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Determination Time of Nitrogen Fertilizer Top Dressing for Teff Grown on Vertisols in the Northern Part of Ethiopia

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Abstract
Teff is a highly valued crop in more than 50-million Ethiopian people. However low plant available soil nitrogen due to depleting soil organic matter content and high leaching losses of mineralized nitrogen during the growing rainy seasons is one of the constraints listed for its low production and productivity in the country. The nationwide N fertilizer Recommendation for heavy soils (including Vertisols) was 60 kgha^{-1} and this rate most of the farmer were recommended to apply at 50% one week after emergence and 50% at 35-40 days after planting that is without any application of nitrogen at sowing/planting. Therefore, a field experiment was carried out during 2012 and 2013 main cropping season from July to November in Tahtay Machew district of central zone of Tigray region, Ethiopia. The objectives was to determine the most effective time of nitrogen fertilizer application for tef production in the study area, effect on yield and yield components of teff and Total nitrogen uptake by the plant.. The treatments were **T1**: (100% applied at Planting) Control, **T2:** (100% applied at Emergence), **T3**: (100% applied at Tillering), **T4:**(75% at Planting and 25% at Tillering), **T5**: (75% at Emergence and 25% at Tillering), **T6:** (75% at tillering and 25% at Emergence, **T7:** (50% at Planting and 50% at Tillering), **T8:** (50% at, Emergence, 25% at Tillering 25% at planting), **T9:** (50% at Tillering and 50% at Emergence), **T10**: (25% at Planting and 75% at Tillering), **T11:** (25 % at emergence, 50% at tillering and 25% at planting), **T12:** (25% at tillering, 25 % at Emergence and 50% at planting. The experiment was laid out as a randomized complete block design with four replications. All the parameters collected were computed using Gen-Stat 13th edition statistical software. The parameters were: days to panicle emergence, days to maturity, plant height, panicle length, lodging percentage, grain yield, biomass yield, harvest index and total Ni uptake by the plant. In general the highest panicle length, plant height, lodging percentage, grain yield, biomass yield, harvest index and total nitrogen was recorded when the recommended N is applied 25% at planting and 75% at tillering as compare to other treatments. Thus in heavy soils, where by the recommendation rate of 60-kgha^{-1} should be applied at a time of 25% at planting and &75% at tillering.
Keywords: Tillering, Lodging percentage, Grain yield, Total N Uptake

1. Introduction

In Ethiopia Teff occupies about 3.01 million hectares (27% of the cereal crop area) of land which is more than any other major cereals such as maize (22.7%), sorghum (19%) and wheat (16%) (CSA, 2013). Ethiopian farmers prefer teff, because the grain and straw bring good prices. Its production area is increasing at unprecedented scale due to increased market-demand both in the local and foreign market. One of the most important characteristics that make teff an efficient crop in arid and semi arid areas is its CO2 assimilation efficiency as a C4 species (Kebede, *et al.,* 1989). Teff is predominantly cultivated on sandy-loam to black clay soils. Teff performs well above any other crops under unfavorable circumstances such as low moisture conditions and often considered as a rescue crop that survives and grows well on residual soil low moisture in seasons when early planted crops (e.g. maize) fail due to low moisture. Moreover its ability to tolerate drainage problems makes it a preferred cereal by farmers (Seyfu, 1997). Ethiopian farmers prefer to grow teff because it can be grown in areas experiencing moisture stress and it can be grown in waterlogged areas and withstand anaerobic conditions better than many other cereals, including maize, wheat and sorghum. Example, in water logged condition teff gives a yield advantage of 81% over wheat (Seyfu, 1997).

The national average yield is about 1.47 t ha^{-1} which is very low (CSA, 2014). The small size of teff seed poses problems during sowing, and indirectly during weeding and threshing. At sowing, the very small seed size makes it difficult to control population density and its distribution. This remains true whether one broadcasts the seed by hand, uses a broadcaster or a seed driller. The uneven plant stand after germination has an impact on nutrient use efficiency of the crop and crop yield. Owing to the scattered plant stand, farmers find it difficult to use mechanical weeding implements and are forced to either hand-weed or to use chemical herbicides (Seyfu, 1997). The low yield is mainly due to the low soil fertility status which is a result of continuous cropping, over grazing, soil erosion and complete removal of field crops' residues without any soil amelioration (Seyfu, 1993) and traditional broadcast sowing method.

