EFFECT OF RATES AND TIME OF NITROGEN FERTILIZER APPLICATION ON YIELD AND YIELD COMPONENTS OF TEF [(*Eragrostis tef* (Zucc.) Trotter] IN ALEFA DISTRICT, AMHARA NATIONAL REGIONAL STATE, ETHIOPIA

M.Sc. THESIS

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EFFECT OF RATES AND TIME OF NITROGEN FERTILIZER APPLICATION ON YIELD AND YIELD COMPONENTS OF TEF [(*Eragrostis tef* (Zucc.) Trotter] IN ALEFA DISTRICT, AMHARA NATIONAL REGIONAL STATE, ETHIOPIA

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In Partial Fulfillment of the Requirements for the Degree of Master of Science in Agronomy

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APPROVAL SHEET

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POSTGRADUATE DIRECOTRATE

As thesis research advisors, we hereby certify that we have read and evaluated the thesis prepared by Getachew Chanie under our guidance, which is entitled "EFFECT OF RATES AND TIME OF NITROGEN FERTILIZER APPLICATION ON YIELD AND YIELD COMPONENTS OF TEF [(*Eragrostis tef* (Zucc.) Trotter] in Alefa district, Amhara National Regional State. We recommend that the thesis be submitted as it fulfills the university requirements.

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As members of the Board of Examiners of the open M.Sc. thesis defense examination of Getachew Chanie, we certify that we have read and evaluated the thesis and examined the candidate. 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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Final approval and acceptance of the thesis is contingent upon the submission of final copy of the thesis to council of graduate studies (CGS) through the departmental or school graduate committee (DGC or SGC) of the candidate.

DEDICATION

This thesis manuscript is dedicated to my beloved wife Melishew Tadesse, and to my mother Kassaye Mamo for their prayers, encouragement, and dedicated partnership in the success of my life.

STATEMENT OF THE AUTHOR

By my signature below, I declare and affirm that this thesis is my own work and I have followed all ethical principles of scholarship in the preparation, data collection, data analysis and compilation of this thesis. All scholarly matter that is included in the thesis has been given recognition through citation and referenced all sources uses in this thesis. Every series efforts have been made to avoid any plagiarism in the preparation of this thesis. I submit this thesis to the University of Gondar in partial fulfillment 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 January 29, 1982 in a small village called Gorgora, in Dmbia district, North Gondar Zone, Amahara regional state. He attended his elementary, junior and secondary school education at Gorgora elementary school, Junior and secondary comprehensive school, respectively. After taking the Ethiopian School Leaving Certificate Examination (ESLCE), he joined Combolcha Agricultural Technical and Vocational Educational Training College (ATVTC) in 2002 and graduated with Diploma in Plant Sciences in June 30, 2005. In August 2005, he was employed in Rural Development main office at Alefa woreda as Crop production Expert. After four years of work, in October 2009, joined Bahir Dar University to pursue his study a graduated with BSc degree in Plant Science in October, 2012 and he served from November 2002 up to September 2015 at the same institution. In October 2016, he joined the School of Graduate Studies at University of Gondar to pursue his MSc. study in agronomy.

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LIST OF ACRONYMS AND ABBREVIATIONS

ANOVA	Analysis of Variance
ATA	Agricultural Transformation Agencies
CEC	Cation Exchange Capacity
CSA	Central Statistical Agency
CV	Coefficient of Variation
DAP	Di-ammonium Phosphate
GDP	Gross Domestic Product
ha	Hectare
HI	Harvest Index
IAEA	International Atomic Energy Agency
LGP	Length of Growth Period
LSD	Least Significant Difference
m.a.s.l	Meter Above Sea Level
MOA	Ministry of Agriculture
MRR	Marginal Rate of Return
N	Nitrogen
NUE	Nitrogen Use efficiency
OM	Organic Matter
P	Phosphorous
RCBD	Randomized Complete Block Design
SNNPR	South Nations Nationalities and People's Regional State
TSP	Triple Superphosphate

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ABSTRACT

Tef [Eragrostis tef (Zucc.) Trotter] is among the major cereals of Ethiopia and occupies the largest cultivated land more than any other cereals. The need for its production as a staple food is increasing from year to year; however, its productivity is low due to low soil fertility and suboptimal use of mineral fertilizers. A field experiment was carried out during the 2016 main cropping season from July to November in Alefa district with the objectives of studying the effects of rates and time of nitrogen fertilizer application on yield and yield components of tef. The treatments consisted of four levels of nitrogen (23, 46, 69 and 92 kg N ha^{-1}) and three time of applications (full dose at sowing, full dose at tillering and ½ dose at sowing + ½ dose at tillering). One additional control treatment consisted of 0kg N ha^{-1} included for comparison. The experiment was laid out in randomized complete block design with factorial arrangements of 4 x 3 = 12 treatment combinations together with the one control treatment, made a total of 13 treatments, which were replicated three times. All the parameters evaluated were affected by the main effect of N fertilizer rate and time of N application. Their interaction effect had significantly affected plant height, lodging index, main panicle-seed-weight, thousand-seed-weight, grain yield, straw yield and biomass yield. But main effect of rate and time of N-fertilizer had significantly affected days to panicle emergency, Number of tiller and panicle length. However days to maturity were not significantly affected by the time of N fertilizer application. The highest plant height, lodging index, biomass, grain and straw yield were recorded at 69 kg N ha $^{-1}$ applied half dose at sowing and half dose at tillering stage. The highest panicle length and Number of tiller was obtained at a rate of 69kg ha^{-1} and in a splits application. Partial budget analysis of N fertilizer rates indicted that higher marginal rate of return (16040 %) were recorded at 69kg N/ha in a split application. This can be recommended for its economic feasibility.

Key words: Fertilizer, Grain, Rate, Split and Teff.

1. INTRODUCTION

Tef *[Eragrostis tef (Zucc) Trotter]* is a cereal crop that belongs to the family Poaceae, sub family *Eragrostidae*, tribe *Eragorsteae* and genus *Eragrostis*. It is a self- pollinated annual cereal (Seyfu, 1993) and is an indigenous cereal crop in Ethiopia. Ethiopia is the origin and the first domesticator of this unique crop (Vavilov, 1951; Seyfu, 1991). Hence, Ethiopia is the appropriate and most important centre for the collection of tef germplasm and is the only country in the world that uses tef as a cereal crop (Gugsa *et al*., 2001).

The crop has been introduced to South Africa and is being cultivated as a forage crop and it is also being cultivated as a cereal crop in northern Kenya (Seyfu, 1993). Also, it is thought to have been spread to Europe through the Portugal contact in the 16th century (Taddesse, 1975). According to Costanza *et al*. (1979) tef was distributed to several countries in the 19th century, and now it is cultivated as a forage grass in Australia, India, Kenya, and South Africa. According to Seyfu (1997), the Royal Botanical Gardens Kew, imported teff kernel from Ethiopia in 1866 and distributed it to India, Australia, USA and South Africa. The word tef has been originated from the Amharic word `*tefa*` which means lost, due to small size of the grain or from the Arabic word `*tahf*` used by Semites in South Arabia (Anon,1987).

Ethiopian farmers grow tef for a number of merits, which mainly attributed to the socio-economic, cultural and agronomic benefits (Seyfu, 1993). Tef has much or even more food value than the major grains such as wheat, barley and maize. Tef grain contains 14-15% proteins, 11-33 mg iron, 100-150 mg calcium, and rich in potassium and phosphorus nutrients (NAS, 1996). Tef grains are milled into flour and mixed with water in order to form slurry and fermented for two or three days to bake in to flat soft bread-just like pancake, locally known as "*Injera*" (Haftamu *et al*., 2009). Tef production has been increasing from year to year and so does the demand for it as staple grain in both rural and urban areas of Ethiopia (Mitiku, 2008). Although tef is found in almost all cereal growing areas of Ethiopia, the major areas of its production are Shewa, Gojjam, Gondar, Wellega and Wello with central highlands of the country (Doris-Piccinin, 2010). In Ethiopia, tef is grown as a major cereal grain crop which occupied about 22.2% (2,730,272.95 ha) of the total acreage of all the seven major cereals grown in Ethiopia (CSA, 2013). This digit in

2014/2015 growing season increased to 24.02% (3,016,053.75 ha), and production accounted 17.57% (47, 506, 57.28 metric tons).

Tef performs well in '*Weina dega'* agro-ecological zones or medium altitude (1700-2400 m.a.s.l). According to Haftamu *et al*. (2009), mean temperature and optimum rainfall for teff during growing season range from 10 to 27 ^{0}C and 450 to 550mm, respectively. Tef gives better grain yield and possesses higher nutrient contents, especially protein, when grown on *Vertisols* rather than on *Andosols* (Seyfu, 1997). Tef withstands low moisture conditions and has the ability to tolerate and grow on *vertisols* having a drainage problem, which make it a preferred cereal by farmers. The length of growing period (LGP) considering rainfall of 450 to 550 mm and evapo-transpiration of 2-6 mm day^{-1} ranges from 60 to 180 days. Depending on variety and altitude, tef requires 90 to 130 days for growth (Haftamu *et al*., 2009).

Regardless of its high area coverage, adaptation to different environmental conditions and requirements as a staple food in Ethiopia, the yield of tef grain is not increasing above the national average grain yield of 1.28 tone ha^{-1} (CSA, 2015). Some of the factors contributing to low yield of tef as compared to other cereals could be associated with the use of traditional and poor soil fertility management and lack of other appropriate management practices (Brhan, 2012). Development of improved and appropriate agronomic practices (seeding rate, planting methods, seedbed or field preparation, fertilizer rate and time of application) would greatly contribute to higher productivity of the crop (Tarekegne, 2010).

Among the major plant nutrients, N is the most essential one and frequently deficient nutrient for successful teff production in most agro-ecological zones. Globally, nitrogen is considered to be the second most limiting factor in crop production (Sattelmacher *et al*., 1994) and limits yields in non-fertilized agriculture. It is applied in order to increase yield and improve crop quality. Nitrogen fertilizer rates and time of application are a decisive factor in influencing high yields, increased protein content and improved gluten quality (Borghi *et al*., 1997; Lo´pez-Bellido *et al*., 1998).

Nitrogen fertilizers are highly soluble and once applied to the soil may be lost from the soil-plant system or becomes unavailable to the plants due to the processes of leaching, NH_3^+ volatilization, denitrification, and immobilization. Therefore, nitrogen shortage is one of the main constraints limiting the productivity of not only tef but also of the major crops such as wheat and other cereals (Andrews *et al*., 2004). According to Miller and Donahue (1997), nitrogen is the key nutrient in plant growth and the most often deficient nutrient markedly affecting plant growth. Crop response to nitrogen fertilizer varies with rate and time of application in relation to plant development. It is an essential constituent of cell wall, cytoplasmic proteins, nucleic acids (the regenerative portions of the living cell), chlorophyll and a vast array of other cell components. Therefore, a low supply of N has a profound influence on crop growth and may lead to a great loss in grain yield (Miller and Donahue, 1997).

Nitrogen fertilizer applied at the correct time and in the right amount to an actively growing crop will result in optimum yield and very little NO_3^- will remain in the soil at harvest minimizing risk of loss by leaching (Johnston, 1994). On the other hand, luxuriant application of N fertilizer at sowing increases the flush of emerging broad leaf weeds thereby increases the labor requirements for hand weeding. Hence, split application of nitrogen was considered more economical both in terms of weed management under farmers' conditions and as a risk aversion strategy, efficient nitrogen use for optimizing grain yield and reducing grain protein with lower nitrogen inputs. Split nitrogen application prior to stem elongation with top-dressing can increase fertilizer nitrogen recovery while maintaining or increasing NUE compared with all-full application (Tanner *et al.,* 1993).

Major factors affecting tef fertilizer recommendation are water logging, seasons of planting, cropping history, lodging and weed growth (Kenea *et al*., 2001). The actual rate of fertilizer used by farmers is below the blanket recommendation, i.e. 100kg DAP/ha and 100kg urea/ha set by the Ministry of Agriculture and Rural Development (Kenea *et al*., 2001). Later, N/P as a recommended by Tareke and Nigusse, (2008) from Debre Zeit Agricultural Research Centre; tef production on heavy clay soils (*Vertisols*) requires 60 kg N and 26 kg P_2O5/ha. However, on sandy clay loam soils (*Andosols*) tef requires 40 kg N and 26 kg P_2O5/ha (Seyfu, 1997; Kabir and Allahdad, 2011). Most farmers of Ethiopia cannot afford to purchase the required amounts of fertilizer to tef production. On the other hand, under conditions where most growth requirements are available and inorganic nutrients rich soils, application of fertilizer without knowing its fertility status causes yield and fertilizer losses (Tekalign *et al*., 2000). These problems are real challenges in Alefa woreda. Similar results also have been described by Bekele *et al*. (2000).

Farmers in Ethiopian highlands apply N fertilizer in the form of urea at sub-optimal blanket rates, mostly only once at the time of sowing, and this limits the potential productivity of cereal crops. In general, blanket recommendations, regardless of considering the physical and chemical properties of the soil as well as application of full dose at one time do not lead to increased crop productivity which is already very low in the country.

Farmers in Alefa district also apply low amounts of nitrogen that is only at the time of sowing or at vegetative growth stage for tef production (Personal communication with crop production expert and local farmers in the district). Determination of optimum fertilizer rates for specific soil types is vital to overcome the problem that arises from the use of blanket fertilizer recommendations. Systematic studies should, thus, be conducted under varying conditions and in various regions to determine the fertilizer requirements of tef for optimizing yield. However, no studies have been conducted on response of tef to rate and time of nitrogen fertilizer application in Alefa district. Therefore, this study was initiated with the following objectives.

1.1 Objectives

1.1.1 General objective

- To study the effects of rates and time of application of nitrogen fertilizer on the growth, yield and yield components of tef.

1.1.2 Specific objectives

- To determine the most appropriate rate and time of nitrogen fertilizer application for the yield performance of tef.
- To evaluate the potential interaction between different rates of nitrogen fertilizer and time of application on the growth and yield of tef.
- To analyze the most economical rate and time of N fertilizer application for study area.

1.2 Significance of the Study

It is hoped that this study would fill the gap on effect of rates and time of nitrogen fertilizer application on yield and yield components of tef. This research would provide an insight to studies on the effect of rates and time of nitrogen fertilizer application on the yield and yield components of tef. In addition, this research would facilitate further researches on this issue because the response of crop to applied fertilizers may vary from one site to another due to different climate conditions, mainly rainfall, and soil (Al-Kaisi and Yin, 2003; Gregory *et al*., 1997). In Ethiopia, adoption and frequency of fertilizer application, especially by small holders, remain very low, despite government's efforts to promote its use (Fufa and Hassen, 2006).

At present, farmers are using blanket which are not based on fertilizer recommendations and crop-nutrient requirements. These factors result in unbalanced and inefficient fertilizer use that results in poor economic returns to the farmers on one hand, costing heavily to the government's hard currency, on the other hand inefficient use of imported inorganic fertilizer materials (Tasnee and Yost, 2003). Farmers in the study area also apply low amount of nitrogen only one time at sowing or at vegetative growth stage for tef production. Due to these reason the productivity of tef is very low. Therefore, rate and time of application interactions should be taken into account when a fertilizer recommendation package for a particular area is designed. Henceforth, this study may serve as a source of additional information and will have a significant use to Alefa district farmers for to apply optimum rate and appropriate time of nitrogen fertilizer for teff.

2. LITERATURE REVIEW

2.1 Morphology and Ecology of Teff

Tef *(Eragrostis tef* (Zucc.) Trotter) belongs to the family Poaceae, sub-family *Eragrostoideae*, tribe *Eragrosteae* and genus *Eragrostis.* Eragrostis*,* consisting of both annuals and perennials, are found over a wide geographic range. These species are classified based on characteristics of culms, spikelet, lateral veins, pedicels, panicle, flowering scales, and flower scale colors. The taxonomy of tef has been also classified by numerical taxonomy techniques, cytology and biochemistry, including leaf flavanoids and seed protein electrophoretic patterns (Eshetu and Lester, 1981).

