price of tef = 20.0 ETB kg^{-1}; Market price of straw= 0.5 ETB kg^{-1}; Cost of blended NPSB fertilizer =12.00 ETB kg^{-1}; Cost of UREA 10.50 ETB kg^{-1} , Cost of Improved seed individual (Quncho, Kora and Dagim) 50 ETB kg^{-1}, Labor cost for fertilizer application=4 persons ha^{-1}, each at 80 ETB day^{-1}.

5. SUMMARY AND CONCLUSION

Tef is one of the major small cereal crops in Ethiopia in terms of both production and consumption. Even though it is such an important cereal crops in Ethiopia, it is giving low yield as compared with other major cereal crops growing in the country due to many production constraints such as minimum use of improved varieties, lack of appropriate management practices, low soil fertility and lack of location specific fertilizer recommendation in Ethiopia in general and in the study area in particular.

Therefore, a field experiment was conducted during the 2018 main cropping season (July to November 2018) at Gelan in Akaki district on a farmer's field with the objectives of assessing the response of tef varieties to blended NPSB fertilizer rates in terms of production and identifying the economically feasible rates of blended NPSB fertilizers application on tef varieties.

The treatments consisted of factorial combinations of three tef varieties (Quncho, Kora and Dagim) and five levels of blended NPSB (0, 50, 100, 150 and 200 kg ha^{-1}) fertilizer rates. The experiment was laid out as a randomized complete block design in a factorial arrangement with three replications. The fertilizer materials used were urea (46% N) and blended NPSB (18.9% N, 37.7% P_2O_5, 6.95% S and 0.1% B).

Analysis of the results revealed that days of panicle emergence, days to physiological maturity, plant height and grain yield were highly significantly ($p<0.01$) affected by the main effects of varieties and blended NPSB fertilizer rate while panicle length, harvest index and thousand kernels weight were highly significant($p<0.01$) only by main effect of varieties; and total and productive tillers were highly significant ($p<0.01$) affected only by NPSB fertilizer rate.

The highest days of panicle emergence (57.20 days) and days to physiological maturity (94 days) were recorded for variety Dagim while the highest grain yield (3936 kg ha^{-1}), panicle length (44.29 cm), harvest index (29.63%) and thousand kernels weight (0.2413 g)were recorded for variety Quncho.
With respect to NPSB fertilizer effect, the highest days of panicle emergence (59.11 days) and days to physiological maturity (97.22 days) were obtained at unfertilized plots whereas

the highest plant height (114.0 cm),total tillers (956.1 plant m^{-2}) and productive tillers (911.7 plant m^{-2}) were obtained at 200 kg NPSB $ha^{-1}$and the highest grain yield (3985 kg ha^{-1})was obtained at 150 kg NPSB ha^{-1}fertilizer rate.

The interactions of the two factors were significant on aboveground dry biomass, straw yield and lodging index. The highest aboveground dry biomass (15926 kg ha^{-1}) and straw yield (11537 kg ha^{-1}) were obtained from combination of Quncho variety with 200 kg NPSB ha^{-1}treatments. The maximum lodging index (45%) was recorded at combination of Kora varieties with 200 kg NPSB ha^{-1} fertilizer rate.

The partial budget analysis revealed that applications of 200 kg NPSB ha^{-1} for variety Quncho gave the best economic benefit of 79531.67 Birr ha^{-1} with MRR of 790%. Therefore, it can be concluded that combined application of 200 kg NPSB ha^{-1} for variety Quncho can be tentatively recommended for production of tef in the study area and other areas with similar agro-ecological conditions. However, since the experiment was conducted for one season at one location, it is suggested that the experiment has to be repeated over seasons and locations using this and other improved tef varieties to make a conclusive recommendation.

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7. APPENDICES

Appendix Table 1. Monthly and yearly total rainfall (mm) at experimental area (2009-2018)

Month	Year									
	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Jan.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Feb.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mar.	0.00	0.00	0.00	12.0	0.00	8.00	15.00	30.00	0.00	25.0
Apr.	0.00	0.00	75.0	0.00	0.00	32.0	0.00	5.00	0.00	10.0
May	0.00	79.0	55.0	35.0	50.0	31.0	65.0	50.0	150	25.0
June	98	165	105	105	95.0	155	165	180	200	95.0
July	293	350	350	201	310	250	380	350	405	325
Aug.	368	405	355	311	200	150	342	285	285	345
Sept.	0.0.0	40.0	55.0	50.0	25.0	7.00	23.0	25.0	15.0	30.0
Oct.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.00	0.00	0.00
Nov.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Dec.	0.00	0.00	0.00	0.00	11.7	0.00	0.00	0.00	0.00	0.00
Total	759	1039	995	714	680	633	990	930	905	855

Source: National Meteorological Agency; Debre-Zeit Station

Appendix Table 2. Mean monthly and annual minimum temperature (^oC) at Experimental area (2009-2018**)**