A recent field trial conducted at Debre Ziet Agricultural Research Center indicated that its yield potential is as high as 6 t ha^{-1} was obtained by application of: 46-kg ha^{-1} N, 46-kg ha $^{-1}$ P_2O5, 57 -kg ha^{-1} K_2O, 21- kg ha^{-1} S and 0.3- kg ha^{-1} Zn fertilizers and 5- kg ha^{-1} of seeds in row planting.. More commonly nitrogen fertilizers are applied on split because application of these fertilizers fully at planting causes high nitrogen losses from the soil. It also reduces nitrogen use efficiency and hence crop yield. Therefore, split application reduces nitrogen losses and increases nitrogen use efficiency of crops. Through the top dressing nitrogen rates is assumed to be 50 % of the total nitrogen rate recommended for is applied at planting and the remaining 50 % at tillering, no clear information is available about the optimum top dressing nitrogen rates for that can maximize its nitrogen use efficiency and its yield. Application of nitrogen rates at an appropriate growing period maximizes yield and hence improve its productivity. This Nitrogen fertilizer may be applied at the same soil types where is mostly grown and produces. For instance, Nitrogen fertilizer applied on Vertisols and extremely sandy needs care because nitrogen loss occurs through identification in the former and leaching in the later soil types. But this is not tested or conducted what will be the application time in relation to growth period of the crop. Determination of the optimum top dressing N-rates for grown on Vertisols and N uptake when nitrogen top dresses is compulsory in order to enhance productivity of the crop which is the main aim of this paper

2. Materials and Methods

The study was carried out during 2012 and 2013 cropping seasons at Tahtay Machew (between 38°52'30"E to 38°56'23"E longitude and 14°07'26"N to 14°11'31"N latitude). The annual rainfall is 750-mm with a variation between 700-mm and 1350-mm and has a monomodal pattern. Rainfall starts in June and ends in mid September. The annual temperature varies from a minimum of 13^0C to a maximum of 27°C. The Hargreaves Temperature method was used to estimate annual Potential Evapotranspiration (PET) which ranged from 740 to 840 mm/annum. Based on rainfall and PET calculations, the length of growing period (LGP) is expected to vary from 100 to 120 days. The major soil type is vertisol according to USDA soil classification and elevation is 2100 meters above sea level. Pre-plant soil samples (0 – 20 cm) were taken and analyzed for total nitrogen (N) by Keldahl method (Jackson, 1958), available phosphorous (P) (Olsen, *etal.,* 1954), particle size distribution by hydrometer method (Gee and Bauder, 1986), organic matter (OC) content by Walkley and Black (1934), and pH (water 1:1.25) by Okalebo *et al.,* (1993). The same analysis was performed on each plot after harvest. At maturity, ten plants were randomly selected from each plot and Oven dried (at 65-70^0C), then ground to pass through a 1-mm size sieve for the determination of uptake of Nitrogen in both the grain and straw. The experimental design was a randomized complete block design (RCBD) with four replications. The recommendation rate of N fertilizer for grown on heavy soils is 60-kgha^{-1}. Varying the amount of N applied at different growing times based on this rate: four amounts (100, 50, and 25%) and three application periods (at planting, emergence and tillering). The treatments were the following: **T1** (100% applied at Planting) **T2** (100% applied at Emergence) **T3** (100% applied at Tillering) **T4** (75% at Planting and 25% at Tillering) **T5** (75% at Emergence and 25% at Tillering) **T6** (75% at tillering and 25% at Emergence) **T7** (50% at Planting and 50% at Tillering) **T8** (50% at Emergence, 25% at Tillering 25% at planting) **T9** (50% at Tillering and 50% at Emergence) **T10** (25% at Planting and 75% at Tillering) **T11** (25 % at emergence, 50% at tillering and 25% at planting) **T12** (25% at tillering, 25 % at Emergence and 50% at planting).. The source of N was urea and P was from Triple supper phosphate (TSP). Full Dose of P (100-kgha^{-1}) was applied at planting, while the N dose was applied according to the time schedule of growth stage of teff. The gross and net plot sizes were 3m x 4m and 2m x 3m, respectively. An improved teff variety 'Dz-01-387' (*Quncho*) which is tolerant to shoot fly attack was sown by row planting 20-cm between rows and planting by drilling with in rows at a rate of 15-kg ha^{-1}.