Tef is a fine stemmed, tufted annual grass characterized by a large crown, many shoots, and a shallow fibrous root system. The inflorescence is an open panicle and produces small seeds (1000-seeds-weights 0.3 to 0.4 g) (Seyfu, 1997). The florets consist of a lemma, three stamens, two stigma and two lodicules. Floret colors vary from white to dark brown.

Tef germplasm is characterized by a wide variation of morphological and agronomic traits. Plant height of tef varies from 25–135cm depending on cultivar type and growing environments. The panicle length ranges from 11–63cm 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 (Hesselbach and Westphal, 1976). Maturity varies from 93–130 days. Grain color 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 1–1.7mm long and 0.6–1mm diameter with l000-seed-weight averaging 0.3–0.4 grams. Grain and straw yield represent the maximum genetic diversity among the observed teff germplasm (Seyfu, 1997).

Tef has the capacity to withstand waterlogged and rainy conditions, often better than other cereal grains (other than rice) (ATA, 2013). Maximum teff production occurs at altitudes of 1700–2400 meter above sea level with growing season rainfall of 450–550 mm, and a temperature range of 10–27°C (Seyfu, 1993). Teff is day length-sensitive and flowers best during 12 hours of daylight

(Duckers *et al*., 2001). However, according to experience gained so far from national yield trials conducted at different locations across the country, tef performs well at an altitude of 1800-2100 m.a.s.l., with annual rainfall of 750–850 mm, growing season rainfall of 450-550 mm and a temperature range of 10°C–27°C (Seyfu,1997). Tef is highly adaptable 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 considered as a low risk grain because its vulnerability to pest and diseases is very low (Fufa *et al*., 2011; Minten *et al*., 2013). In addition to that tef can resist to extreme water conditions, as it is able to grow under both drought and waterlogged conditions (Teklu and Teffera, 2005; Minten *et al.*, 2013). Teff is mainly planted during the main *meher* rains between July and November, while harvesting is done in February.

2.2 Characteristics of Tef

2.2.1 Tef as a cereal in Ethiopia

The fact that the genetic diversity tef exists nowhere in the world except in Ethiopia, indicates that tef originated and was domesticated in Ethiopia. Vavilov (1951) identified Ethiopia as the centre of origin and diversity of teff. Tef is endemic to Ethiopia and it has been widely produced for many centuries (Teklu and Teffera, 2005). Tef can be grown under diverse agro-ecological conditions as it adapted to environments ranging from drought stress to waterlogged soil conditions. The major tef producing areas are Amhara, Oromia, Tigray and SNNP regions (CSA, 2012).

In tradition, the tef seeds are broadcasted on a well ploughed land and lightly covered with soil for germination to occur in shorter period of time. During the growing period, several repeated weeding are often required (Assefa *et al*., 2011). Tef is the most important staple grain in terms of the rate of consumption and amount of production. According to CSA (2013) report during 2012/13 *meher* rains, 22% of the country’s grain area was covered by tef and tef production activity engaged 6 million farmers. From this tef land a total of 4 million metric tons of tef yield were obtained which accounts for 16 percent of all grain output. CSA (2015) report shows that in 2015, the average tef yield reached 1.28- 1.5 tons per hectare with an increase of eight percent over 2012 years average production. According to Taffesse *et al.* (2011), the recent teff grain yield increase was mainly due to an increase in production area and yield improvement strategies. According to the evaluation made on tef production for 2012 by Minten *et al.* (2013), tef is the most important food grain in Ethiopia. The value of its commercial surplus is second only to coffee. In addition to its importance as a staple food, tef straw is important for fodder and use in house construction (Teklu and Teffera, 2005).

2.2.2 Consumption of tef in Ethiopia

In Ethiopia, tef is a highly value crop and it 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* (both are local alcoholic drink) (Seyfu, 1997; Hailu and Seyfu, 2001). These researchers also suggested that 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. It has high protein, fiber and complex carbohydrates content with relatively low calorie gain, and it is gluten free as well (Berhane *et al*., 2011; ATA, 2013). It accounts for between 11 and 15 percent of all calories consumed in Ethiopia (Berhane *et al.,* 2011; ATA, 2013) and tef provides about 66 percent of day- to-day protein intake (Fufa *et al*., 2011). More than 60 % of the Ethiopian population use tef as their daily staple food. It is estimated that per person consumption grew by four percent over the last 5 years (ATA, 2013).

Tef is highly considered as an economically superior food and relatively more consumed by urban and richer consumers (Berhane *et al*., 2011; Minten *et al*., 2013). In urban areas the level of tef consumption is much higher than that of rural areas with the share for each person consumption of 23 percent from the total food expenditure in the country, while in rural area this is only 6 percent. In rural areas, tef is seen as a luxurious grain consumed only by elders or during special occasions. Growth in average incomes and faster urbanization in Ethiopia are likely to increase the demand for tef over time (Berhane *et al*., 2011).

2.2.3 Economic importance of tef

Agriculture is a major contributor to the national economy of Ethiopia, representing 41% of Ethiopia's GDP (CSA, 2012). Tef has as much or even more food value than the major grains; 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). Teff is grown in almost all regions of the country for home consumption since it is a preferred grain, and for local market too as it fetches the highest grain price compared with other cereals and is used as a cash grain by farmers (Seyfu, 1997).

When tef is grown as a cereal, farmers highly value the straw 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 to the straw of any other cereal and its price is higher than thus of other cereals (Seyfu, 1997). The quantity and quality of residues from various cereal grains vary greatly depending on the grain species. Wheat and barley usually give high straw yields, though of inferior quality. Among cereals, tef straw is relatively the best and is comparable to a good natural pasture (Bekabil *et al*., 2011). Seyfu (1997) reported that tef is not attacked by weevils and other storage pests; therefore, it is easily and safely stored under local storage conditions for an extended period of time without attack by storage pests. This results in reduced post-harvest management costs.

Despite the domestic preference for tef, it can be internationally classified as an "*orphan*" grain given that it has been largely unnoticed by the global scientific community and relatively unimproved by modern production technologies (ATA, 2013a). The major reasons why tef remains as an important grain in Ethiopia are firstly, it is the diet of most Ethiopians; secondly, it can grow under diverse soil type and climatic conditions like drought-prone or waterlogged condition; thirdly, it is a reliable cash grain because if unexpected drought or pest infestation occurs, the field can be re-planted with tef; fourthly, the straw is of relatively higher digestibility to livestock (ATA, 2013).

2.3 Tef Production Constraints in Ethiopia

Declining soil fertility has continued to be a major constraint to food production in many parts of the tropical region. The low soil fertility in the tropics has been attributed to the low inherent soil fertility, loss of nutrients through erosion and crop harvests and little or no addition of external inputs in the form of organic or inorganic fertilizers (Fischer *et al*., 1993). Environmental stress is the most important factor which affects crop production. According to Cassman (2002), 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 the 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 meager 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 of teff 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 (Balesh *et al*., 2007).Lodging has been one of the most important challenges for tef production and it has been a concern for years to strive in improving tef cultivars having strong stems to bring a remedy to the challenge.

As it was defined by Seyfu (1983), lodging is an abnormal growth condition caused by internal or external factors of the plant, or by interaction between the two, resulting in the displacement of the aerial parts of the plant from the upright position. The severity of lodging and the extent of yield loss from it depend mainly on environmental factors of the crop. Favorable growing environment that promotes crop growth and grain yield will enhance lodging and increase its severity. Pinthus (1993) indicated that lodging is affected very strongly by environmental conditions through their effect on plant characteristics prone to environmental effects, namely Culm internodes and the total Culm length.

Lodging of tef can be caused by rates of N application. The use of high doses of N fertilizer considerably increases yield of teff (Tekalign *et al*., 2000). However, lodging does not allow using increased amount of N fertilizer to produce maximum yield which could be attained owing to the inherent potential of the crop. Lodging also limits the mechanized large scale production of tef as it causes harvesting difficulties. Moreover, lodging results in direct yield loss by affecting yield components such as grain yield per panicle, and 1000-grain-weight (Seyfu, 1983; Fufa *et al*., 1999; Temesgen, 2001). Lodging causes damage to the whole plant part due to rotting and rapid pathogen and pest spread that result in both low quantity and quality straw and grain. Seyfu (1983) has estimated that the overall grain yield loss due to lodging ranges between 11-22% with an average loss of 17%. A soil test-based fertilizer rate application has to be designed as fertilizers are among the causes of lodging (Seyfu, 1983).

2.4. Role of Nitrogen in Plant Nutrition

Plants require N in the largest amount among the three major primary nutrients (others being P and K). It has many functions including: promotion of rapid growth, increasing leaf sizes, enhancing fruit and seed development; forms an integral component of many important components in plants including amino acids that are building blocks of proteins and enzymes, that are involved in catalyzing most biochemical processes (Forth and Ellis,1998; Brady and Weil, 2008). 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 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 (Ortiz-Monasterio *et al*., 2002).

As a result, deficiency in the supply of N has a profound effect on crop growth and development, and can lead to a total loss of grain yield in extreme cases (Miller and Donahue, 1995). 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).Nitrogen exerts its influence on crop growth in various ways. It promotes rapid growth and increases tiller production.

Excess N supply causes higher photosynthetic activity and vigorous vegetative growth which is disadvantageous early in the growing season when moisture limits plant growth, and is accompanied by weak stem. Dark green color, low product quality, delay in maturity, increase in susceptibility to lodging, insect pests and diseases (especially fungal diseases), and build-up of nitrite which is harmful to foliage and straw feed are common effects of excess N application in tef (Temesgen, 2001; Legesse, 2004). The similar results noted by Evans (1993) indicated that high N rates stimulate root and leaf growth and thereby increase photosynthetic activity and growth. Kidanu *et al*. (1999) demonstrated that the carryover benefit of N applied fertilizer enhanced the yield and N content of grain and straw of both wheat and tef, resulting in significant increase in (N) uptake.

As applied N rates increased, the grain uptake also increased which was also reflected in the plant height, yield and yield components like panicle length, panicle weight, grain yield, straw yield and biomass yield (Legesse, 2004). The same author further stated that the straw N uptake was significantly increased as applied N rate increased. Similarly, application of P fertilizer significantly affected straw N uptake though the increment was inconsistent (Legesse, 2004).

2.5 Effects of Nitrogen Fertilizer Rates on Yield and Yield Components of Tef

Management of nitrogen fertilizing is important to increase tef production. So, among chemical fertilizers a high correlation was reported between nitrogen and tef yield. Use of low rates for high-yielding modern crop cultivars, especially by farmers in developing countries, is another cause of N deficiency (Fageria, 2003). In developing countries, intensive agricultural production systems have increased the use of N fertilizer in efforts to produce and sustain high crop yields (Fageria *et al*., 2003). Tef responds to N application with remarkable changes in its all yield and yield components. Studies on the response of tef to N fertilizer, by different authors show that, increased application results in increased production. Different studies in various environment and time reported that tef responds highly to higher N fertilizer rates. Mitiku (2008) and Haftamu *et al*. (2009) noted that, application of high N fertilizer rate (90 kg N ha^{-1}) was the best to obtain high total biomass yield, straw yield and grain yield.

Haftamu *et al*. (2009) reported that nitrogen fertilizer rate caused significant effect in yield attributes. Tef plants with higher plant height (92cm) and panicle length (38cm) were found by applying high amount of N fertilizer (92 kg N ha^{-1}). This is because high nitrogen usually favors vegetative growth of tef which results in taller teff plants having relatively greater panicle length. They also reported that the biomass and grain yields were obtained by applying 92 kg N ha^{-1}. Application of nitrogen improves various yield related traits like 1000-grain-weight, productive tillers, number of spikes per unit area, number of grains per spike and biological yield (Al-Abdul Salam, 1997; Warraich *et al.,* 2002), thus resulting in higher yields. Zahran *et al.* (1997) also reported that plant height, flag leaf area, tillers number and dry weight per unit area of wheat were increased with increasing N rates. Similarly, Legesse (2004) found that, high yield components were recorded in response to application of the highest N rate (69 kg N ha^{-1}).

According to Tilahun (1994), the highest grain yield often resulted from high N rate (69kg ha^{-1}). The author noted that high N rate gives high grain yield per square meter. Similarly, Mulugeta (2003) found that application of high rates of N (92kg ha^{-1}) fertilizer increased the number of fertile panicles of tef. Increasing nitrogen application induced increasing leaf area, tiller formation and leaf area index. This resulted in producing more dry matter and grain yield. Gasim (2001) showed that plant height and number of leaves per plant increased as nitrogen levels increased was not significant as compared to the control.

According to Temesgen (2001), application of different levels of N fertilizer affected grain, straw and biomass yield significantly on farmer's field. Increasing N fertilizer rate consistently increased tef grain yield from 1620 kg ha^{-1} in the control (no application of N) treatment to 1950 kg ha^{-1} in the treatment where the highest rate of N (69 kg/ha) was applied. In general, high levels of N supply result in higher protein content, but increased efficiency of N utilization is realized when concentration in the kernels increases and grain yield remains stable (Ortiz-Monasterio *et al.,* 2002).

2.6 Effects of Timing of Nitrogen Fertilizer Application on Yield and Yield Components of Tef

The results of Vaughan *et al*. (1990) indicated that compared with other nutrients, N is highly soluble and may be lost from the soil-plant system by leaching, denitrification, volatilization and erosion. Substantial quantities of N may also be immobilized in organic forms that are not readily available to crops. There is high rate of nutrient depletion in Ethiopia due to lack of adequate synthetic fertilizer input, limited return of organic residues and manure, high biomass removal, erosion, and leaching (Balesh *et al*., 2007). The solution for these adversaries would be selecting combinations of nutrient source, appropriate rate and timing of fertilizer application; that would optimize fertilizer use efficiency as well as increase economic return (Grant *et al*., 2002).

Timing of N application had a significant role on reducing N losses, increasing NUE and avoiding unnecessary vegetative growth (Jan *et al*., 2010). When N was applied before the onset of stem elongation (Mossedaq and Smith, 1994) and at first node stage (Limon-Ortega *et al.,* 2000), the total N uptake was greater than at planting time. Further, fertilizer recovery was higher when N was applied at anthesis compared to at planting (Wuest and Cassman, 1992). The similar results suggested by Jeremy (2007) indicate that early nitrogen stimulates high tiller numbers, many of which die off during stem elongation. Early nitrogen also stimulates a large leaf area which uses more water than a thinner canopy and can lead to early drought for the crop. Leafy crops are also more prone to leaf diseases like *mildew* and *septoria*.

Delayed application of nitrogen fertilizer reduces these problems while giving the same or better yield and higher protein levels than sowing and tillering application at the same rates of N. Especially, application of nutrients before peak crop nutrient demand is critical; and adequate nutrients early in the growing season are necessary to maximize yield as N and P ensure good grain or seed fill (Clain, 2011). There are many advantages from early application, like increased nutrient use efficiency and reduced adverse environmental effects.