Month	Year										
	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Mean
Jan.	6.4	9.0	7.2	7.8	5.8	6.2	7.3	5.9	9.2	5.2	7.0
Feb.	6.9	8.4	10.4	11.0	12.0	7.8	8.9	8.0	9.5	9.1	9.2
Mar.	8.0	9.1	9.8	9.5	9.0	10.3	10	9.0	10.9	10.0	9.6
Apr.	9.1	9.5	10.6	9.6	10.5	9.4	9.9	10	8.0	9.8	9.5
May	10.1	9.4	11.2	10.2	10.6	10.8	10.1	10.5	9.8	10.8	10.3
June	12.0	11.0	11.5	10.5	11.6	12.5	11.6	12.3	11.0	11.7	11.6
July	13.5	12.0	11.5	13.0	13.5	12.0	13.8	12.5	12.9	13.4	12.9
Aug.	13.8	13.0	12.4	12.6	11.9	12.0	13.2	12.5	12.8	13.8	12.7
Sept.	9.5	10.2	11.2	10.0	9.6	11.0	9.0	9.2	10.6	11.5	10.1
Oct.	7.5	8.0	7.0	7.5	8.7	9.0	9.5	8.5	9.0	9.5	8.4
Nov.	9.0	7.0	8.0	7.4	7.5	6.5	7.0	7.8	8.5	7.8	7.6
Dec.	6.0	8.0	7.5	5.2	6.5	6.3	6.2	8.5	5.4	6.2	6.5
Mean	9.3	9.5	9.8	9.5	9.8	9.5	9.7	9.6	9.8	9.9	9.7

Source: National Meteorological Agency; Debre-Zeit Station

Appendix Table 3. Mean monthly and annual maximum temperature (^{o}C) at experimental area (2009-2018).

	Year										
Month	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Mean
Jan.	20.7	20.1	20.3	20.5	21.1	20.0	20.6	20.6	20.9	20.8	23.5
Feb.	21.6	21.6	21.0	22.0	20.0	23.0	21.2	23.0	22.7	19.5	22.5
Mar.	23.4	23.2	21.8	22.0	23.4	23.7	22.3	23.2	24.3	23.4	23.2
Apr.	22.6	23.1	22.1	24.0	21.0	24.7	22.3	24.0	23.0	23.6	23.0
May	22.9	24.1	22.7	24.5	24.6	23.4	22.4	22.9	21.6	22.5	24.5
June	22.0	23.6	22.6	22.3	22.0	22.1	23.1	22.4	21.9	21.2	22.3
July	19.3	17.9	18.6	19.5	18.4	17.8	19.6	21.1	18.8	18.0	19.0
Aug.	18.4	18.3	17.6	19.0	18.5	19.0	17.8	18.8	18.3	18.8	18.5
Sept.	19.6	19.7	18.8	21.0	20.0	19.1	18.7	19.7	19.5	19.0	19.5
Oct.	20.0	19.2	20.0	21.5	20.9	19.0	19.4	20.7	19.0	18.5	19.8
Nov.	21.0	19.9	19.6	21.5	21.	20.0	20.0	20.8	19.5	22.0	20.5
Dec.	21.0	19.2	19.6	22.0	21.0	22.0	21.0	21.0	22.0	21.5	22.5
Mean	21.1	20.8	20.4	21.7	21.0	21.2	20.7	22	20.9	20.7	21.0

Source: National Meteorological Agency; Debre-Zeit Station

Appendix Table 4. Mean squares of ANOVA for phenologicl and growth parameters of tef as affected by varieties and blended NPSB fertilizer rates

		Mean squares			
Source	DF	Days to panicle emergence	Days to maturity	Plant height (cm)	Panicle length (cm)
Replication	2	11.022	31.489	550.48	36.140
Varieties	2	20.689^{**}	33.689^{**}	107.55^{*}	9.456^{**}
NPSB rate	4	36.778^{**}	75.526^{**}	85.14^{*}	2.392^{ns}
Varieties x NPSB rate	8	3.911^{ns}	6.272^{ns}	19.14^{ns}	2.015^{ns}
Error	28	2.808	5.775	25.47	1.537
CV (%)		3.0	3.8	4.0	2.9

Where,**=highly significant; * = significant; ns = non-significant at 5% probability level; DF = degrees of freedom and CV =coefficient of variation

Appendix Table 5. Mean squares of ANOVA for yield components and yield of tef as affected by varieties and blended NPSB fertilizer rates

Source	DF	Mean squares			
		No. of total tillers	No. of productive tillers	Thousand kernels weight	Biomass yield
Replication	2	47869	34875	0.0018956	4332990
Varieties	2	71354^{ns}	61932^{ns}	0.0020689^{**}	1596365^{*}
NPSB rate	4	178967^{**}	183622^{**}	0.0006256^{ns}	8039266^{**}
Varieties x NPSB rate	8	39428^{ns}	40071^{ns}	0.0003522^{ns}	2567301^{**}
Error	28	40075	39417	0.0002765	776259
CV (%)		26.3	28.1	7.2	6.7

Where, **=highly significant; * = significant; ns = non-significant at 5% probability level; DF = degrees of freedom and CV=coefficient of variation

Appendix Table 6. Mean squares of ANOVA for grain yield, straw yield, harvest index and lodging index as affected by varieties and blended NPSB fertilizer rates

Source	DF	Mean squares			
		Grain yield	Harvest index	Straw yield	Lodging index
Replication	2	51943	11.100	3691655	19.09
Varieties	2	494169^{**}	34.481^{**}	1923079^{**}	376.82^{**}
NPSB rate	4	427372^{**}	5.179^{ns}	5004464^{**}	400.14^{**}
Varieties x NPSB rate	8	121579^{ns}	6.004^{ns}	1858574^{**}	40.04^{**}
Error	28	89251	4.289	572952	13.83
CV (%)		8.0	7.2	8.0	14.8

Where, **=highly significant; * = significant; ns = non-significant at 5% probability level; DF = degrees of freedom and CV=coefficient of variation.