Crop paramerts measured were**:** (1) Days to Panicle Emergence: was determined by counting the number of days from sowing to the time when 50% of the plants started to emerge the tip of panicles through visual observation. (2) A day to Maturity was determined as the number of days from sowing to the time when the plants reached maturity based on visual observation. It was indicated by Senescence of the leaves as well as frees threshing of grain from the glumes when pressed between the forefinger and thumb. (3) Plant height**:** was measured at physiological maturity from the ground level to the tip of panicle from ten randomly selected plants in each plot. (4) Panicle length**:** It is the length of the panicle from the node where the first panicle branches emerge to the tip of the panicle which was determined from an average of ten selected plants per plot. (5) Grain yield**:** Grain yield was measured by harvesting the crop from the net middle plot area of 2 x 3 m to avoid border effects. (6) Biomass yield: At maturity, the whole plant parts, including leaves and stems, and seeds from the net plot area were harvested and after drying for seven days, the biomass was measured quintal per hectare (Qtha^{-1}). (7) Harvest index: was calculated by dividing grain yield by the total above ground air dry biomass yield.(8) Lodging index was assessed just before the time of harvest by visual observation based on the scales of 1-5 where 1 (0-15°) indicates no lodging, 2 (15-30°) indicate 25% lodging, 3 (30-45°) indicate 50% lodging, 4 (45-60°) indicate 75% lodging and 5 (60-90°) indicate 100% lodging (Donald, 2004). The scales were determined by the angle of inclination of the main stem from the vertical line to the base of the stem by visual observation. Each plot was divided based on the displacement of the aerial stem in to all scales by visual observation. Each scale was multiplied by the corresponding percent given for each scale and average of the scales represents the lodging percentage of that plot. Data recorded on lodging percentage were subjected to arcsine transformation described for percentage data by Gomez and Gomez (1984).

All crop collected data in this study were subjected to one way statistical analysis of variance (ANOVA) following a procedure appropriate to a randomized complete block design as suggested by (Gomez and Gomez, 1984) and was computed using Gen-Stat 13th edition statistical software. Whenever the treatment was significant, least significance differences (LSD) by Dunken's multiple range comparison was used for mean separation at p=0.05 &p=0.001.The statistical model used for analysis of the data collected from the experimental field is given by:

Yijk = μ+Ai+Bj+ εijk

Where:

Yijk = the response variable

μ = Overall mean.

Ai = Effect of split nitrogen application,

Bj= Effect of blocking (Replication),

εijk = Treatment error Effect of split nitrogen application and replication as block K.

3. Results and Discussion

3.1. Pre-planting Surface Soil Laboratory Results

The pre-sowing composite surface soil sample (0-20 cm) collected from the experimental site was analyzed for some selected physcio-chemical soil properties. The result of the soil analysis showed that the textural class of the soil as clay (14% sand, 25% silt and 61% clay) with a soil pH of 5.68, available phosphorus of 7.98 ppm, CEC of 25.8 meq/100gsoil, organic carbon of 2.54%, and total nitrogen of 0.14% (Table 1). The soil is medium available potassium and bulk density (126.8 and 1.34 respectively), and moderately acidic (5.6-6.1) and total N (0.14%) and the response to applied N indicated that the available form of the total soil N could be inadequate and it is likely to be stored in organic matter and clay minerals (Birkeland, 1984). and low soil organic carbon (2.54) (Table 1) (Landon, 1991; Defoer *et al.,* 2000). According to these results, clearly justify, the need for the external application of inorganic sources based on the base recommendation for the different crops grown in the area.

Table 3.Results showing The Status of the Soil before Planting

SN.	Characteristics	Unit	Value
1	Sand	Percent	14
2	Silt	Percent	25
3	Clay	Percent	61
4	Textural Class Name	-	Heavy Clay
5	PH	-	5.68
6	Organic Carbon percent	Percent	2.54
7	CEC meq/100gsoil	meq/100g soil	25.8
8	Total nitrogen percent	Percent	0.14
9	Available phosphorus ppm	Ppm	7.98
10	Available potassium ppm	Ppm	126.8
11	Bulk density	gcm^{-3}	1.34

3.2: Response of split N application on Crop Phenology

3.2.1 Days to Panicle Emergence

Days to panicle emergence was highly significantly ($P < 0.05$) affected by the effects of timing of the N fertilizer application (Table 2). In general, increasing the time of nitrogen application significantly prolonged the days to panicle emergence of the plants across the application times. Over all times of nitrogen application, **T10** (25% at Planting and 75% at Tillering) had significantly delayed days to panicle emergence than those grown at the other time of nitrogen application time. The maximum number of days to panicle emergence (**60.8**) was observed when the recommended rate of N for in heavy soil (60 kg N ha^{-1}) was applied in two splits (25% at Planting and 75% at Tillering) and the minimum days to Panicle Emergence **(51.3)** was observed when the recommended N rate was 100% applied at emergence of the crop (7-days after planting) (Table 2). Generally, the number of days to panicle emergence recorded over all the treated plots was significantly lower than the **T10** (25% at Planting and 75% at Tillering) plot. The delay in panicle emergence of teff plants in response to time of N split applications might be because the fact that N time split application promoted vigorous vegetative growth and development of the plants possibly due to synchrony of the time of need of the plant for uptake of the nutrient and availability of the nutrient in the soil. This result is in line with the finding of Getachew (2004) and Mekonen (2005) who reported that the heading was significantly delayed at the highest N fertilizer rate compared to the lowest rate on wheat and barley crops, respectively. In contrast, to the results of the present study, Sewnet (2005) reported early flowering with an increase in the rate of N application in rice.