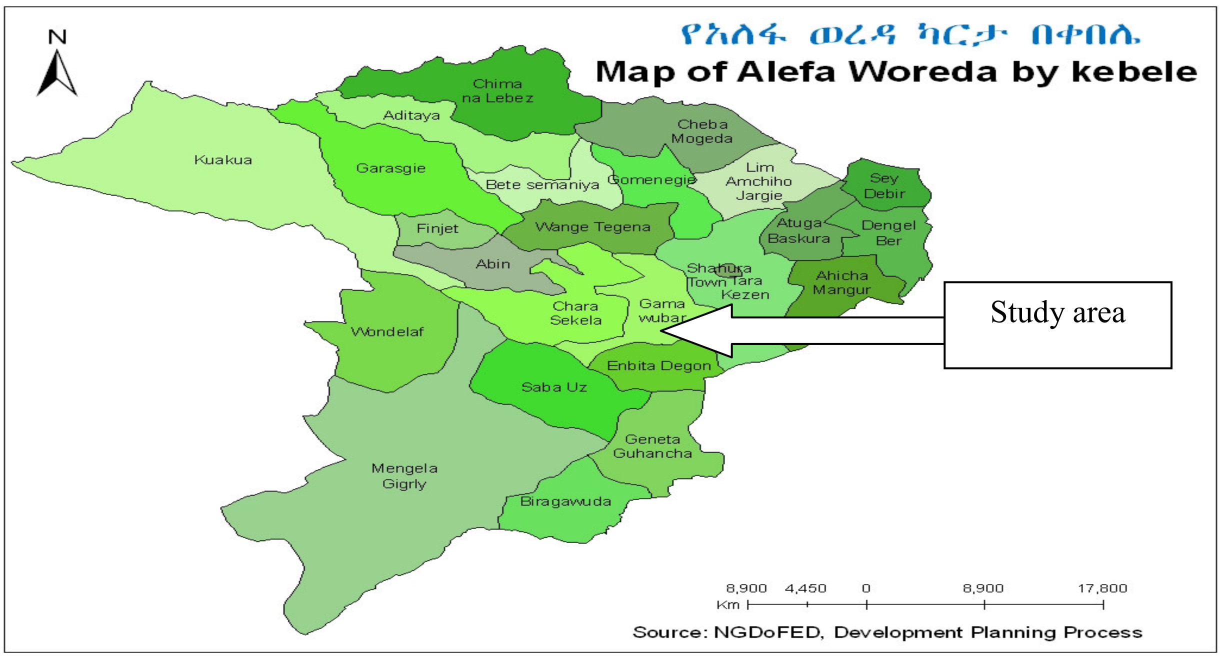
Most researchers report split application as superior to application of all N at sowing, particularly in areas of high seasonal precipitation. This justification supported by Asnakew *et al.* (1991) and Tilahun *et al*. (1996) stands by the fact that luxuriant application of N fertilizer at sowing increased the flush of emerging broad leaf weeds, thereby increasing the labor requirements for hand weeding. Hence, split application of nitrogen was considered more economical both in terms of weed management under farmers' conditions and as a risk aversion strategy, efficient nitrogen use for optimizing grain yield. Split application increases N management flexibility and potentially reduces N losses (Vaughan *et al*., 1990; Alcoz *et al*., 1993). Nitrogen fertilizer applied at the correct time and in the right amount to an actively growing crop will result in optimum yield and very little NO_3^- will remain in the soil at harvest minimizing risk of loss by leaching (Johnston, 1994). In practice, the optimal strategy for applying N to rain fed cereals depends on the interaction between soil N, amount and distribution of rainfall, and crop N uptake over time (Anderson, 1985).

Several studies have demonstrated the importance of time of N application to increase growth potential content (Fowler *et al*., 1989; Yesuf and Duga, 2000) and reduce N losses (Vaughan *et al*., 1990) from the soil-plant system. This may be attributed to the presence of an active root system for absorbing the fertilizer N at the time of application. Tolessa *et al.* (1994) reported that the best use of nitrogen is obtained when 50% of the total requirement is applied at sowing and the remaining 50% is given as top dressing. The other option is application of the total requirement in three equal splits at sowing, knee-height and flag leaf emergence.

3. MATERIALS AND METHODS

3.1 General Description of the Study Area

The study was conducted in Alefa district of northern Gondar zone of Amahara Regional State at Gamawber farmer training center site from July – November during the main cropping season of 2016. The place is located at 12^0 30 N and 36^0 30 E at an altitude of 2200 meters above sea level. Shahura town is the administrative seat of the district. Physiographical plateaus, mountains, hills, plains and valleys characterize the district (OSCA, 2016 unpublished)



It is located at 605km, 88km,142km away from Addis Ababa, Bahirdar and Gondar on the road to Alefa, respectively and characterized by annual rainfall of 900 to 1400 mm and mean minimum and maximum temperature of 22ºC and 28 ºC, respectively (OMS, 2016 unpublished). It is classified into *woina degas* (45%) and *kola* (55%) agro-climatic zones with highly variable rainfall both temporally and spatially. Most predominantly soil types in this district are red and clay soil with 75% and 25% share, respectively. Crops predominantly grown in the study area are maize (3344 ha), millet (2445 ha), teff (3477 ha), barely (1234 ha) and wheat (458 ha) (OARD, 2016 unpublished).

3.2 Experimental Materials

3.2.1 Planting material

The tef variety named *Quncho* (DZ-Cr-387), which was developed and released by Debre Zeit Agricultural Research Centre in 2006 was used as test crop. The seeds were obtained from the farmers' cooperative union. *Quncho* (DZ-CR-387) is a high yielding white-seeded cultivar adapted to a wide range of altitudes (MOARD, 2008).

3.2.2 Fertilizer material

Urea (46% N) and TSP (46% P_2O_5) were used as a source of nitrogen and phosphorus nutrient elements.

3.3 Treatments and Experimental Design

The treatments consisted of four levels of nitrogen (23, 46, 69 and 92 kg N ha^{-1}) and three timing of applications (full dose at sowing, full dose at tillering, two split applications (½ dose at sowing + ½ dose at tillering). One additional control treatment consisted of 0kg N ha^{-1} for economic comparison. The experiment was laid out in randomized complete block design (RCBD) with factorial arrangements of 4 x 3 = 12 treatment combinations together with one control treatment making a total of 13 treatments, which were replicated three times. Each plot 3 m wide x 2.2m long (6.6 m^2) and the distances between plots and blocks were kept at 0.5m and 1m, respectively. The total area used for this study including the border area was 11m by 34.6 m (380.6m^2). Seeds were sown into rows of 0.2m apart and 2.2m long. Each plot consisted of 15 rows. The net central unit areas marked each plot consisted of 13 central rows of 2.2 m length each (5.6 m^2) were used for data collection and measurement.

3.4 Field Management

The experimental field was prepared following the standard production (conventional tillage) practices before planting the tef. In accordance with the specifications of the design, a field layout was prepared and each treatment was assigned randomly to experimental plots within a block. After the seedbeds were leveled and compacted, at the rate of 5 kg ha $^{-1}$ seeds were sown manually in rows spaced 20 cm apart as recommended by ATA (2012). Before sowing seeds were mixed with soil (1:2) to reduce the sowing problem in the rows. Seeds were sown on July 21, 2016 at experimental site. Phosphate fertilizer in the form of TSP (46% P_2O_5) at the recommended rate of 46 kg P_2O_2 ha^{-1} was applied equally to all plots as drill application at planting. Nitrogen fertilizer at a specified rate and time was applied in by drilled urea. The second N fertilizer application as dry urea was done by side dressing at the specified tillering stage of the crop, i.e. at the beginning of August. Weeds were removed by hand according to the locally recommended practices, 24 and 65 days after emergence. Additionally, weeding out of late-emerging grasses was done to avoid interference with the teff in the uptake of applied N. The crop was harvested on 16-23 October 2016.

3.5 Soil Sampling and Analysis

Soil samples for soil analysis, were taken randomly in a zigzag pattern before planting. Twenty soil samples were taken from the entire experimental field using an augur to a depth of 0-30 cm from the top soil layer. The soil samples were composited into a bucket. Crumbs of the soil were broken into small pieces and thoroughly mixed. Sample weighing from this mixture, a composite 1 kg was filled into a plastic bag. The soil was air-dried and sieved through a 2mm sieve. The working samples obtained from each submitted samples were bagged, properly labeled and transported to the laboratory for analysis of selected physico-chemical properties following standard laboratory analysis methods. In the laboratory, the pre-plant composite soil samples were used to determine organic carbon, total N, soil pH (H_2O), available phosphorus, exchangeable Cation, K and texture. All samples were analyzed following standard laboratory procedures as outlined by Sahlemedhin and Taye (2000).

Accordingly, Soil organic carbon content was determined by the wet digestion method as described by Olsen (1954). Total nitrogen was determined using Kjeldhal method (Jackson, 1993). Available phosphorus was determined by extraction with 0.5 M $NaHCO_3$ according to the methods of Landon (1991).

Particle size distribution (soil texture) was done by hydrometer method (differential setting within a water column) according to FAO (2008) using particles less than 2 mm diameter. The procedure measures percentage of sand (0.05-2.0 mm), silt (0.002-0.05 mm) and clay (< 0.002 mm) fractions in soils. The soil pH was determined from the filtered suspension of 1:2.5 soils to water ratio using a glass electrode attached to a digital pH meter (potentiometer). Analysis of the soil was analyzed at Gondar soil analytical Service Laboratory.

3.6 Crop Data Collection and Measurements

3.6.1 Phenological data

3.6.1.1 Days to 50% panicle emergence

It was determined by counting the number of days from sowing to 50% panicle emergence (as 50% of the plants started to form panicles). Visual observation was used to determine panicle emergence of the plants.

3.6.1.2 Days to 90% physiological maturity

Days to physiological maturity was determined as the number of days from sowing to 90% maturity based on visual observation as indicated by senescence of the leaves as well as free threshing of seeds from the glumes when pressed between the thumb and the forefinger.

3.6.2 Lodging index

The degree or extent of lodging was assessed just before the time of harvest by visual observation based on the scales of 1-15 which, 1 (0-15^0) indicates no lodging, 2 (15-30^0) indicates 25% lodging, 3 (30-45^0) indicates 50% lodging, 4 (45-60^0) indicates 75% lodging and 5 (60-90^0)

indicates 100% lodging (Donald, 2004). The scale was determined by the angle of inclination of the main stem from the vertical line to the base of the stem by visual observation.

3.6.3 Growth and yield component data

Data on plant height, panicle length, number of effective tillers, 1000-kernel-weight, grain yield, straw yield, above-ground dry biomass and harvest index were collected to determine the yield and yield components of the crop.

3.6.3.1 Plant height

Plant height was measured at physiological maturity from the ground level to the tip of panicle of ten randomly selected plants in each plot.

3.6.3.2 Panicle length

It was determined by measuring the length of panicle from the node where the first panicle branch had emerged to the tip of the panicle utilizing the ten plants selected for the measurement of panicle length.

3.6.3.3 Number of effective tillers

The numbers of effective tillers were determined by counting the tillers from an area of 30 cm x 40 cm in area plants by throwing a quadrate into the middle portion of each plot.

3.6.3.4 Main panicle seed weight

The average seed weight of the main panicle at harvest was recorded from average of five randomly selected pre-tagged plants.

3.6.3.5 Thousand-kernel-weight

The weight of 1000-kernels was determined by carefully counting the small grains taken from each plot and it was adjusted at 12.5% moisture content weighting them using a digital balance.

3.6.3.6 Biomass yield

At maturity, the whole plant biomass including leaves, stems, seeds etc was harvested from the net plot area and air-dried, after which the weight was recorded.

3.6.3.7 Straw yield

It was determined by subtracting grain yield from above ground dry biomass yield.

3.6.3.8 Grain yield

Grain yield was measured by harvesting the crop from the net plot area. The grain moisture was adjusted to 12.5%. The final yield was determined by using the formula as:

$$\text{Adjusted grain yield} = \text{Recorded grain yield (kg ha}^{-1}) \times \frac{(100\text{-}\%MC)}{(100\text{-}12.5)}$$

Where, MC=grain moisture contents

3.6.3.9 Harvest index

It was recorded as the ratio of grain yield to shoot biomass at harvest in kg from net plot.

3.7 Data Analysis

The data collected were subjected to analysis of variance (ANOVA) using general linear model (GLM) procedures of SAS version 9.1 (SAS Institute, 2002). Means of significant treatment effects were separated using the Least Significant Difference (LSD) test at 5% level of significance.

3.8 Partial Budget Analysis

For economic analysis, a simple partial budget analysis was employed using CIMMYT approach (CIMMT, 1988). For partial budget analysis, the factors with significant effect were considered. The yield was adjusted by subtracting 12.5 % moisture content of grain from average grain yield. Then after, net yield benefit was obtained by multiplying the adjusted yield by the price of grain (18 birr kg^{-1}). Net benefit was calculated, by subtracting the cost labor and the cost of 100 kg urea (1216 birr) from net yield. Finally marginal rate of return (MRR) was obtained, by dividing marginal net benefit to the marginal cost and expressed as percentage (CIMMT, 1988). The mean market price of tef was obtained by assessing the market at harvest (2016/2017 cropping season).

4. RESULTS AND DISCUSSION

4.1 Selected Physical and Chemical Properties of the Soil of Experimental Site

The result of analysis of the top 0-30cm depth soil of the experimental site is indicated in Table 1. The results of the laboratory analysis for some physical and chemical properties of the experimental soil indicated that the soil is clay loam in texture with pH (H_2O) of 5.02, the organic matter content of the soil amount to 4.23%, the soil has contents of total N amounting to 0.2%, available P (Olson) of 18.06 mg kg soil^{-1} and Cation Exchange Capacity (CEC) of 33.71 Cmol/kg soil^{-1} (Table 1).

Sahlemedhin (1999) classified total N content of 0.1 to 0.2% as low and organic matter content of 3-5% as high and more than 5% as very high. The author also described CEC by sodium acetate at pH 8.2 or ammonium acetate pH 7 with values between 25 and 40 Cmol/kg soil^{--1} as high to medium and satisfactory for agricultural production with the use of fertilizers and CEC > 40 Cmol/kg $^{-1}$ as very high. Cation exchange capacity (CEC) is an important parameter of soil because it gives an indication of the type clay mineral present in the soil and its capacity to retain nutrient against leaching. This shows that the content of organic matter in the experimental soil is high and total N content is low.

Mengel and Kirkby (2001) stated that the critical available P content in the soil according to analytic method of Landon (1991) for optimum plant growth lay near 20 mg kg soil^{-1}. This shows that the available P content of the experimental soil (18.06 mg kg soil^{-1}) is just near sufficiency for plant growth. These classifications of soil nutrient status are consistent also with those of London (1991). There for with these considerations, the total N content of the experimental soil is in lower range and CEC is high. The pH of the soil was 5.02, which is with range 4 to 8 suitable for tef production (FAO, 2008). The relatively medium to sufficient available P might have occurred due to the continuous intensive P fertilizer application. However the actual response of crops to P application may depend on many other factors such as availability of other nutrients in the soil such as N and potassium as well as moisture (Mengel and Kirkby, 2001).

Table 1. Physico-chemical properties of the experimental soil depth of 0-30cm during the 2016 main growing season at Alefa.

% Clay	% Silt	% Sand	Soil Class	TN (%)	Av.P (ppm)	Av. K (ppm)	OM %	pH (H_2O)	CEC (Cmol/kg)
32.8	37.8	29.2	Clay loam	0.2	18.06	2.12	4.23	5.02	33.71

Where, TN= Total Nitrogen, Av.P= Available Phosphorous, Av. K= Available Potassium and OM= Organic matter; CEC=Cation exchange capacity; ppm=Part per million.

4.2 Effects of Nitrogen Rate and Time of application on Crop Phenology of Tef

4.2.1 Days to panicle emergence

Analysis of variance of the data revealed that the main effects of N rate and time of application highly significantly ($P \leq 0.01$) influenced day to panicle emergence. However, the interaction effect of the two factors did not significantly influenced days to panicle emergence (Appendix 2). Days to panicle emergence was significantly increased in response to increasing rate of nitrogen. While, there was consistency in the increase of this parameter with the increase in nitrogen application. Days to panicle emergence of tef plants were hastened under lower N rate compared to the higher rates. Thus, increasing the rate of nitrogen from 0 to 23 kg N ha^{-1} prolonged day to panicle emergence by about 6.8%; while, increasing the rate of nitrogen further from 0 to 46, 69 and 92 kg N ha^{-1} prolonged days to panicle emergency by about 9.12%, 11.26% and 12.62%, respectively. However, there was no significant difference in days to panicle emergence attained at 69 and 92 kg N ha^{-1} (Table 2).

Compared with days to panicle emergence obtained for the control treatment, the mean value of day to panicle emergence obtained at 92 kg N ha^{-1} was higher by about 12.62%. Generally, the number of days to panicle emergence recorded over all the fertilized plots was significantly higher than the controlled (Table 2). Similar results were reported by Abraha (2013), who observed that, the maximum number of day to panicle emergence where at 92 kg N ha^{-1} and the lower number of days to panicle emergence was recorded in plants treated by lower rate.

The study also showed increasing tendency of days to panicle emergence with increasing N application time. Increasing the time of nitrogen application significantly prolonged the day to panicle emergence of plants across the application times. Over all times of N application, T3 (50% at sowing and 50% at tillernig) had significantly delayed day to panicle emergence than those grown at the other time of nitrogen application time. The maximum number of days to panicle emergency (58.08) was observed when in two splits (50% at sowing and 50% at tillernig) and the minimum days to panicle emergence (55.89) was observed when 100% applied at sowing of the crop (Table 2)

Generally, the number of days to panicle emergence recorded over all the treated plots was significantly lower than the T3 (50% at sowing and 50% at tillernig) plot. The delay in panicle emergence of tef plants in response to time of N split application might be because of the fact that N time split application promoted vigorous vegetative growth and development of the plant possibly due to synchrony of the time need of the plant for uptake of the nutrient and availability of nutrient in the soil. This result in line with finding of Getachew (2004) and Mekonen (2005) who reported that heading was significantly delayed at the highest N fertilizer rate compared to lowest rate on wheat and barley crops, respectively. In contrast, to the results of the present study, Sewenet (2005) reported early flowering with an increase in the rate of N application in rice.

Table 2. Mean days to panicle emergence of tef affected by rate and time of nitrogen fertilizer application.

Treatments:	Mean days to panicle emergence
N rate (Kg ha^{-1})	
0	51.26^{d}
23	55.00^{c}
46	56.41^{b}
69	57.77^{a}
92	58.67^{a}
LSD(0.05)	1.02
Timing	
T1	55.89^{c}
T2	56.92^{b}
T3	58.08^{a}
LSD(0.05)	0.88
CV (%)	1.83

Where, T1= full dose at sowing, T2= full dose at tillering, T3=½ dose at sowing + ½ dose at tillering. Mean followed by the same letter with a column are not significantly different at 5% probability. NS=non-significant at 5% probability.

4.2.2 Days to 90% physiological maturity

Early maturing crop is preferred due to many agronomic reasons such as water stress, low soil fertility, insect and pest attack, etc. That is why days to 90% physiological maturity of the crop is one of the important agronomic parameter used to evaluate the efficiency of nutrient supply. Days to physiological maturity of teff plant was highly significantly ($P \leq 0.01$) affected only by the main effect of N fertilizer rate while the main effect of timing of application and the interaction effect of the two factors did not effect this parameter (Appendix 2).

According to Table 3, N fertilizer prolonged days to 90% physiological maturity of tef. In general, the maturity of tef plants was hastened under lower N rates than the higher rates. Thus, increasing the rate of nitrogen from 0 to 23 kg N ha^{-1} prolonged days to maturity by about 3.73% over that of nitrogen rate. Increasing the rate of nitrogen further from 0 to 46 kg N ha^{-1} prolonged days to maturity by about 3.98%.

However, increasing the rate of nitrogen from 23 kg N ha^{-1} to 46 kg N ha^{-1} did not significantly affect number of days to maturity; while, increasing the rate of nitrogen further from 0 to 69 and 92 kg N ha^{-1} prolonged days to maturity by about 6.11%, and 7.82%, respectively (Table 3).

Delayed in maturity of tef plants in response to the increased N rate (92 kg N ha^{-1}) might be because the fact that high N rate promoted vigorous vegetative growth and development of the plants possible due to synchrony of the time of need of the plant for uptake and availability of the nutrient in the soil. The results obtained from this are in conformity with the established fact that abundant supply of nitrogen delays physiological maturity by promoting vigorous vegetative growth of the plant (Brady and Weil, 2008). The findings are in line with the fact that N application by facilitating vegetative growth stage of cereals also prolongs the maturity. Similar observations were also noted by Temesgen (2001) who reported that application of 69 kg N ha^{-1} delayed maturity of tef by seven days over the control treatment (0 kg N ha^{-1}) at farmers fields and research station in Kobo Vertisols. Consistent with the result of this study, Gobeze (1999) reported that N rates delayed the maturity of sorghum.

Table 3. Mean days to physiological maturity of tef affected by rate and time of nitrogen fertilizers application.

Treatments:	Mean days to physiological maturity
N rate (Kg ha^{-1})	
0	91.00^{d}
23	94.53^{c}
46	94.78^{c}
69	96.93^{b}
92	98.72^{a}
LSD(0.05)	1.423
Timing	
LSD(0.05)	NS
CV (%)	1.512

Where, T1= full dose at sowing, T2= full dose at tillering, T3=½ dose at sowing + ½ dose at tillering. Mean followed by the same letter with a column are not significantly different at 5% probability. NS=non-significant at 5% probability.

4.3 Effects of Nitrogen Rate and Time of application on Lodging Percentage of Tef

Lodging percentage of teff plant was highly significantly (P≤ 0.01) affected by the main effects of rate and timing of N fertilizer application and interaction effects on this parameter (Appendix 2). Increasing the rate of nitrogen increased the lodging index of tef crops across all nitrogen fertilizer application times. This result is consistent also with that of Tekalign *et al*. (2000) who has obtained significant difference in lodging percentage of tef due to N application at the rate of above 60 kg N ha^{-1}. These result are consistent with the suggestion of Brady and Weil (2008) who reported that excess N application causes high vegetative growth, and enlargement of stem cells the consequently leads to weak stem making it prone to lodging. However, marked increases in lodging due to the increased application of nitrogen fertilizer were observed for crops supplied with nutrient into two-split of equal dose sowing and tillering.

The lowest lodging index was obtained for plants grown under treatment when the rate of 23 kg N ha^{-1} was applied as full dose of N at sowing. The lodging index of plants supplied with 92 kg N

ha^{-1} as full dose at sowing, full dose at tillering and half dose at sowing and the other half at tiilering exceeded the lodging index of plants supplied with 23 kg N ha^{-1} as full dose at sowing by 41.6%, 47.8% and 40.5%, respectively. The current result are in agreement with that of Abraha (2013) who reported lowest and highest lodging indices for plants grown at the rate of 46 kg N ha^{-1} was applied as full dose at sowing and 92 kg N ha^{-1} applied as full dose at sowing and full dose at tillering, respectively. These results reveal that increasing the rate of nitrogen to the extent of one full dose and increasing the frequency of application by way of half dose at sowing and the other half at tillering leads to the detrimental effect of crop losses due to lodging.

On the other hand, the results showed that applying optimum rates of nitrogen full dose at sowing or splitting into two equal doses (half of the dose at sowing and half dose at tillering) profoundly prevented f tef from lodging. The presence of excess N promotes development of the aerial organs with relatively poor root growth. Synthesis of protein and formation of new tissues are stimulated, and thus carbohydrates of high molecular weight are synthesized in insufficient amounts, resulting in abundant dark green (high chlorophyll) tissue of soft consistency. This increases the risk of lodging, reduces the plant's resistance to harsh climatic conditions, foliar diseases and insect predation.

On the other hand, splitting the nitrogen into two doses as observed from the experiment results might have provided enough time space for the plant to take up N according to its demand, resulting in better synchrony of growth with supply of the nutrient. This may have resulted in better growth of the tef plants with stouter stem. This result is corroborated by that of Cassman *et al*. (2002) who reported that synchrony between crop demand and nutrient supply is necessary to improve nutrient-use-efficiency and better growth of plants. Over all, the lodging index recorded under fertilized plot exceeded the unfertilized plots by about 51%.

Table 4. Mean lodging index (%) of tef as affected by rates and timing of nitrogen application.

N rate kg ha^{-1}	Timing of application (T)			
	T1	T2	T3	Mean
23	18.40^{f}	20.06^{fe}	24.43^{d}	20.96^{d}
46	20.26^{fe}	24.63^{d}	27.96^{c}	24.28^{c}
69	22.50^{de}	29.83^{bc}	30.70^{bc}	27.67^{b}
92	31.53^{b}	35.30^{a}	30.93^{b}	32.58^{a}
Mean	23.17^{b}	27.45^{a}	28.50^{a}	26.38^{h}
Control				13.00^{g}
	R	T	R*T	Treated vs. control
LSD (0.05)	1.6	1.4	2.78	2.86
CV (%)			6.23	6.71

Where, R= rate, T= timing of application, T1= full dose at sowing, T2= full dose at tillering, T3=½ dose at sowing + ½ dose at tillering. Mean followed by the same letter with a column are not significantly different at 5% probability.

4.4 Effects of Nitrogen Rate and Time of application on Tef Growth Parameter

4.4.1 Plant height

Plant height at physiological maturity was highly significantly ($P \leq 0.01$) affected by the main effects of N rate and time of application. It was also significantly affected ($P \leq 0.05$) by the interaction of treatment combinations (Appendix 3).

Plant height generally increased with the increase in the rate and time of N application. Plot treated with the half-dose of N at sowing and the other half-dose of N at the tillering, resulted in tallest plant in response to the application of 92 kg N ha^{-1}. Among all rates of nitrogen, shortest plants were observed from plot supplied 23 kg N ha^{-1} with one-dose application at sowing, whereas the tallest plant height (124.06 cm) were obtained when 92 kg N ha^{-1} was applied in two split, i.e. ½ of the dose at sowing and ½ of the dose at tillering. However, it was statistically at par with the plant height recorded in plot fertilized with 69 kg N ha^{-1} (123.6 cm) and 92 kg N ha^{-1} (124.06 cm), respectively, in two split application of ½ at sowing and ½ at tillering and also under 92 kg N ha^{-1} (121.2 cm) with full application at tillering, 69 kg N ha^{-1} (119.9 cm) with application at tillering and 46 kg N ha^{-1} (19.3 cm) with two split application were statistically at par in plant height (Table 5).

Thus, the mean height of plants grown at the rates of 92 kg N ha^{-1} applied half dose at sowing and other half dose at tillering significantly exceeded the mean heights of plants treated with 23, 46, 69, and 92 kg N ha^{-1} rate applied full dose at sowing time by 8.3%, 6.77%, 6.09% and 6.39%, respectively (Table 5). This difference may be due to the fact that recovery of the nutrient by roots and enhanced plant growth. This could be attributed to the fact that application of full dose of nitrogen at one time to crops may lead to loss due to leaching as nitrate ion (NO_3^-) as stated by Mengel and Kirkby (2001). Who reported significant increments in plant height due to application of high rate of nitrogen fertilizer.

Many study revealed significant influence of N on plant height as it play vital role in vegetative growth of plants. A similar result was also reported by Haftamu *et al.* (2009) showing tef plants taller (92 cm) and panicle longer (38 cm) due to application of high amount of N fertilizer (92 kg N ha^{-1}). This may be attributed to the fact that N usually favors vegetative growth of tef, resulting in higher stature of the plants with greater panicle length. Legesse (2004) also reported that high N application resulted in significantly taller plants of tef due to direct effect of N on vegetative growth of plant.

Table 5. Mean plant height (cm) of tef as affected by rates and timing of nitrogen fertilizer application.

	Time of application (T)			
N rate kg ha^{-1}	T1	T2	T3	Mean
23	113.76^{e}	114.66^{de}	115.66^{de}	114.70^{c}
46	115.66^{de}	116.80^{d}	119.33^{c}	117.26^{b}
69	116.50^{d}	119.90^{c}	123.66^{ab}	120.02^{a}
92	116.16^{de}	121.20^{de}	124.06^{a}	120.47^{a}
Mean	115.52^{c}	118.14^{b}	120.68^{a}	118.11^{h}
Control				109.36^{f}
	R	T	R*T	Treated vs. control
LSD (0.05)	1.4	1.2	2.48	2.45
CV (%)			1.24	1.24

Where, R= rate, T= timing of application, T1= full dose at sowing, T2= full dose at tillering, T3=½ dose at sowing + ½ dose at tillering. Mean followed by the same letter with a column are not significantly different at 5% probability.

4.4.2 Number of effective tillers per $1m^2$ area

Tiller number is one the yield components of tef that contributes to high straw and biomass yield. The number of effective tillers per $0.12m^2$ was highly significantly ($P \leq 0.01$) affected by both main effect of N rate and timing of application but not their interaction effects for this parameter (Appendix 3). Thus, there is increased significant in number of effective tillers per meter square in response to increasing rate of nitrogen and its timing (Table 6). As a result of the main effect of N application rates the maximum numbers of tiller (263.8 m) where produced when 69 kg N ha^{-1} was applied; which is 32.63% higher over control, followed by 92 kg N ha^{-1} (32.1%). However, the effects of 69 kg N ha^{-1} and 92 kg N ha^{-1} were statistically at par with each other in production of effective tillers per meter square area. Generally, there was an increasing trend in tiller numbers with increasing N rate. Similar work also confirmed that with increasing nitrogen rates there was increase in number of tillers (Abdo *et al.*, 2012; Girma *et al.*, 2012).

The study also showed increasing tendency of number in the tiller per meter square with split or increasing N time of application. The maximum number of effective tillers were recorded under N split application time, i.e. ½ at sowing and the remaining ½ at tillering (257.6 m) which was 13.7% over applications of at sowing time or full dose at tillering (220.1 m) fetching 7.84% advantage. Therefore, application of N at different growth stage of tef may help to retain N for plant growth and reduce N loss from leaching contributing to eutrification of water bodies and environmental pollution. These results are in agreement with the finding of several workers (Tilahun *et al*., 1996; Abdo *et al*., 2012; Haile *et al*., 2012).

Table 6. Mean number of effective tillers per 1m^2 of tef as affected by rate and timing of nitrogen fertilizer application.

Treatments:	Mean number of effective tillers (1m^2)
N rate (kg ha^{-1})	
0	177.75^c
23	204.58^b
46	225.00^b
69	263.83^a
92	262.00^a
LSD (0.05)	20.56
Timing	
T1	220.14^b
T2	238.89^c
T3	257.64^a
LSD (0.05)	17.8
CV (%)	8.8

Where, R= rate, T1= full dose at sowing, T2= full dose at tillering, T3=½ dose at sowing + ½ dose at tillering. Mean followed by the same letter with a column are not significantly different at 5% probability.

4.4.3 Main panicle length

Panicle length is one of the yield attributes of tef that contributes to grain yield. Crops with higher panicle length could have higher grain yield. The results obtained on main panicle length were highly significantly (P≤0.01) influenced by the main effects of rate and time of nitrogen application but not, by the interaction effect of the two factors (Appendix 3).

Main panicle length increased significantly in response to increasing rate of nitrogen. However, there was no significantly difference in panicle length attained under fertilization by 46 and 92 kg N ha^{-1} (Table 7). The highest panicle length (42.81cm) was recorded in response to nitrogen applied at the rate of 69 kg N ha^{-1} while the lowest panicle length (33.10 cm) was obtained from plots untreated by nitrogen. An increase of nitrogen rate from 0 to 23 kg N ha^{-1} increased the teff panicle length by about 12.27%. Increasing the rate of nitrogen further from 0 to 46 and 69 kg N ha^{-1} markedly increased the panicle length of the plant by about 15.98% and 18.53%, respectively (Table 7). These results are in agreement with those of Abraha (2013) who reported that the maximum panicle length was obtained from the rate of 69 kg N ha^{-1} and no further in panicle length was recorded beyond this level of N supply. This result is in contrast to that of Haftamu *et al*. (2009) who reported that teff panicle length increased in response to increasing rate of nitrogen application, with the longest panicles has been obtained under fertilization by 92 kg N ha^{-1} of nitrogen.