3.2.2. Days to Maturity

Days to maturity of teff plant was highly significantly (P < 0.05) affected of timing of N fertilizer application (Table 2). The highest (**94**-Days) and the lowest (**83**-Days) to maturity was recorded in **T10:** (25% at Planting and 75% at Tillering) and **T2:** (100% applied at Emergence) respectively (Table2). In general, the maturity of teff plants in **T10:** (25% at Planting and 75% at Tillering), in **T11:** (25 % at emergence, 50% at tillering and 25% at planting) in **T7:** (50% at Planting and 50% at Tillering) was showed delay in days to maturity than the other time of N applications treatments. Consequently, higher Nitrogen portion at tillering (**50%** and **75%** of the recommended rate 60 kg N ha^{-1}) delays to Days Maturity (Table 2). This result is in line with the report of Marschener (1995), Tanaka *et al*. (1995) and Brady and Weil (2002) that N applied in excess than required delayed plant maturity. The findings are also in line with the fact that higher rate of N application by facilitating vegetative growth stage of cereals also prolongs the maturity. Similar observation was noted by Temesgen (2001) who reported that application of 69 kg N ha^{-1} delayed maturity of by ten days over the control treatment (0 kg N ha^{-1}) at kobo agricultural research center station of Kobo Vertisols. Likewise this is in line with the findings of Marschner (1995) who reported that plants treated with adequate nutrients and enough space remained green for longer duration while without fertilizer showed yellow stem, leaves and panicle earlier, this could be N deficiency symptoms that leaf and stem indicating early physiological maturity.

Table 4: showing the Effect of split application of nitrogen fertilizer on DPE (Days to Panicle length Emergence in Days) and DM (Days to Maturity in Days) 2013 cropping season in

Treatment (N split application time)	DPE (Days To Panicle Emergence in Days)	DM (Days To Maturity in Days)
T1	51.9bc	85b
T2	51.3bc	83b
T3	54.6bc	86b
T4	52.4bc	84b
T5	51.9bc	84b
T6	52.8bc	85b
T7	55.8abc	91a
T8	52.3bc	85b
T9	52.7bc	84b
T10	60.8a	94a
T11	57.5ab	92a
T12	53.8bc	83b
Mean	53.9	86.33
CV	9.08	11.4
LSD	5.06	4.8

T1: (100% applied at Planting) Control, **T2:** (100% applied at Emergence), **T3**: (100% applied at Tillering), **T4:**(75% at Planting and 25% at Tillering), **T5**: (75% at Emergence and 25% at Tillering), **T6:** (75% at tillering and 25% at Emergence, **T7:** (50% at Planting and 50% at Tillering), **T8:** (50% at, Emergence, 25% at Tillering 25% at planting), **T9:** (50% at Tillering and 50% at Emergence), **T10**: (25% at Planting and 75% at Tillering), **T11:** (25 % at emergence, 50% at tillering and 25% at planting), **T12:** (25% at tillering, 25 % at Emergence and 50% at planting). Means sharing the same superscript letter do not differ significantly at **P = 0.05** according to the LSD test.

3.3. Effects on lodging percentage

Lodging index was significantly (**P < 0.05**) affected by the timing of N fertilizer application (Table 3). Increasing the time of nitrogen application increased the lodging percentage of tef crops in all nitrogen fertilizer application times (treatments). The lowest lodging percentage was observed for plants grown at the N applied full dose at **T2:** (100% applied at Emergence), **T1**: (100% applied at Planting), **T8:** (50% at, Emergence, 25% at Tillering 25% at planting) and **T12:** (25% at tillering, 25 % at Emergence and 50% at planting) which scored 27.48, 28.28, 28.58, 28.90 cm respectively (Table 3). This result is consistent also with that of Seyfu (1983) who reported that lodging in cereals is considered to be caused by high rate of nitrogen fertilizer application. On the other hand the higher percentage of lodging was observed in **T6** (**52.41** cm) and **T3** (**47.45** cm), this result 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 result reveals that the application of N applications nutrient leads to the detrimental effect of crop losses due to lodging. The increase in crop lodging could be due to the profound effect of high N supply on increasing vegetative growth thereby leading to bending of the weak stem of the plant due to the sheer load of the canopy. 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. In over all, the lodging index recorded under fertilized plots exceeded the unfertilized plots by about 51%.