An increased application of N caused increased panicle length and hence crops with higher panicle length produced significantly higher total biomass yield, grain yield and straw yield than those with shorter panicles (Mulugeta, 2000; Legesse, 2004; Mitiku; 2008; Haftamu *et al*., 2009). However, excessive concentration of N resulting from increased rate of N application reduced panicle length. Increase in panicle length due to optimum rate of applied N increased the number of spikelet per panicle and thereby increased grain yield (Behera, 2000).

The study also showed increasing tendency of main panicle length with increasing N timing, i.e. split application. The maximum panicle length (41.72 cm) was recorded by two N split application (½ application at sowing and the remaining ½ at tillering) which resulted in 8.02% and 3.33% highest over full dose application at sowing and tillering time, respectively. Similar to the current study, Kidu (2016) reported that panicle length was highly significantly ($P \leq 0.05$) influenced by application timing of N fertilizer. Thus, increase of timing of N application increased the teff panicle length.

Table 7. Main panicle length of teff affected by rate and time of nitrogen fertilizers application.

Treatments:	Mean to panicle length (cm)
N rate (kg ha^{-1})	
0	33.10^{d}
23	37.73^{c}
46	39.40^{b}
69	42.81^{a}
92	40.63^{b}
LSD (0.05)	1.59
Timing	
T1	38.37^{c}
T2	40.33^{b}
T3	41.72^{a}
LSD (0.05)	1.38
CV (%)	4.06

Where, T1= full dose at sowing, T2= full dose at tillering, T3=½ dose at sowing + ½ dose at tillering. Mean followed by the same letter with a column are not significantly different at 5% probability.

4.5 Effects of Nitrogen Rate and Time of Application on Yield and Yield Components of Tef

4.5.1 Main panicle-seed-weight

Analysis of variance indicated that the main panicle-seed-weight was highly significantly ($P \leq 0.01$) influenced by the main effects of N rate, timing of N fertilizer application as well as by the interaction effect of the two factors being significant only at 5% probability (Appendix 3). The highest main panicle-seed weight (7.86g) was recorded in response to nitrogen applied at the rate of 69 kg N ha^{-1} with two equal splits (½ at sowing and ½ at tillering).While, the lowest main panicle-seed-weight (3.9g) was obtained from plots treated with 23 kg N ha^{-1} as full dose application at sowing time. Compared with 23 kg N ha^{-1} in full application of nitrogen at sowing or tillering time, 69 kg N ha^{-1} with two two-time equal split N applications (at sowing and tillering) exceeded by 50.4% and 45.76%, respectively (Table 8). Similarly, Abraha (2013) reported that the highest main panicle-seed-weight (9.00g) was obtained from 69 kg N ha^{-1} applied as three split applications. Moreover, Husssins and Shah (2002) also reported that the number of kernels per spike increased with an increase in N rate.

Increasing the rate of N fertilizer from 23 to 46 kg N ha^{-1} with all two application timings, increased panicle-seed-weight. Similarly, also increasing the rate of nitrogen from 46 to 69 kg N ha^{-1} with all the above application timings increased the main panicle-seed-weight, but further increase to 92 kg N ha^{-1} significantly decreased the size of panicle-seed-weight (Table 8). The results obtained from this study is in conformity with the established fact that the presence of N in excess promotes development of the aerial organs with relatively poor root growth causing lodging which leads to not only poor grain filling and thus reduced main panicle-seed-weight but also cause damage to the vegetative part of the plant rooting, fast spread of disease and pests (Seyfu, 1993).

Table 8. Mean values of main panicle-seed-weigh (gram) of tef as affected and timing of nitrogen fertilizer application.

N rate kg ha^{-1}	Timing of application (T) T1	T2	T3	Mean
23	3.90^{gh}	4.26^{gf}	4.66^{ef}	4.27^{d}
46	6.20^{c}	5.70^{d}	6.26^{c}	6.05^{b}
69	6.83^{b}	7.46^{a}	7.86^{a}	7.38^{a}
92	5.00^{e}	5.46^{d}	5.84^{dc}	5.43^{c}
Mean	5.48^{c}	5.72^{b}	6.16^{a}	5.79^{f}
Control				3.56^{h}
	R	T	R*T	Treated vs. control
LSD (0.05)	0.27	0.23	0.47	0.45
CV (%)			4.83	4.78

Where, R= rate, T= timing of application, T1= full dose at sowing, T2= full dose at tillering, T3=½ dose at sowing + ½ dose at tillering. Mean sharing the same superscript letter do not differ significantly at P= 0.05 according to the LSD test.

4.5.2 Thousand-seed-weight

Thousand-seed-weights were measured at moisture contents of seeds to adjusted 12.5%. The analysis of variance showed that thousand-seed-weights were highly significantly ($P \leq 0.01$) affected due to the main effects of nitrogen rate and timing of applications and the interaction of the two factors ($P \leq 0.05$) Appendix 3).

Thousand-seed-weight is an important yield determining component and reported to be a genetic character which is influenced least by environmental factors (Ashraf *et al*., 1999). Considering the main effect of N fertilizer rate, the highest 1000-seed-weight (0.348g) was obtained in response to the application of 69 kg N ha^{-1}, with the two-time split application (½ at sowing and ½ at tillering) and the lowest 1000-seed-weight (0.26g) was obtained with 23 kg N ha^{-1} rate, in all type of application time. Under 92 kg N ha^{-1}, this parameter was markedly low at full applications at tillering time compared to the other treatments except 23 kg N ha^{-1}. Compared with full application of N at sowing and at tillering time, the two-time equal split N application at sowing and tillering resulted in 6.9% higher 1000-seed-weight (Table 9).

Increasing the rate of N fertilizer from 23 to 46 kg N ha^{-1} across full dose application at sowing time, increased the thousand-seed-weight. Such result as suggested by Gooding and Daives (1997) is obtained due to an excessive N availability early in the season that can lead to reduced kernel-weight. The associated grain shriveling could also contribute to the reduced packing efficiency and low specific weight. Similarly, increasing the rate of nitrogen from 46 to 69 kg N ha^{-1} across T1 and T2 increased the thousand-seed-weight, whereas further increase to 92 kg N ha^{-1} significantly decreased this component of the yield (Table 9). Similar to the current study, Abraha (2013) who found the maximum 1000-seed-weight (0.3249g) from plants supplied with 69 kg N ha^{-1}, however, increasing the rate of nitrogen from 69 to 92 kg N ha^{-1} did not significantly affect 1000-seed-weight.

Generally, the weight of 1000-seed of tef increased linearly as the rates of applied N increased from the lowest to the highest N rate but increasing it beyond optimum requirements, decreased thousand-seed-weight. In conformity with this result, Abraha (2013) also reported increased thousand-kernel-weight due to N application in tef but with optimum level. However, in contrast to the finding of this study, Melesse (2007) reported no significant effect of application of different rates of nitrogen fertilizers (0, 46 and 69 kg N ha^{-1}) on 1000-kernel-weight of bread wheat.

Table 9. Mean values of thousand-seed-weight (gram) of tef as affected by rate and timing of nitrogen fertilizer application.

	Time of application (T)			
N rate kg ha^{-1}	T1	T2	T3	Mean
23	0.260^{e}	0.260^{e}	0.261^{e}	0.260^{c}
46	0.265^{e}	0.285^{de}	0.314^{cb}	0.288^{b}
69	0.308^{dcb}	0.328^{ab}	0.348^{a}	0.328^{a}
92	0.306^{dcb}	0.283^{de}	0.300^{dc}	0.296^{b}
Mean	0.284^{b}	0.289^{b}	0.306^{a}	0.293^{d}
Control				0.260^{e}
	R	T	R*T	Treated vs. control
LSD (0.05)	0.0147	0.0127	0.0254	0.0252
CV (%)			5.11	5.14

Where, R= rate, T= timing of application, T1= full dose at sowing, T2= full dose at tillering, T3=½ dose at sowing + ½ dose at tillering. Mean sharing the same superscript letter do not differ significantly at P= 0.05 according to the LSD test.

4.5.3 Above ground biomass yield

Biomass yield is one of the yield components of tef plant and the result of ANOVA indicated that the main effects of N rate and timing of N application highly significantly influenced biomass yield ($P \leq 0.01$) as well as the interaction of the two factors ($P \leq 0.05$) (Appendix 4). Thus, the increased total biomass yield significantly increased in response to increasing rate of nitrogen and its timing (Table 10). The highest biomass yield (9867.2 kg ha^{-1}) was obtained under in plot supplied with 69 kg N ha^{-1} in two equal splits (½ dose at sowing and ½ dose at tillering), followed by (7880.6 kg ha^{-1}) was obtained plots treated with 92 kg N ha^{-1} in two equal split application. Whereas the lowest biomass yield (4960 kg ha^{-1}) was obtained with 23 kg N ha^{-1} at sowing time, followed by 46 and 92 kg N ha^{-1} rate in full dose at sowing (Table 10).

Thus, the maximum biomass yield exceeded the minimum biomass yield by about 49.73%. This significantly enhanced biomass yield by nitrogen application is in agreement with the results of Ali *et al*. (2005) and Iqtidar *et al*. (2006) who also reported a significant increase in biomass yield of wheat as a result of increased rate of N application. In line with this result, Abraha (2013) reported the highest biomass yield (9004 kg ha^{-1}) under plots supplied with 69 kg N ha^{-1} applied in two equal splits (½ at sowing and ½ at tillering) whereas, the lowest biomass yield was obtained from plots grown at the lowest rate applied as full dose at sowing.

As compared to 69 kg N ha^{-1} applied in two split application (½ at sowing and ½ at tillering) the least response in the biomass yield was observed to the highest level of N rate applied in full dose at sowing. The lowest biomass yield might be due to the effect of lodging result from full dose of N fertilizer application that tended to encourage vegetative growth and plant height leading to lodging before the translocation of dry matter to economic yield since biomass includes the economic yield tool. This result is, however, in contrast to that of Haftamu *et al*. (2009) who found the highest biomass yield of tef in response the application of 92 kg N ha^{-1}. This may be attributed to possible differences in the inherent fertility of the two soils, whereby the soil on which these authors conducted their experiment may have been lower in organic matter than the soil used for this experiment. This may have rendered the later soil to have lower ability to supply N from mineralization, thus requiring the application of more external nitrogen (92 kg N ha^{-1}) for increased biomass production of tef than the soil used for this experiment. Generally, increasing the rate of nitrogen from 0 to 69 kg N ha^{-1} significantly increased aboveground biomass by about 68.5%.

Table 10. Mean values of above ground biomass yield of tef (kg ha^{-1}) as affected by rate and timing of nitrogen fertilizer application.

N rate kg ha^{-1}	Timing of application (T)			
	T1	T2	T3	Mean
23	4960.03^{f}	5434.50^{ef}	5869.00^{def}	5421.2^{c}
46	6899.06^{dbc}	7577.80^{bc}	6909.06^{dbc}	7128.6^{b}
69	7459.76^{bc}	7330.60^{bc}	9867.23^{a}	8219.2^{a}
92	6405.63^{dec}	7531.06^{bc}	7880.56^{b}	7272.4^{b}
Mean	6431.1^{b}	6968.5^{b}	7631.5^{a}	7010.36^{c}
Control				3105.9^{g}
	R	T	R*T	Treated vs. control
LSD ().05)	741.86	642.47	1284.9	1232.7
CV (%)			10.8	10.9

Where, R= rate, T= timing of application, T1= full dose at sowing, T2= full dose at tillering, T3=½ dose at sowing + ½ dose at tillering. Mean sharing the same superscript letter do not differ significantly at P= 0.05 according to the LSD test.

4.5.4 Straw yield

Biological is an important factor because farmers are also interested in straw yield in addition to grain. Straw of tef plant is important in nutrient cycling and livestock feed for the highland farmers. Like biomass yield, straw yield was affected highly significantly by the main effect of N fertilizer rate ($P \leq 0.01$) and timing of application ($P \leq 0.01$). The two factors interacted significantly ($P \leq 0.05$) to influence straw yield (Appendix 4). The maximum straw yield of 7473.3 kg ha^{-1} was obtained when tef plants were treated with 69 kg N ha^{-1} in two equal split doses (½ at sowing and ½ at tillering). Whereas, the lowest 3491.5 kg ha^{-1} was recorded under 23 kg N ha^{-1} applied in full dose of nitrogen at sowing.

Thus, compared to the straw yield obtained in response to applying 23 kg N ha^{-1} in same time of application with the tef straw yield obtained in response to applying 69 kg N ha^{-1} in two equal split doses at sowing and tillering was higher by about 42.2% (Table 11). The increased straw yield might be caused due to the effect of high N application on the production of effective large number of tillers, increased plant height and panicle length that might have resulted in increased straw production. However, it was statistically at par with the same straw yield recorded at 92 kg N ha^{-1} (5986.6 kg ha^{-1}), 46 kg N ha^{-1} (5880 kg ha^{-1}) and 92 kg N ha^{-1} (5695.3 kg ha^{-1}), respectively, in two split application (½ at sowing and ½ at tillering) or full application at sowing or at tillering.

Increasing level of N up to 69 kg N ha^{-1} significantly increased straw yield but decreased at 92 kg N ha^{-1}. This may be attributed the vigorous vegetative growth enhancing property of nitrogen whereby increased number of tiller and dry matter may have been produced due to efficient uptake of the nutrient by the plants over two major growth stages. Similar results were found by Temesgen (2001), Legesse (2004), Mitiku (2008) and Haftamu *et al.* (2009) who reported that the higher straw yield was obtained in response to the application of higher rates of N application. In agreement with this report, Amsal *et al***.** (2000) reported that N rate significantly enhanced the straw yield of wheat, since N usually promotes the vegetative growth of a plant.

Table 11. Mean values of straw yield of tef (kg ha^{-1}) as affected by rate and timing of nitrogen fertilizer application.

	Timing of application (T)			
N rate kg ha^{-1}	T1	T2	T3	Mean
23	3491.46^{e}	3931.00^{de}	4317.16^{dec}	3913.2^{b}
46	5880.76^{b}	5638.70^{b}	4891.73^{dbc}	5470.4^{a}
69	4995.16^{dbc}	5373.43^{bc}	7473.26^{a}	5947.3^{a}
92	4771.63^{bcd}	5695.30^{b}	5986.56^{b}	5484.5^{a}
Mean	4784.8^{b}	5159.6^{ab}	5667.2^{a}	5203.8^{c}
Control				2242.9^{f}
	R	T	R*T	Treated vs. control
LSD (0.05)	731.37	633.39	1266.8	1217.7
CV (%)			14.37	14.52

Where, R= rate, T= timing of application, T1= full dose at sowing, T2= full dose at tillering, T3=½ dose at sowing + ½ dose at tillering. Mean sharing the same superscript letter do not differ significantly at P= 0.05 according to the LSD test.

4.5.5 Grain Yield

Grain yield was highly significantly ($P \leq 0.01$) influenced by the main effect of N fertilizer rate and timing of application as well as the interaction of nitrogen rate and time of application ($P \leq 0.05$) (Appendix 4). Grain yield significantly increased in response to increasing rates of nitrogen across the application time (Table 12). The maximum grain yield of 2346 kg ha^{-1} was obtained in response to nitrogen applied at rate of 69 kg N ha^{-1} with two-time split application (½ at sowing and ½ at tillering). While, the lowest grain yield of 1439 kg ha^{-1} was obtained from plots treated with 23 kg N ha^{-1} all applied at sowing. In conformity with this result, Abraha (2013) reported the highest grain yield was obtained in response to application of 69 kg N ha^{-1} in two equal split doses at sowing and mid-tillering. While, the lowest grain yield was obtained from plots treated with lower rate as full dose application at sowing time.

Tef yield did not increase with the increase in the highest rate of nitrogen application (Table 12). This shows that at the higher rate of 92 kg N ha^{-1}, applied as full dose at sowing was not effective in increasing the yield. Similarly, average grain yield obtained under 46 kg N ha^{-1} was not significantly different from using 92 kg N ha^{-1} applied as full dose at sowing. In line with the result of this study Tekalign *et al*. (2000) also reported that N fertilizer beyond the maximum nutrient requirement level of the crop resulted either in lodging or decline in yield. However, due to the positive effect of N on yield components such as number of tillers per plant, number of spikelet per panicle and number of panicle per unit area increased grain yield can be obtained.