TABLE 5 MEAN PLANT HEIGHT AND PANICLE LENGTH AS AFFECTED BY TIMING OF NITROGEN FERTILIZER APPLICATION.

Treatment (N split application time)	Lodging Percentage
T1	**28.28c**
T2	**27.48c**
T3	**47.45a**
T4	**30.78bc**
T5	**30.72bc**
T6	**51.41a**
T7	**36.98bc**
T8	**28.58c**
T9	**29.80bc**
T10	**36.50bc**
T11	**36.41bc**
T12	**28.90c**
Mean	**34.35**
CV	**12.93**
LSD	**7.42**

T1: (100% applied at Planting) Control, **T2:** (100% applied at Emergence), **T3**: (100% applied at Tillering), **T4:**(75% at Planting and 25% at Tillering), **T5**: (75% at Emergence and 25% at Tillering), **T6:** (75% at tillering and 25% at Emergence, **T7:** (50% at Planting and 50% at Tillering), **T8:** (50% at, Emergence, 25% at Tillering 25% at planting), **T9:** (50% at Tillering and 50% at Emergence), **T1**0: (25% at Planting and 75% at Tillering), **T11:** (25 % at emergence, 50% at tillering and 25% at planting), **T12:** (25% at tillering, 25 % at Emergence and 50% at planting). Means sharing the same superscript letter do not differ significantly at **P = 0.05** according to the LSD test.

3. 4 Growth Parameters

3.4.1. Plant height

The analysis of variance showed that plant height was affected significant ($P< 0.05$) by timing of N application (Table 4). Plant height generally increased with the increase in time of N application (Table 4). Thus, plants in **T10**: (25% at Planting and 75% at Tillering) that is higher portion of N at tillering showed the tallest plant height **(125.04-**cm**)** followed by **T11** and **T7** scored with **123.80-**cm and **122.80-**cm respectively (Table 3). The smallest plant height was recorded (**114.6** cm) at **T2:** (100% at Emergence). Thus shortest plants were observed from plots supplied with one-dose application at emergence. In general the mean height of plants grown at the **T10, T**11 and **T7** of time of N-application significantly exceeded the mean heights of other treatments. This difference may be to the fact that only one-time application of full dose of nitrogen at time of emergence or sowing may not lead to efficient recovery of the nutrient by roots and enhanced plant growth. This could be attributed to that application of full dose of nitrogen at one time to crops may lead to loss due to leaching as nitrate ion ($NO3^{-1}$) as stated by Mengel and Kirkby (2001) and El-Karamity (1998) who reported significant increments in plant height due to application of high nitrogen fertilizer rate. Many studies revealed significant influence of N on plant height as it plays vital role in vegetative growth of plants. A similar result was reported by Haftom *et al.* (2009) showing that teff plants with higher plant height (92 cm) and panicle length (38 cm) were found by applying a high amount of N fertilizer (92 kg N ha-1). This may be attributed to the fact that N usually favours vegetative growth of teff, resulting in higher stature of the plants with greater panicle length. Legesse (2004) also reported that high N application resulted in teff plants with significantly taller plants due to direct effect of N on vegetative growth of crop plants. In line with this finding Mekonn (2005) reported that plant height measured at physiological maturity increased significantly with increasing levels of N in wheat and sorghum respectively. Similarly, Tenaw (2000) and Zeidan *et al.* (2006) reported a significant effect of increased N fertilizer on the stature of maize plants. The plant height obtained from the all treated plots was significantly higher than the unfertilized plot. This is because nitrogen fertilizer has a great role in plant growth.

However, the results of the present study contradict the study of Temesgen (2001), who did not find significant increase in plant height of teff with increasing levels of N fertilizer application on Vertisols of Kobo, North Wollo. The lack of response may be attributed to the variability of fertility levels, particularly, soil N. Also, varieties and erratic moisture condition of the area may be blamed. Generally, N response could be expected from most soils provided that other growth factors, in particular, soil moisture are not limiting. It is well known that soil moisture is one of the most important limiting growth factors in the semiarid areas. Stevenson (1982) noted that response to N application was limited when water availability was restricted. In addition, the response to N depends on how well the crop is supplied with other nutrients, in particular P and K. Although most investigators have revealed that crops usually responded to N fertilizer, these might not be true always as indicated in the study by Temesgen (2001).