Thus, compared to the tef grain yield obtained in response to applying 23 kg N ha^{-1} and 92 kg N ha^{-1} in two equal split of half at sowing and half at tillering, the grain yield obtained in response to applying 69 kg N ha^{-1} at the same time of application was significantly higher by 35.1% and 20.8%, respectively. Similarly, the grain yield obtained from the application of 69 kg N ha^{-1} in two equal splits of half dose at sowing and half at tillering exceeded the grain yield obtained from the application of 23 kg N ha^{-1} applied in full dose at sowing by about 38.65%. However, at the rate of 23 kg N ha^{-1}, there tended to be no change in grain yield across the timing of nitrogen application. This show that at sub-optimal rate of 23 kg N ha^{-1}, applied as the full dose at any time or in splits did not increased yield, indicating that the rate was too low to favor growth, development and yield of the crop.

Similarly, the result of this study also revealed that applying a full dose of even the highest rate of nitrogen did not increase grain yield of the crop. This may be attributed to the asynchrony in the time of availability of sufficient amounts of nutrient in the soil proportionate to the demand of the plant for uptake. Thus, applying the whole dose of nitrogen at sowing was perhaps wastage as the small tef seedlings would not have the capacity to take up the nutrient in any significant amounts at that stage of growth. Similarly, applying the whole dose of even the highest amount of nitrogen at tillering may enable the plant to take up a maximum amount of the nutrient at the particular time.

However, since the plants may have hunger for nitrogen and suffered from its deficiency during the earlier time of vegetative growth, supplying a sufficient amount only at tillering cannot guarantee optimum growth and development, therefore, yield may be suppressed. In this connection, most of the applied nitrogen left over from uptake by the plant from the fully applied at sowing or tillering may have been lost to leaching or volatilization owing to the high rainfall and temperature during the main growing season.

On the other hand, increasing the number of split N applications from once (at sowing or at tillering) to twice (50% at sowing and 50% at tillering) significantly enhanced teff grain yield (Table 12). In line with the result of this study, Temesgen (2001) reported that, N fertilizer palliate application at different times significantly affected grain yield of teff on farmer's field. This may be because of the right time of N application results in higher net assimilation rate and there by increased grain yield. Physiologically, this may be so because the plants may have been able to take up balanced amounts of nitrogen throughout the major growth stages due to synchrony of the demand of the nutrient for uptake by the plant and its availability in the root zone might not have been too high to be left over from uptake by plants and be predisposed to leaching.

Table 12. Mean values of Grain yield of tef (kg ha^{-1}) as affected by rate and time of nitrogen fertilizer application

	Timing of application (T)			
N rate kg ha^{-1}	T1	T2	T3	Mean
23	1439.2^{d}	1473.4^{d}	1520.7^{d}	1477.7^{c}
46	1547.4^{d}	1900.3^{b}	1977.3^{b}	1808.3^{b}
69	1865.8^{b}	1918.0^{b}	2346.1^{a}	2043.3^{a}
92	1601.3^{dc}	1799.1^{bc}	1856.1^{b}	1752.1^{b}
Mean	1613.4^{c}	1772.6^{b}	1925.0^{a}	1770.3^{b}
Control				845.7^{e}
	R	T	R*T	Treated vs. control
LSD (0.05)	128.47	111.26	111.26	102.46
CV (%)			7.42	7.44

Where, R= rate, T= timing of application, T1= full dose at sowing, T2= full dose at tillering, T3=½ dose at sowing + ½ dose at tillering. Mean sharing the same superscript letter do not differ significantly at P= 0.05 according to the LSD test.

4.5.6 Harvest index

Harvest index was computed as the ratio of grain yield to the total aboveground dry biomass yield. Analysis of variance indicated that the harvest index did not respond significantly ($P \leq 0.05$) to the effects of N rate, timing of application whereas the interaction effect of rate and timing of nitrogen application significantly ($P \leq 0.05$) affected this parameter of plant growth and yield performance (Appendix 4).

The highest nitrogen rate treatment significantly reduced harvest index as compared to the lowest rate. However, there were no significant difference between the 23 kg N ha^{-1} and 46 kg N ha^{-1} treatments applied with full dose at sowing and two split applications (½ at sowing and ½ at tillering, respectively. Reductions in HI relative to the 23 kg N ha^{-1} applied in full application were 4.16%, 18.5% and 19.2% due to 46,69, and 92 kg N ha^{-1} in two split application (½ at sowing and ½ at tillering treatment), respectively. HI to the 23 kg N ha^{-1} in full application at sowing treatment had resulted in the highest harvest index (29.6%) followed by N rate of 46 kg N ha^{-1} in two split application (½ at sowing and ½ at tillering), with a harvest index value of 28.23%. the lowest harvest index recorded from application of highest rate of N in two split application (½ at sowing and ½ at tillering resulted in 21.2%) (Table 13). In line with these results Abdo (2009) reported highest harvest index from treatments with the lowest rate of nitrogen application on wheat plant. An increase in N application favors huge vegetative growth and thereby results in lower percent of productive tiller, panicle number and finally lower harvest index. Similar to this study Mulugeta (2003) found the lowest harvest index at the highest N rate was applied when compared to the lower treatment in tef. This might be due to the more biomass yield more number of tillers, more plant height, long panicle length and thick stalk compared the other treatment. The result also supports that of Legesse (2004) and Mitiku (2008) the highest harvest index from no N application and the lowest harvest index from application of high N. This might be because of higher dry matter production occurs under high N application than under lower rates. In contrast to these findings, Sewent (2005) reported increased harvest index in response to increased in N application in rice.

Table 13. Mean values of harvest index (%) of tef as affected by rate and timing of nitrogen fertilizer application.

	Timing of application (T)		
N rate kg ha^{-1}	T1	T2	T3
23	29.60^{ab}	27.66^{ab}	26.46^{cab}
46	24.06^{cb}	25.73^{cab}	28.36^{ab}
69	28.23^{ab}	27.36^{ab}	24.26^{cab}
92	25.60^{cab}	24.53^{cab}	21.20^{c}
Control			29.80^{a}
	R*T	Treated vs. control	
LSD (0.05)	5.18	5.53	
CV (%)	11.68	2.45	

Where, R= rate, T= timing of application, T1= full dose at sowing, T2= full dose at tillering, T3=½ dose at sowing + ½ dose at tillering. Mean followed by the same letter within a table are not significantly different at 5% probability.

4.6 Partial Budget Analysis

As indicated in Table 14, the partial budget analysis showed that the highest net benefit of 47328 Birr ha^{-1} was obtained in the treatment that received 69 kg N ha^{-1} in two split application (½ at sowing + ½ at tillering). However, the lowest net benefit of 17452 birr ha^{-1} was obtained from the unfertilized treatment. This analysis is done by considering grain and straw yield of teff. The dominated treatments were rejected from further economic analysis.

To identify treatments with the optimum return to the farmer's investment, marginal analysis was performed on non-dominated treatments. For a treatment to be considered as worthwhile to farmers, 100% marginal rate of return (MRR) as the minimum acceptable rate of return (CIMMYT, 1998). The marginal rate of return (MRR) 16040 was obtained from the plot treated with 69 kg N ha^{-1} in two split applications (½ at sowing + ½ at tillering). Therefore, application 69 kg N ha^{-1} in two split (½ at sowing + ½ at tillering) is profitable and is recommended to farmers in Alefa district and other areas with similar agro-ecological condition.

Table 14. Marginal analysis of teff grain yield influenced by N fertilizer rate and time of application.

NR (Kg/ha	NT	Total variable cost	Adjusted grain yield (kg/ha)	Grain Net benefit (Birr/ha)	Straw Net benefit (Birr/ha)	Total Net benefit (Birr/ha)	Marginal variable cost	Marginal net benefit	Marginal rate of return (%)
0	-	0	845	15210	2242	17452	-	-	-
23	T2	731	1473	25783	3931	29714	731	12262	1677.4
23	T3	791	1520	26569	4317	30886	60	1172	1953
46	T2	1462	1900	32738	5638	38376	671	7490	1116
46	T3	1582	1977	34004	4891	38895	60	519	865
69	T2	2193	1918	32331	5373	37704	671	-1191	-177
69	T3	2373	2346	39855	4773	47328	60	9624	16040
92	T2	2924	1799	29458	5695	35153	671	-12175	-1814
92	T3	3164	1856	30244	5986	36230	60	1077	1795

Where, NR=Nitrogen rate, NT= Timing of nitrogen, T2=full dose at tillering and T3= ½ dose at sowing +½ dose at tillering.

5. SUMMARY, CONCLUSION AND RECOMMENDATIONS

Low available soil nutrient status and reduced plant-use-efficiency are some of the major constraints limiting tef yield in growing areas of Ethiopia. Ensuring a well-balanced supply of N to the tef crop may result in higher grain yield. The national recommendation of nitrogen fertilizer rate in heavy soil is 46 kg N ha^{-1} and this rate is recommended to most of the farmer to apply in two splits, i.e. is 50% at sowing and 50% at tillering stage but in the study area there is little knowledge among farmers of the rate and time of N-fertilizer application. Therefore, a field experiment was carried out during 2016 main cropping season from July to November in Alefa district of western Ethiopia with the objectives of studying the effects of rates and timing of nitrogen fertilizer application on yield and yield component of tef and determining the most economic rate and time of nitrogen fertilizer application for tef production in study area.

The experiment was laid out in randomized complete block design in factorial arrangement with three replications. The treatments consisted of four levels of nitrogen (23, 46, 69 and 92 kg N ha^{-1}) and three timings of application (full dose at sowing, full dose at tillering and ½ dose at sowing + ½ dose at tillering). One additional control treatment consisted of 0 kg N ha^{-1} for comparison. The experiment was laid out in random complete block design (RCBD).

The main effect due to rate of N application and timing of application significantly influenced day to panicle emergence, panicle length and tiller numbers. Due to application of 92 kg N ha^{-1}, day to panicle emergence were maximized by 7.4 days as compared to treatment having no fertilization. Panicle length was significantly increased in response to increasing rates of nitrogen and time of application. The maximum panicle length (42.81 cm) was recorded in response to nitrogen applied at the rate of 69 kg N ha^{-1}.

The highest effective tiller number per 0.12 m^2 (31.66) was recorded in response to nitrogen applied at the rate of 69 kg N ha^{-1} while, the lowest effective tiller number per 0.12m^2 (21.33) was obtained from the plots without nitrogen. The main effect of rate of N had significant effect on days to maturity of tef plants being hastened under lower N rates than under higher N rate. The maximum numbers of days to physiological maturity (98.72 days) were observed when fertilized with 92 kg N ha^{-1}.

The main effect and interaction effect of rate and time of N application had significant influence on the plant height and lodging percentage. The highest plant height was obtained at the highest N application rate of 92 kg N ha^{-1} with two-time split application (½ at sowing and ½ at tillering) resulting in highest plant height (124.06 cm).While, the shortest plants were observed from plots supplied 23 kg N ha^{-1} with one dose application at sowing. The highest lodging index was obtained at the highest N application rate of 92 kg N ha^{-1} with full dose application at tillering in highest lodging percentage (35%). While, the lowest lodging index (18.4%) were observed from plot supplied 23 kg N ha^{-1} with one dose application at sowing.

In general, all the yield and yield components of tef (main panicle-seed-weight, thousand-seed-weight, biomass yield, grain yield, straw yield and harvest index) were significantly influenced by the interaction effects of rate and timing of fertilizer application while, there were non-significant effect due to the main effect of rate of N and time of application on harvest index.

The highest main panicle-seed-weight and 1000-seed weight, respectively (7.8g and 0.348g) were recorded in response to nitrogen applied at the rate of 69 kg N ha^{-1} with two splits (½ at sowing and ½ at tillering). While, the lowest main panicle-seed-weight and 1000-seed-weight, respectively (3.9g and 0.26g) were obtained from plots treated with 23 kg N ha^{-1} at full application at sowing time.

Harvest index tended to decrease with increased application of nitrogen. However, there was no consistent trend of increase or decrease in harvest index with the dose of nitrogen and time of application. The highest harvest index (29.6%) was obtained for plants supplied with 23 kg N ha^{-1} applied full dose at sowing, whereas, the lowest harvest index (21.2%) was obtained for plants grown at 92 kg N ha^{-1} with two equal split applications (half at sowing and the other half at tillering).

Biomass yield increases significantly with the increase in the rate of nitrogen across the increasing frequency of applications. The highest biomass yield (9867.2 kg ha^{-1}) was obtained for plants supplied with 69 kg N ha^{-1} applied in two equal splits at sowing and tillering whereas, the lowest biomass yield (4960 kg ha^{-1}) was obtained for plants grown at 23 kg N ha^{-1} applied in full dose at sowing.

Further, the results indicated that the highest straw yield (7473.3 kg ha^{-1}) was recorded under application of 69 kg rate of N ha^{-1} into two split applications whereas, the lowest (3491.5 kg ha^{-1}) was recorded under full dose of nitrogen (23 kg N ha^{-1}) at sowing.

The highest grain yield (2394 kg ha^{-1}) was obtained in response to applying 69 kg N ha^{-1} in two equal split dose one each at sowing and at tillering. This grain yield was, however, in statistical difference with the grain yield obtained response to applying the same rate of nutrient in full dose either at sowing or tillering time. While, the lowest grain yield of 1468.6 kg ha^{-1} was obtained from plots treated with 23 kg N ha^{-1} applied in full at sowing.

In general, plots treated with 69 kg N ha^{-1} in two equal splits (½ dose at sowing and ½ dose at tillering) produced high biomass, grain and straw yields, coupled with best economic benefit or profitability. Therefore, this treatment can be suggested to the farmers in the study area instead of using 23, 46 or 92 kg N ha^{-1} full dose either at sowing or at tillering stage. However, since the current results are from a one-season experiment, conducting the field experiment at least for one more season is recommended in order to confirm the current results, soil tested based fertilizer application could advantage for higher production of crop through efficient nutrient management, moderate rate of nitrogen fertilizer could be used to prevent lodging and improved tef yield and economic aspect of fertilizer has to be taken in to consideration as well.

6. REFERENCES

Abdo Woyema, 2009. Effect of different rate of nitrogen fertilizer on yield, yield related traits and quality of durum wheat (*Triticum turgidum* L. var. durum). M.Sc. Thesis, Haramaya University, Haramaya, Ethiopia.

Abdo Woyema, Geremew Bultosa and Asefa Taa, 2012. Effect of different nitrogen fertilizer rate on yield and yield related trait for seven durum wheat (*Triticum turgidum* L. var. durum) cultivar grown at Sinana South Eastern Ethiopia. *AJFAND* 12 (3): 6079-6094.

Abraha Arfaine, 2013. Effects of rates and time of nitrogen fertilizer application on yield and yield components of teff [*Eragrostis teff* (Zucc) trotter]: In Habro district, Eastern Ethiopia. M.Sc. Thesis, Haramaya University.

Al-Abdul Salam, M. A. 1997. Influence of nitrogen fertilization rates and residual effect of organic manure rate on the growth and yield of wheat. *Arab Gulf Journal of Science Research* 15: 647-660.

Alcoz, M., Frank, M and Haby, V. 1993. Nitrogen fertilizer timing effect on wheat production, nitrogen uptake efficiency, and residual soil nitrogen. *Agronomy J*ournal 85:1198-1203.

Ali, H., Shakeel, A., Hina, A. and Hassan, F.H. 2005. Impact of Nitrogen Application on Growth and Productivity of Wheat (*Triticum aestivum* L.). *Journal of Agricultural Science* 3: 216-218.

Al-Kaisi, M and Yin, X. 2003. Effect of nitrogen rate, irrigation rate and plant population on com yield and water use efficiency. *Agronomy Journal* 95:1474- 1482.