3.4.2. Panicle Length

Panicle length is one of the yield attributes of that contribute to grain yield. Crops with higher panicle length could have higher grain yield. Panicle length was highly significantly (**P<0.05**) influenced by the timing of N fertilizer (Table 4). An increase of time of N application increased the teff panicle length. This result is in agree with that of Haftom *et al*. (2009) who reported that teff panicle length increased in response to increasing rate of nitrogen application, with the longest panicles being obtained at the highest rate **92** kg N ha^{-1} of nitrogen.

TABLE 6 MEAN PLANT HEIGHT AND PANICLE LENGTH AS AFFECTED BY TIMING OF NITROGEN FERTILIZER APPLICATION.

Treatment (N split application time)	PH (Plant Height In cm)	PL (Panicle Length In cm)
T1	115.42b	42.2b
T2	114.20b	42.5b
T3	117.40b	44.2ab
T4	115.07b	43.3ab
T5	115.6b	42.2b
T6	117.50b	42.8b
T7	122.80a	44.2ab
T8	114.80b	42.6b
T9	115.02b	42.3b
T10	125.04a	47.2a
T11	123.80a	47.1a
T12	116.05b	42.4b
Mean	117.66	43.6
CV	10.08	9.8
LSD	3.80	4.2

Means sharing the same superscript letter do not differ significantly at P = 0.05 according to the LSD test

3.5. Yield and Yield Components

3.5.1. Grain yield

The analysis of variance showed that grain yield of tef was highly significantly (**P < 0.05**) influenced by the timing of N application (Table 5).The highest grain yield of **29.81** Qt ha^{-1} was recorded at **T10** which was significantly different from all treatments except **T11:** (25 % at emergence, 50% at tillering and 25% at planting) scored **24.81**Qt ha^{-1} (Table 5). From the farmer's perception and economical standpoint, it is more profitable to use twice N application rather than three times (**T10** rather than **T11).** Earlier studies by Tekalign et al (2002) and Mulegeta (2003) confirmed that 60 kg N ha^{-1} is the optimum rate of N fertilizer in the region. Application of N significantly (**P < 0.05**) increased grain yield by 54% over the control. As expected, low grain yield **22.63** ha^{-1} was obtained in the plot with application of nitrogen full dose at emergence and at planting (Table 5). Similarly, the result of this study 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 the nutrient in the soil proportionate with the demand of the plant for uptake. Thus, applying the whole dose of nitrogen at sowing and at emergence was perhaps wastage as the small teff 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, at tillering may not enable the plant to take up a maximum amount of the nutrient at that particular time. Consequently, the plants may have hungered for nitrogen and suffered from its deficiency during the earlier time of vegetative growth, supplying a full dose of N only at tillering cannot guarantee optimum growth and development. Thereby, the yield obtained from this treatment may be suppressed. In this connection, most of the applied nitrogen left over from uptake by the plant from the fully applied dose at sowing, emergence, 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 application from once (at sowing, emergence and at tillering) to twice (25% at Planting and 75% at Tillering) significantly enhanced teff grain yield (Table 5). This may be because the plants may have been able to take up balanced amounts of nitrogen throughout the major growth stages due to enhanced synchrony of the demand of the nutrient for uptake by the plant and its availability in the root zone in sufficient amounts. In this case, leaching losses may also be reduced since the amount of nitrogen made available in the root zone may not be too high to be left over from uptake by plants and be predisposed to leaching. The highest grain yield was obtained in response to application of 60 kg N ha^{-1} in two split doses 25% at Planting and 75% at Tillering. This grain yield was, however, in statistical parity with the grain yield obtained in response to applying three splits 25 % at emergence, 50% at tillering and 25% at planting (Table 5). This result is also in line with that of Mohammad *et al*. (2011) who reported significantly higher yield of wheat from two equal split applications of N with 1/2 dose at sowing and 1/2 dose at tillering. Likewise, Temesgen (2001) reported that application of different levels of N significantly affected grain yield of tef on farmer's field. Thus, compared to the tef grain yield obtained in response to applying 46 kg N ha^{-1} and 92 kg N ha^{-1} in two equal splits of half at sowing and half at mid-tillering, the grain yield obtained in response to applying 69 kg N ha^{-1} at the same times and doses was significantly higher by 14% and 21%, 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 mid-tillering exceeded the grain yield obtained from the application of 46 kg N ha^{-1} full dose at sowing by about 40%. The results of this study are consistent with that of Sage and Pearcy (1987) who reported that a well-balanced supply of N results in higher net assimilation rate and increased grain yield as also found by Al-Abdulsalam (1997). Corroborating the results of this study, Blankenau *et al*. (2002) stated that proper time of N application are critical for meeting crop needs, and indicated considerable opportunities for improving yields. Consistent with the results of this study, also Ashraf and Azam (1998) reported that growth stage of plants at which fertilizer is applied determines the final yield of the crop. In agreement with the results of this study, Michael *et al*. (2000) and Anthony *et al*. (2003) indicated that split N application as dry fertilizer material was effective in attaining higher grain yield of wheat. Consistent with the results of this study, Limaux *et al*. (1999) suggested that supplying N in two or three applications is a good recommendation to increase N use efficiency in wheat. The results of this study are consistent also with that of Cassman *et al.*, (2002) who reported that greater synchrony between crop demand and nutrient supply is necessary to improve nutrient use efficiency, and split applications of N during the growing season, rather than a single, large application, are known to be effective in increasing N use efficiency. According to farmers of the study area and Office of Agriculture and Rural Development (OARD, 2006), farmers usually get an average grain yield of nearly **6 – 8** $Qtha^{-1}$ during normal season regardless of N application. So far, the national average for teff grain yield is around **13.65** $Qtha^{-1}$ (CSA, 2013). In view of this, the contribution of N to teff grain yield is appreciable. Nationwide as well as location-specific fertilizer trials on teff substantiate the findings of the present study (Tekalign *et al.*, 2002). The result also supports that of Temesgen (2001) where the response of teff to N significantly ($p<0.01$) increased grain yield from 1620 kg ha-1 in the check plot to 1920 kg ha^{-1} in plots with 69 N kg ha^{-1} on Vertisols at North Wollo.