Amsal, T and Tanner, D.G. 2000. Effects of fertilizer application on N and P uptake, recovery and use efficiency of bread wheat grown on two soil types in Central Ethiopia. *Ethiopian Journal of Natural resource* 3(2): 219-244.

Anderson, W.K. 1985. Differences in response of winter cereal varieties to applied N in the field. Field Crops Research 11:369-385.

Andrews, M., Lea, P., Raven, J. and Lindsey, K. 2004. Can genetic manipulation of plant nitrogen assimilation enzymes result in increased crop yield and greater N use efficiency? An assessment. *Annals of Applied Biology* 145: 25-40.

Anon, 1987. Teff (*Eragrotis, Abyssinica*), Royal gardens, Kew Bulletin of Miscellaneous information 1: 2-6.

Arkin, G.F. and Taylor, H.M. 1983. Modifying the root environment to reduce crop stress. *American Society of Agricultural Engineering* 51:416-420.

Ashraf, A., Khaid, A. and Ali, K. 1999. Effects of seeding rate and density on growth and yield of rice in saline soil, *Pakistan Biological Science*. 2(30):860-862.

Asnakew Woldeab, Tekalign Mamo, Mengesha Bekele and Teferra Ajema, 1991. Soil fertility management studies on wheat in Ethiopia, pp.137-172. In: Hailu Gebre-Mariam, Tanner, D.G. and Mengistu Hulluka (eds). Wheat research in Ethiopia: A historical Perspective. IAR/CIMMYT, Addis Ababa, Ethiopia.

ATA (Agricultural Transformation Agency) , 2012. Innovations to help our country grow, (http://www.ata.gov.et/programs/ value chain-programs /teff) Accessed on March 2013.

ATA (Agricultural Transformation Agency), 2013. "Working strategy for strengthening Ethiopia' teff value chain vision, systematic challenges and prioritized interventions". Addis Abeba, Ethiopia.

.

Balesh, T., Bemt., A. and Breland, T. 2007. Availability of organic nutrient sources and their effects on yield and nutrient recovery of teff [*Eragrosits teff* (Zucc.) Trotter] and on soil properties. *Journal of Plant Nutrition and Soil Science* 170:543-550.

Behera, U.K., Chougule, B.A., Thakur, R.S., Ruwali, K.N., Bhawsar, R.C. and Pandey, H.N. 2000. Influence of planting dates and nitrogen levels on yield and quality of durum wheat (*Triticum durum*). *Indian Journal of Agriculture 70: 434-6.*

Bekabil Fufa, Befekadu Behute, Rupert Simons and Tareke Berhe, 2011.Strengthining the teff value chain in Ethiopia (Unpublished Report). Agricultural Transformation Agency.

Bekele Hundie, Verkuijji, H., Mawangi, W. and Tanner, D.G. 2000. Adaptation of improved wheat technologies in Addaba and Dodola district of the Bale Highland of Ethiopia. EARO/CIMMYT, Addis Ababa, Ethiopia.

Berhane, G., Paulos, Z. and Tafere, K. 2011. "Food grain consumption and intake patterns in Ethiopia". *ESSP II Working* Paper 23. International food policy research institute (IFPRI). Addis Ababa, Ethiopia.

Borghi, B., Corbellini, M., Minoia, C., Palumbo, M., Di Fonzo, N. and Perenzin, M. 1997. Effects of Mediterrenanean climate on wheat bread-making quality, *European Journal of Agronomy* 6:145-154.

Brady, N.C. and Weil, R.R. 2008. The nature and properties of soils, 13theds. Person education Ltd, USA, 621.

Cassman, K.G., Dobermann, A. and Walters, D.T. 2002. Agro-ecosystems, nitrogen-use efficiency, and nitrogen management. *Ambio* 31(2): 132-40.

CIMMYT (International Center for Maize and Wheat Improvement), 1988. From agronomic data to farmer recommendations: An economics training manual. Completely revised edition. Mexico, DF. 79.

Clain, J. 2011. Nutrient uptake timing by crops to assist with fertilizing decisions. *Book of soil Science*. Montana state University, 67-78.

Costanza, S.H, Dewej, M. and Harlan, J. 1979. Literature review and numerical taxonomy of *Eragrosits teff*. *Economic Botany* 33(4): 413-424.

CSA (Central Statistical Authority), 2012. Agricultural sample survey: Report on area and production for major crops (private peasant holding *meher* season), vol. 1. Addis Ababa, Ethiopia.

CSA (Central Statistical Authority), 2013. Agricultural sample survey: Report on area and production for major crops (private peasant holding *meher* season), vol. 1. Addis Ababa, Ethiopia.

CSA (Central Statistical Agency), 2015. Agricultural Sample Survey: Report on area and production of major crops, 1, Addis Ababa.

Demeke, M. and Di Marcantonio, F. 2013. Analysis of incentives and disincentives for teff in Ethiopia. *Technical notes series*, MAFAP, FAO, Rome.

Donald, L.S. 2004. Understanding and reducing lodging in cereals. *Advance in Agronomy* 84: 217-271.

Doris-Piccinin, M.S.D. 2010. More about Ethiopia food: Teff development of nutrition and food science, University of Washington, America.

Duckers, J., Spaargaren, O. and Nachtergaele, F. 2001. Vertisols: Genesis, properties and soils cape management for sustainable development. FAO, Rome, Italy, 20.

Evans, L.T. 1997. Crop Evolution, Adaptation and Yield 1st ed. Cambridge University Press, New York, Porchester.

Fageria, N.K.2003. Plant tissue test for determination of optimum concentration and uptake of nitrogen at different growth stages in lowland rice. *Communal of Soil Science and plant Anatomy* 34:259-270.

FAO (Food and Agriculture Organization of the United Nations), 2008. Fertilizers and Their Use. 4th edition. International Fertilizer Industry Association. Rome, Italy. 164p.

Foth, HD. And Ellis, BG. 1998. Soil fertility, 7th ed. John Wiley and Sons, Inc. New York, USA.

Fowler, D.B.., Brydon, J. and Baker, R.J. 1989. Nitrogen fertilization of no-till winter wheat and rye influence on grain protein. *Argonomy Journal* 81:72-77.

Fufa, B., Simons, R. and Berhe, T. 2011. “Teff diagnostic report: strengthening the teff value chain in Ethiopia”. Addis Ababa, Ethiopia.

Fufa, B. and Hassen, RM. 2006. Determinants of fertilizer use on maize in eastern Ethiopia:-A weighted endogenous sampling analysis of the extent and intensity of adoption, Agreckon, Vol. 45, No. 1.

Fufa Hundra., Efrem Bechere and Hailu Tefera, 1999. Interrelationships of grain yield, lodging and agronomic trait in teff *Eragrosits teff*. *Tropical science* 39:63-69..

Gasim, S.A. 2001. Effects of nitrogen, Phosphorous and seed rate on growth, yield and quality of forage maize (*Zea mays*). M.Sc. Thesis, Faculty of Agriculture, University of Khartoum.

Gerba Leta, Getachew Belay and Walelign Worku, 2013. Nitrogen fertilization effects on grain quality of durum wheat (*Triticum turgidum* L.var.durum) varieties in central Ethiopia Agricultural Sciences. *Agricultural Sciences*. 4(3): 123-130.

Getachew Fisseha, 2004. Soil characterization and bread wheat (*Triticum aestivum L.*) response to N and P fertilization. M.Sc. Thesis, Aemaya University, Alemaya, Ethiopia.

Girma Fana, Haile Deressa, Reta Dargie, Mengistu Bogela, Seyfudin Mehadi and Firehiwot Getachew, 2012. Grain hardness, hectoliter weight, nitrogen and phosphorous concentrations of durum wheat (*Triticum turgidum* L.var. durum) as influenced by nitrogen and phosphorous fertilization. *World Applied Sciences Journal* 20 (10): 1322-1327.

Gobeze Lho, 1999. Effect of special arrangement and nitrogen fertilizer application on (*Sorghum binocular* L. Moench) and ground nut (*Arachis hypogeal*) intercrop system in Eastern Ethiopia. M.Sc. Thesis, Alemaya University, Alemaya, Ethiopia..

Gooding, M.J. and Davies, W.P. 1997. Wheat production and utilization systems quality and the environment. CAB International, USA.

Grant, C.A., Peterson, G.A. and Campbell, C.A. 2002. Nutrient considerations for diversified cropping system in the Northern Great Plains, *Agronomy Journal* 94: 186-198.

Gregory, P., Simmonds, L. and Warren, G. 1997. Interactions between plant nutrients, water and carbon dioxide as factors of limiting crop yields. *The Royal Society of Philosophical, Transaction and Biological Sciences* 352:987-996.

Gugsa Lemi, Getachew Belay and Seyfu Ketema, 2001. The cytogenetic of teff. Narrowing the Rift: Teff [*Eragrostis teff* (Zucc) Trotter] research and development. *Proceeding of the international workshop on teff genetics and improvement*, Oct. 16-19, Ethiopian Agricultural Research Organization, Debre Zeit, Ethiopia 3 (7): 49-57.

Haftamu Gebretsadik, Mitiku Haile and Charles, F. 2009. Tillage frequency, soil compaction and N- fertilizer rate effects on yield of teff [*Eragrostis teff* (Zucc) Trotter] in Central zone of Tigray, Northern Ethiopia Thesis presented to Mekelle University Ethiopia.

Haile Deressa, Nigusse Dechassa and Amesalu Ayana, 2012. Nitrogen use efficiency of bread wheat: Effects of nitrogen rate and time of application. *Journal of Soil Science and plant Nutrition* 12 (3): 389-410.

Haile Deressa, Nigusse Dechassa and Amesalu Ayana, 2013. Nitrogen use efficiency of bread wheat: Effects of nitrogen rate and time of application. *Journal of Soil Science and plant Nutrition* 12 (3): 389-410.

Hailu Tefera and Seyfu Ketema, 2001. Production and importance of tef in Ethiopian Agriculture pp.3-7 In: Hailu Tefera , Getachew Belay and Mark Sorrels (eds.). Narrowing the Rift: Tef Research and development. *Proceedings of International Workshop on Tef Genetics and Improvement*, 16-17 October 2000. Addis Ababa, Ethiopia.

Hesselbach, D. and Weatphal, A. 1976. Effects of fertilization on development, dry matter production and nutrient uptake of teff. pp. 214-225 In: *Proceeding of the sixth annual research seminar*, 12-14 Nov. 1975. Addis Ababa, Ethiopia, Institute of Agricultural Research (IAR), Addis Ababa, Ethiopia.

Hussain, M.I., Shah, S.H. 2002. Growth, yield and quality response of three wheat (*Triticum aestivum* L.) varieties to different levels of N, P and K. Int. *Journal of Agriculture and Biology.* 4 (3): 362-364.

IAEA (International Atomic Energy Agency), 2000. Optimizing nitrogen fertilizer application of irrigated wheat, IAEA –TECDOC-1164, IAEA, Vienna.

Iqtidar, H., Muhammad, A. K. and Ejaz, A. K. 2006. Bread wheat varieties as influenced by different nitrogen levels. *Journal of Zhejiang Univ. Science.* 7 (1): 70-78.

Janckson, M.L. 1993. Soil chemical analysis. Prentice-Hall of India, New Delhi.

Jan, MT., Khan, MJ., Khan, A., Arif, M., Shafi, M. and Farmanullah, 2010. Wheat nitrogen indices response to nitrogen source and application time. *Pakistan Journal of Botany*. 42(6): 4267-4279.

Jeremy, L. 2007. Nitrogen management for wheat protein and yield in the Esperance Port Zone. State of Western Australia, 14-20.

Johnston, A.E. 1994. The efficient use of plant Nutrients in agriculture, IFA, Paris, France.

Kabir Khan, A. A. and Allahdad, S.T. 2011. Effect of seed rate on growth, yield components and yield of mash bean grown under irrigated conditions of arid uplands of Balochistan, Pakistan. *Pakistan journal of Bot*any 43(2): 961-969

.

Kenea Yadeta, Getachew Ayele and Workneh Negatu, 2001. Farming research on teff: small holders' production practice. In: Hailu Tefera, Getachew Belay and Sorrels, M. (eds.), *Narrowing the Rift*: Teff research and development. Ethiopia Agricultural Research Organization (EARO), Addis Ababa, Ethiopia, 9-23.

Kidanu, S., Tanner, D.G. and Tekalign Mamo, 1999. Effect of nitrogen fertilizer applied to teff on the yield and N response of succeeding teff and durum wheat on a high land vertisol. *African Crop Science Journal*, vol.7. No. 1, 35-46pp.

Legesse admassu, 2004. Response of teff [*Eragrostis teff* (Zucc) Trotter] to Phosphorous and Nitrogen application in north eastern Ethiopia. M.Sc. Thesis presented to the School of Graduate studies of Alemaya Unversity, 71pp.

Limo-Ortega, A., Sayre, KD. And Francis, CA. 2000. Wheat nitrogen use efficiency in bed planting system in northwest Mexico. *Agronomy Journal* 92: 303-308.

London, J.R. 1991. Booker tropical soil manual: A handbook for soil survey and agricultural land evaluation in the tropics and sub-tropics. Longman Scientific and Technical, Essex, New York. 474p.

Lo̕Pez-Bellido, L., Fuentes, M., Castillo, J.E. and Lo̕Pez-Garrido, F.J. 1998. Effects of tillage, crop rotation and nitrogen fertilization on wheat-grain quality grown under rain fed Mediterranean condition. *Field Crop Research* 57: 265-276.

Mekonnen Asrat, 2005. Response and uptake of barley (*Hordem Vulgarae L*.) to different rates of ORG- Pand N fertilizer. MSc Thesis, Alemaya University, Alemaya, Ethiopia.

Melesse Harfe, 2007. Response of bread wheat (*Triticum aestivum* L.) verities to N and P fertilizer rates. M.Sc. Thesis, Haramaya University, Haramaya, Ethiopia.

Mengel, K. and Kirkby, E.A. 2001. Principles of Plant Nutrition, Panimo Publishing Corporation, New Delhi, India.

Miller, R.W. and Danahue, R.L. 1995. Soil in our environment, 7th ed. Prentice-Hall of India Private limited, New Delhi.

Miller, R.W. and Danahue, R.L. 1997. Soil in our environment, 7th ed. Prentice-Hall of India Private limited, New Delhi.

Minten, B., Tamru, S., Engida, E., and Kuma, T. 2013. "Ethiopia's value chains on the move: The case of teff". *ESSP II Working Paper* 52. International food policy research institute (IFPRI) Addis Ababa, Ethiopia.

Mitiku Melaku, 2008. Effect of seeding and nitrogen rate on yield and yield components of teff [*Eragrostis teff* (Zucc) Trotter] at Adet North Western Ethiopia. M.Sc. Thesis presented to College of Agriculture in Department of Plant sciences of Haramaya University, 24-29.

MOARD (Ministry of Agriculture and rural development), 2008. Crop variety register, animal and plant regulatory directorate, Addis Ababa, Ethiopia, June 2008.

Mossedaq, F. and Smith, DH. 1994. Timing nitrogen application to enhance spring wheat yields in Mediterranean climates. *Agronomy Journal*, 221-226.

Mulugeta Seyoum, 2000. Uptake and report of rice (*Orayza sativa* L to N and P fertilization under rain fed lowland condition of fogera plain, Northern Ethiopia. M.Sc. Thesis, Alemaya University of Agriculture. Ethiopia, 93.

Mulugeta Gezahagn, 2003. Response of teff [*Eragrostis teff* (Zucc) Trotter] to applied nitrogen and phosphorus in vertisols of Raya, Tigry. M.Sc. Thesis presented to the school of graduate studies of Alemaya University, 60.

NAS (National Academy Science), 1996. Lost crops of Africa volume 1, Grains. BOSTID national research council. National Academy Press. Washington, D.C. USA.