3.5.2. Biomass yield

The biomass yield was significantly (**$P < 0.05$**) influenced by the timing of N fertilizer application (**$P < 0.05$**) (Table 5). Biomass yield generally increased significantly with the increasing frequency of application. The highest biomass yield (**83.44** Qt ha^{-1}) was obtained under plants supplied N with 25% at Planting and 75% at Tillering) whereas the lowest biomass yield (**67.89** Qt ha^{-1}) was obtained from plants grown with supplied N with 100% at emergence (Table 5). Thus, the maximum biomass yield exceeded the minimum biomass yield by about **22.91**%. This could be attributed to the well-known effects of N on vegetative growth of cereals under sufficient soil moisture conditions. These results concurred with the study of Temesgen *et al.* (2001) who observed a significant (**$p< 0.05$**) biomass yield response to N on Vertisols in the central highlands of Ethiopia. Also, the results corroborated the work of Temesgen (2001) who found that N application consistently increased the biomass yields of teff. This nitrogen application time significantly enhanced biomass yield is in agreement with the result of Amanuel *et al*. (1991) who reported a significant increase in biomass yield of wheat as a result of increased rate of N application. The lowest biomass yield might be due to the effect of lodging resulted from full dose of N fertilizer that encourage vegetative growth and height leading to lodging before the translocation of dry matter to economic yield since biomass includes the economic yield. This result is, however, in contrast to that of Haftom *et al*. (2009) who found the highest biomass yield of tef in response to 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 latter 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.

3.5.3. Harvest index

Harvest index was computed as the ratio of grain yield to the total above ground dry biomass yield. Timing of nitrogen application significantly affected harvest index (Table 5). The highest harvest index were scored (**0.35** each) under treatments of **T1, T5** and **T10 (**Table 5**)**. This may indicates that, full dose application of nitrogen may lead to relatively less shoot biomass growth due to leaching at the seedling stage of the crop, when the plant had no sufficient capacity to take up larger amounts of the nutrient. This is might be also due to the results obtained in proportionally higher seed yield than vegetative biomass yield. Similar to this study Mulugeta (2003) found the lowest harvest index at the highest N rate was applied when compared to the control treatment in teff. 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 treatments.

Table 7 Mean Grain yield, Biomass yield Harvest index in percent as affected by Timing of Nitrogen Fertilizer Application

Treatment (N split application time)	GYLD (Grain yield in Qtha $^{-1}$)	BYLD (biomass yield in qtha^{-1})	HI (Harvest index in Percent)
T1	23.99bc	68.98c	0.35a
T2	22.63bc	67.89c	0.33abc
T3	24.2bc	70.72c	0.35abc
T4	23.24bc	69.71c	0.33abc
T5	23.91bc	68.72c	0.35a
T6	24.03ab	71.08c	0.33abc
T7	25.48ab	76.45b	0.33abc
T8	24.25ab	71.74bc	0.33abc
T9	23.30bc	69.89c	0.33abc
T10	29.81a	83.44a	0.35a
T11	24.81abc	77.24b	0.32bc
T12	23.61bc	70.82c	0.33abc
Mean	**24.47**	**72.35**	**0.34**
CV	**11.78**	**12.08**	**6.68**
LSD	**5.2**	**4.6**	**0.02**

T1: (100% applied at Planting) Control, **T2:** (100% applied at Emergence), **T3**: (100% applied at Tillering), **T4:**(75% at Planting and 25% at Tillering), **T5**: (75% at Emergence and 25% at Tillering), **T6:** (75% at tillering and 25% at Emergence, **T7:** (50% at Planting and 50% at Tillering), **T8:** (50% at, Emergence, 25% at Tillering 25% at planting), **T9:** (50% at Tillering and 50% at Emergence), **T10**: (25% at Planting and 75% at Tillering), **T11:** (25 % at emergence, 50% at tillering and 25% at planting), **T12:** (25% at tillering, 25 % at Emergence and 50% at planting). Means sharing the same superscript letter do not differ significantly at **P = 0.05** according to the LSD test.

3.6. Total Nitrogen Uptake

Total nitrogen uptake kg ha^{-1} was significantly (**P<0.05**) affected by the N timing of applications (Table 6). The highest total nitrogen uptake (**0.699** Qtha^{-1}) was recorded in **T10** (25% at Planting and 75% at Tillering) and the lowest (**0.324** Qtha^{-1}) was recorded in **T2** (100% applied at Emergence) (Table 6). The highest total N uptake is because the nitrogen uptake by straw and grain were the highest at this treatment and hence these two grain and straw nitrogen uptake added up to the high total nitrogen uptake. The total nitrogen uptake has a positive association with grain yield. Therefore, the highest grain yield was recorded at the treatment that gave maximum total nitrogen uptake. This agrees with split N application significantly (p< 0.05) increased N uptake to cultivated crops has little or residual effects due to plant consumptive use and /or losses through leaching volatilization, denitrification (Wild, 1988).

TABLE 8 MEAN TOTAL N UPTAKE (QT HA^{-1}) OF TEFF AS AFFECTED BY TIME OF NITROGEN FERTILIZER APPLICATION.

Treatment (N split application time)	**Total Nitrogen Uptake in Straw and Grain of in Qt ha^{-1}**
T1	**0.352bc**
T2	**0.324bc**
T3	**0.383bc**
T4	**0.454bc**
T5	**0.472abc**
T6	**0.482abc**
T7	**0.510abc**
T8	**0.421bc**
T9	**0.390bc**
T10	**0.699a**
T11	**0.480abc**
T12	**0.420bc**
Mean	**0.448**
CV	**7.9**
LSD	**0.242**

T1: (100% applied at Planting) Control, **T2:** (100% applied at Emergence), **T3**: (100% applied at Tillering), **T4:**(75% at Planting and 25% at Tillering), **T5**: (75% at Emergence and 25% at Tillering), **T6:** (75%

at tillering and 25% at Emergence, **T7:** (50% at Planting and 50% at Tillering), **T8:** (50% at, Emergence, 25% at Tillering 25% at planting), **T9:** (50% at Tillering and 50% at Emergence), **T1**0: (25% at Planting and 75% at Tillering), **T11:** (25 % at emergence, 50% at tillering and 25% at planting), **T12:** (25% at tillering, 25 % at Emergence and 50% at planting). Means sharing the same superscript letter do not differ significantly at **P = 0.05** according to the LSD test.

4. Summary and conclusion

The national recommendation of nitrogen fertilizer rate in heavy soil is 60-Kg ha^{-1} and the time of application is 50% at tillering and 50% before heading. There is no clear information in the study area whether there is a need Nitrogen at sowing or not. Hence, an experiment was conducted during the 2012/2013 cropping season at Tahatay Machew, central zone Tigray to determine the appropriate time of N fertilizer application within the respective cropping stage of teff. The results indicated that, application of N by 25% at planting/sowing and 75% at tillering significantly (**p< 0.05**) improved grain yield, biomass yield, plant height, panicle length, harvest index , lodging of plants and total Nitrogen uptake. The highest grain and biomass yields were obtained at **T10 (**N application time 25% at planting and 75% at tillering**),** equivalent to an increase of 31.73% and 22.91% over the control, respectively. Furthermore the higher total N uptake was in this treatment, this leads for the increment of the NUE. In this study is possible to recommend that in vertisol of the dry land areas of tigray it is possible to use the recommended rate earlier (60-kgha^{-1}N) in split application form in a manner of 25%at planting and 75% at tillering. It is also possible to recommend that studies should be repeated at various soil types.

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