Olesn, S.R., Cole, C.W., Watanabe, F.S. and Dean, L.A. 1954. Estimation of available phosphorous in soils by extraction with sodium bicarbonate circular 939, US. Department of Agriculture.

OMS (Office of meteorology station of Alefa district), 2016. Unpublished Report Annual weather data.

OARD (Office of Agricultural and Rural Development of Alefa district), 2016. Unpublished Report Annual Crop Evaluation on production and productivity.

Ortiz-Monasterio, J.I., Manske, G.B. and Van Ginkel, M. 2002. Nitrogen and Phosphorus use efficiency. Pp. 200-207. In: Reynolds, M.P., Ortiz-Monasterio, J.I., McNab, A (eds). Application of physiology in wheat breeding, Mexico, D.F.: CIMMYT.

OSCA (Office of state communication of Alefa destrict), 2016. Unpublished Report Annual Crop Evaluation on production and productivity.

Pinthus, 1993. Lodging in wheat, barley and Oats: The phenomenon, it causes, and preventive methods. *Advances in Agronomy* 25: 209-263.

Reddy, M.S. and Kidane, G. 1991. Development of technologies for the dry land farming areas of Ethiopia (eds). Nazert, Ethiopia SAS. 2002. SAS/STAT User's Guide, version 9.1.3. SAS institute Inc, Cary, NC.

Sahlemedhin Sertsu, 1999. Draft guideline for regional soil testing laboratories. NFIA, Addis Ababa, Ethiopia.

Sahlemedhin Sertsu and Taye Bekele, 2000. "Procedures for soil and plant analysis" National soil research center, Ethiopia Agricultural research organization, Technical paper No. 74. Addis Ababa, Ethiopia.

SAS (Statistical Analysis System), 2002. SAS for windows released 9.0 SAS Institute, Inc. Cary, NC, USA.

Sattelmacher, B., Horst, W.J. and Becker, H.C. 1994. Factors that contribute to genetic variation for nutrient efficiency of crop plants. *Z.P flanzenernahr Bodenkd* 157: 224-225.

Sewnet Ashebir, 2005. Effects of nitrogen and seed rates on grain yield components and nitrogen uptake of rain fed rice (*Oryza sativa*) in Fogera, South Gondar. M.Sc.Thesis, Alemaya University, Alemaya, Ethiopia.

Seyfu Ketema, 1983. Studies of lodging floral biology and breeding techniques in teff [*Eragrostis teff* (Zucc) Trotter] PhD. Thesis presented to the school of graduate studies of University of London.

Seyfu Ketema, 1991. Germplasm evaluation and breeding work on teff [*Eragrostis teff*) in Ethiopia. Cambridge University Press. Cambrige England.

Seyfu Ketema, 1993. Teff [*Eragrostis teff* (Zucc) Trotter]: Breeding genetic resource, agronomy utilization and role in Ethiopia Agriculture. Institute of Agriculture Research, Addis Ababa, 147.

Seyfu Ketema, 1997. Teff [*Eragrostis teff*) promoting the conservation and use of underutilized and neglected crops, 12. (ISBN 92-9043-304-3). Biodiversity Institute, Addis Ababa.

Tadesse Ebba, 1975. Teff [*Eragrostis teff*) cultivars: Morphology and classification, Part II. *Experimental station Bulletin* 66, Addis Ababa University, College of Agriculture, Dire Dawa, Ethiopia, 73.

Taffesse, A., Dorosh, P. and Asrat, S. 2011. "Crop production in Ethiopia: Regional patterns and trends." ESSP II Working paper 16, International food policy research institute (IFPRI).Addis Ababa, Ethiopia.

Tanner, D., Amanule, G. and Asefa, T. 1993. Fertilizer effect on sustainability in the wheat based smallholder-farming systems of Southeastern Ethiopia. Field Crops research 33: 235-248.

Tareke Berhe and Nigusse Zena, 2008. Results in a Trial of Systems of Tef Intensification (STI) at Debre Zeit Research Centre, Debre Zeit, Ethiopia.

Tarekegn Berhe, 2010. Breeding and genetic resources of teff [*Eragrostis teff*) in Ethiopia. Institute of Agricultural Research, Addis Ababa, Ethiopia.

Tasnee, A., and Yost, RS. 2003. A site-specific nutrient management approach for maize, better crops international vol. 17, No.1.

Tekalign Mamo, Teklu Erkossa and Balesh Tulema, 2000. Review of soil fertility and plant nutrition research conducted on teff. *Proceeding of the international workshop teff genetics and improvement*, Addis Ababa, Ethiopia. 37-38.

Teklu Yilma and Tefera Hailu, 2005. "Genetic Improvement in Grain Yield Potential and Associated Agronomic Traits of Tef (Eragrostis Tef)." *Euphytica* 141 (3): 247–254.

Temesgen Kassa, 2001. Effect of sowing date and nitrogen fertilization on yield related traits of teff [*Eragrostis teff*) on vertisols of Kobo area, North Wollo. M.Sc. Thesis presented to Alemaya..

Tilahun Gelato, 1994. The effect of nitrogen fertilizer sources, rates and time of application on the nitrogen uptake, grain yield and yield components of wheat. M.Sc. Theis, Alemaya University of Agriculture, Alemeya, Ethiopia..

Tilahun Gelato, Tanner, D.G., Tekalign Mamo and Getinet Gebeyehu, 1996. Response of rain fed bread and durum wheat to source, level and timing of nitrogen fertilizer on two vertisol sites in Ethiopia. II. N uptake, recovery and efficiency. Fertilizer research 44: 195-204.

Tolessa Debele, Gemechu Gedeno and Melageselam Leul, 1994. Response of maize to split application of nitrogen fertilizer at Bako. *Sebil* 6:56-60.

Vaughan, B., Westall, D.G. and Barbarick, K.A. 1990. Nitrogen rate and timing effects on winter wheat grain yield, grain protein and economics. *Productivity of Agricultural. Journal* 3: 324-328.

Vavilov, N.I. 1951. The origin, variation, immunity and breeding of cultivated plants. *Chronica Bot*. 13: 1-351.

Walkley, A. and Black, C.A. 1954. An examination of Degtjareff method for determining soil organic matter and proposed modification of the chromic acid titration method. *Journal of Soil Sciences* 37: 29-38.

Warraich, E.A., Ahmad, N.S., Basra, M.A. and Afzal, I. 2002. Effect of nitrogen on source–sink relationship in wheat. *Introduction Journal of Agriculture and Biology* 4: 300-302.

Wuest, SB. And Cassman, KG. 1992. Fertilizer- nitrogen use efficiency of irrigated wheat: Uptake efficiency of pre plant versus late-season application. *Agronomy Journal* 682-688.

Yesuf Assen and Duga Deble, 2000. The effect of rate and time of application on its uptake by bread wheat varieties and soil characteristics on farmers' field. *Ethiopia Journal of Natural Resources* 2(2): 137-150.

Zahran, M., Mosalem, M.E. El-Menofi, M.M. and Moussa, A.M. 1997. Effect of sowing date, seeding rate and nitrogen level on wheat production: Growth attributes. First annual conference, September 1-3, NRC, Egypt.

7. APPENDIX

Appendix Table 1. Soil physical and Chemical Properties of the study area.

% Clay	% Silt	% Sand	Soil Class	TN (%)	Av. P (ppm)	Av. K (ppm)	OM (%)	pH (H2O)	CEC (cmol/kg)
32.8	37.8	29.2	Clay loam	0.21	18.06	2.12	4.23	5.02	33.71

Where, TN= Total N, Av. P= Available P, Av. K= Available Potassium, OM= Organic Matter, CEC= Cation exchange capacity, ppm = Parts per Million.

Appendix Table 2. Mean Square Values of Phenology of Teff as Influenced by N rate and Timing of Application.

Source of variation	Degrees of Freedom	Days to panicle Emergence	Days to 90% physiological maturity	Lodging Percentage
Replication	2	4.9308	1.08	16.11
Rate	3	23.2866 **	34.98 **	221.73**
Timing	2	14.4258 **	4.45 ^{NS}	95.78**
Rate *Timing	6	0.5480 ^{NS}	1.23 ^{NS}	18.58**
Error	24	1.09	2.12	2.70
CV (%)		1.83	51	6.23

Where, ** = Highly significant; * = Significant; NS = Non-significant

Appendix Table 3. Mean Square Values of Tiller Numbers, Panicle Length, Main Panicle Seed Weight and Thousand Seed Weight of Teff as Influenced by N Rate and Timing of Application.

Source Of variation	DF	TN	PH	PAL	MPSW	TSW
Replication	2	368.52	4.503	2.316	0.179	0.00036
Rate	3	7578**	64.80**	41.15**	15.11**	0.00698**
Timing	2	4181**	79.83**	33.98**	1.41**	0.00151**
R*T	6	200 ^{NS}	6.66*	5.80 ^{NS}	0.22*	0.00064*
Error	24	442.6	2.14	2.65	0.07	0.00022
CV (%)		8.8	1.24	4.06	4.83	5.11

Where, ** = Highly significant; * = Significant; NS = Non-significant; DF= Degree of freedom; TN=Tiller number; PH= Plant height; PAL=Panicle length; MPSW= Main panicle seed weight; TSW= Thousand seed weight.

Appendix Table 4. Mean Square Values of Yield and Yield Components of Teff as Influenced by N Rate and Timing Application.

Source of variation	Degrees of Freedom	TBMY kg/ha	GY kg/ha	SY kg/ha	HI %
Replication	2	2043943.2	21099.6	1733250.0	16.608
Rate	3	12208386.3**	485693.5**	7104790.3**	16.931 ^{NS}
Timing	2	4338237.8**	291377.6**	2353637.5*	0.116 ^{NS}
Rate *Timing	6	1547150.6*	44408.8*	1836497.7*	25.935*
Error	24	575825.1	17267.9	559657.8	9.382
CV (%)		10.82	7.42	14.37	11.68

Where, ** = Highly significant; * = Significant; NS = Non-significant; TBMY= Total biomass yield; GY=Grain yield; SY=Straw yield; HI= Harvest index.

Appendix Table 5. Raw Data of this Study

R	N	T	TR	dpe	pal	tno	ph	ldgp	DM	PSW	tsw	BOYK	Ac/gyk	syk	hi
1	0	0	0	50.4	30.4	18	110.1	12.9	92.0	3.60	0.240	3573.8	853.5	2720.3	23.9
2	0	0	0	52.3	33.7	22	108.4	11.4	90.0	3.50	0.265	2643.6	936.1	1707.5	35.4
3	0	0	0	51.1	35.2	24	109.6	14.7	91.0	3.60	0.275	3100.3	799.4	2300.9	25.8
1	1	1	1	53.5	35.1	26	112.4	16.1	92.0	3.80	0.261	4738.3	1351.1	3387.2	28.5
2	1	1	1	52.8	38.1	23	115.6	18.7	94.1	3.90	0.253	5245.6	1486.1	3759.5	28.3
3	1	1	1	54.9	36.9	25	113.3	20.4	96.0	4.00	0.266	4896.2	1568.5	3327.7	32.0
1	1	2	2	53.6	37.2	22	112.9	18.7	96.2	4.10	0.264	5457.4	1486.2	3971.2	27.2
2	1	2	2	56.1	35.7	26	114.4	21.6	91.8	4.30	0.261	5279.7	1520.9	3758.8	28.8
3	1	2	2	55.9	38.6	21	116.7	19.9	95.3	4.40	0.255	5566.4	1503.4	4063	27.0
1	1	3	3	55.3	40.4	25	114.6	22.6	96.9	4.80	0.256	5875.1	1471.6	4403.5	25.0
2	1	3	3	56.7	39.4	24	116.5	24.8	93.1	4.60	0.274	6045.5	1536.7	4508.8	25.4
3	1	3	3	56.2	38.2	29	115.9	25.9	95.4	4.60	0.255	5686.4	1647.2	4039.2	29.0
1	2	1	4	54.7	36.2	24	113.5	18.5	93.8	6.20	0.271	8578.5	1499.7	6100.9	19.7
2	2	1	4	55.6	37.8	30	117.1	22.9	96.1	6.30	0.264	5776.5	1534.7	6004.1	20.4
3	2	1	4	56.3	39.6	25	116.4	19.4	93.6	6.10	0.261	6342.2	1702.6	5537.3	23.5
1	2	2	5	56.7	42.5	23	114.8	23.7	94.1	5.90	0.271	7036.8	2149.4	4887.4	30.5
2	2	2	5	57.3	38.4	22	118.9	25.4	96.9	5.60	0.320	8164.9	1932.4	6232.5	23.7
3	2	2	5	56.1	41.2	27	116.7	24.8	93.8	5.60	0.264	7531.7	1735.5	5796.2	23.0
1	2	3	6	57.5	37.6	34	118.7	26.3	96.4	6.30	0.292	8678.5	2194.5	6484	25.3
2	2	3	6	57.4	41.5	28	117.6	29.9	93.9	6.50	0.318	5806.5	1988.6	3817.9	34.2
3	2	3	6	56.1	39.8	30	121.7	27.7	94.5	6.00	0.333	6242.2	1868.9	4373.3	29.9
1	3	1	7	56.5	38.1	35	116.3	19.6	95.0	6.30	0.291	7600.6	2010.3	6568.2	23.4
2	3	1	7	56.3	40.8	29	117.8	23.8	96.3	6.80	0.322	7538.8	1900.6	3875.9	32.9
3	3	1	7	58.1	39.3	30	115.4	24.1	95.9	7.40	0.311	7239.9	1800.8	4541.4	28.4
1	3	2	8	56.2	44.7	32	121.5	31.8	95.5	7.60	0.345	8750.8	1798.6	6952.2	20.6
2	3	2	8	59.1	40.9	28	119.8	28.6	97.1	7.30	0.336	6884.4	2167.4	4717	31.5
3	3	2	8	56.9	42.5	30	118.4	29.1	96.8	7.50	0.305	6356.6	1905.5	4451.1	30.0
1	3	3	9	57.4	45.5	36	122.7	30.4	97.9	7.90	0.350	9886.5	2499.6	7386.9	25.3
2	3	3	9	60.3	46.4	31	124.4	33.2	98.1	7.60	0.334	9978.5	2294.8	7683.7	23.0
3	3	3	9	59.2	47.1	34	123.9	28.5	99.8	8.10	0.360	9736.7	2387.5	7349.2	24.5
1	4	1	10	56.5	37.8	34	114.8	29.3	99.1	4.90	0.303	6338.5	1600.7	4737.8	25.3
2	4	1	10	56.9	39.7	30	116.2	31.8	97.3	4.80	0.311	7277.7	1800.6	5477.1	24.7
3	4	1	10	58.6	41.1	33	117.5	33.5	98.6	5.30	0.304	5600.7	1500.7	4100	26.8
1	4	2	11	58.7	42.2	27	122.3	36.4	98.2	5.70	0.268	8567.5	1939.4	6628.1	22.6
2	4	2	11	59.4	39.8	30	121.5	35.6	99.3	5.10	0.288	6789.2	1832.4	4956.8	27.0
3	4	2	11	57.1	40.3	29	119.8	33.9	99.6	5.60	0.293	7236.5	1735.5	5501	24.0
1	4	3	12	58.6	42.5	34	124.7	28.6	97.7	5.60	0.283	8231.5	2064.5	6167	25.1
2	4	3	12	62.4	39.2	35	123.6	33.4	98.9	5.44	0.307	7464.9	1878.6	5586.3	25.2
3	4	3	12	59.9	43.1	31	123.9	30.8	99.8	6.50	0.311	7945.3	1738.9	6206.4	21.9

Where:

Rep=Replication, N=Nitrogen rate, T=Time of application, TRET=Treatment, DP=Date of panicle emergency, PL=Panicle length, TN=Tiller number, PH=plant height, LP=Lodging %, DM=Date of maturity, PSW=Main panicle seed weight, TSW=Thousand seed weight, BY=Biomass yield kg/ha, AGY= Actual Grain yield kg/ha, SY=straw yield kg/ha and HI=Harvest index %.