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Grain Yield, Nitrogen Use Efficiency and Economic Benefits of Bread Wheat (Triticum aestivum L.) Production as Influenced by Nitrogen Split Application Timing in Central Highlands of Ethiopia

Legesse Admassu* Sakatu Hunduma
Ethiopian Institute of Agricultural Research, Holeta Agricultural Research Center, P.O. Box 2003, Addis Ababa, Ethiopia

Abstract
This experiment was initiated to evaluate the appropriate nitrogen fertilizer split application timing for Hidase bread wheat variety. This experiment was done at Holeta Agricultural Research center, West Shoa, Ethiopia. The split nitrogen application times were ½ at sowing + ½ at mid tillering, ½ at sowing + ½ at anthesis, nil at sowing + ½ mid tillering + ½ at anthesis, nil at sowing + full at mid tillering, nil at sowing + full at anthesis, ½ at sowing + 2/3 at mid tillering, 1/3 at sowing + 1/3 mid tillering + 1/3 at anthesis, nil at sowing + 1/3 mid tillering + 2/3 at anthesis, 2/3 at sowing + 1/3 mid tillering, 2/3 at sowing + 1/3 at anthesis, full at sowing and negative control. The experiment was laid out randomized complete block design with three replications. The wheat variety was investigated for plant height, productive tiller number, spike length, seed number per spike, thousand seed weight, above ground biomass yield and grain yield. Timing of nitrogen fertilizer has significant effect on the yield and yield component wheat. Timing of nitrogen fertilizer one third at sowing plus two third at mid tillering gave the highest plant height, spike length, number of productive tillers, number seeds per spike and thousand kernel weight and harvest index, compared with other nitrogen timing. Application of nitrogen fertilizer one third at sowing plus two third at mid tillering gave the highest grain yield. This application method gave a yield advantage of 13.3 % over the commonly practiced 1/2 at sowing and 1/2 at mid tillering. It also gave the highest economic return and agronomic Nitrogen Use Efficiency.
Keywords: split application timing, nitrogen fertilizer, Grain yield, Nitisols, wheat

1. Introduction

Wheat (*Triticum aestivum L.*) was among the first of the domesticated and most widely cultivated food crop (Raza et al., 2014). It is a self-pollinating annual plant in the true grass family *Gramineae (Poaceae*), is extensively grown as major staple food sources for 30% world population (Mollasadeghi and Shahryari, 2011; Yadav and CS Dhanai, 2017). It is exclusively produced under rain fed conditions both in the *meher (long*) and *belg* (short) rainy seasons. It can be grown below sea level to 5000m altitude and in areas where rainfall ranges between 300-1300 mm. It is the most important food for humans in Europe, West Asia and North Africa and rapidly urbanizing and industrialized countries in sub-Saharan Africa and Asia (China and India) and Mexico (Shewry and Hey, 2015). Wheat is an important cereal crop in Ethiopia that is widely cultivated in a wide range of altitude (Hailu, 1991). Ethiopia is the second largest producer of wheat in sub-Saharan Africa, following South Africa (White et al., 2001).

Wheat is one of the major cereal crops in the Ethiopian highlands (White et al. 2001). The most common wheat species cultivated in Ethiopia are bread wheat (*Triticum aestivum* L.) and durum wheat (*Triticum durum* Desf.) (Tesemma and Belay 1991). It is the fourth most important cereal crop both in area and production after tef, maize, and sorghum. Wheat in Ethiopia is grown over a large area (1.61 million ha), occupying about 20% of the total cereal area but productivity is as low as 24.4 t ha^{-1} (CSA, 2014) which is lower than the world average (3.3 t ha^{-1}), (FAO, 2016) average cereal yields of 3 t ha^{-1} in the developing world and wheat yield of 6-7 t ha^{-1} in the developed country. This is due to poor soil fertility and crop management practices (Tarekegne and Tanner 2001; Zeleke et al. 2010). The low productivity of wheat in Ethiopia is mainly due to four major reasons; poor soil fertility management practices coupled with suboptimal rates of mineral fertilizers application, Limited use of legumes in the cropping system, continuous cropping which have aggravated the decline in soil fertility and crop yield (Tanner et al., 1999; Agegnehu et al., 2008; Zeleke et al., 2010; Tarekegne and Tanner, 2001).

Nitrogen (here after N) is major and expensive macro nutrient constraint limiting wheat production in Ethiopian highlands (Tanner et al., 1993). It is key factor in achieving optimum and economic grain yield of wheat. Early season N application results in accumulation of dry matter by enhanced tiller number and larger photosynthetic surface (Morgan 1988). Late application of N at or after the emergence of flag leaf do not increase the leaf area but increase N contents of vegetative parts and prolongation of leaf area duration is the major cause for the increase in yield (Pearman et al., 1979). Plant use efficiency of N depends on several factors including application time, rate of N applied, cultivar and climatic conditions (Moll et al., 1982). Increasing N supply to a crop drives the production of greater canopy biomass with the potential for higher photosynthesis and productivity. Availability of N has impacts throughout the crop development affecting seedling establishment, tillering, number grains per spike, canopy development and grain filling (Ali et al., 2000; Hawkesford, 2014). N availability influences the uptake, not only of itself, but also secondary nutrients (Abbas et al., 2011). Therefore, it is very crucial to apply N fertilizer to boost wheat grain yield and protein content in Ethiopia.

One of the most important target of modern crop production is to improve nitrogen use efficiency (here after NUE) as this will lead to increased profitability through the greater yield or reduced fertilizer cost and environmental protection through the reduction in greenhouse gas emissions and nitrate leaching (Foulkes et al., 1998; Hirel et al., 2007). Cereal crops are quite inefficient in using N as less than 40% of the applied N as fertilizer can be recovered in the grain indicating serious inefficiency in N utilization (Raun and Johnson, 1999; Glass 2003). Garnett (2009) also reported that 30-50% being taken by the plant depending on the species and cultivar. Globally, studies have also revealed that about 50% of the applied N fertilizer remains unavailable to a crop due to N losses to the environment (Eickout et al., 2006). Hodge et al. (2016) also reported 50-70% of the N provided to the soil is lost due to volatilization, runoff denitrification and leaching. Thus the farmer is compelled to apply more than the actual need of the crop to compensate the loss (Abd El-Lattief, 2011) making the farmer vulnerable to economic loss besides polluting the environment. Hence, crops production would not increase unlimitedly as rising applied N, worldwide NUE is approximately 33% (Raun and Johnson 1999). More attention was paid to the increasing N application rationally (Galloway et al. 2004). On the contrary, Bartholomew (1972) reported that Recoveries of N from 70–80% are physically feasible in most situations with efficient N application through improvement in timing and placement. Plant NUE depends on several factors including application time, rate of N applied cultivar and climatic conditions (Moll et al., 1982).

In central Ethiopian highlands wheat is produced under heavy bi-modal amount and intensity of rainfall pattern coupled with steep slopes which makes nutrients like N out of reach of the active root zone. In high-altitude wheat growing areas where rainfall is high and water-logging is created, leaching, surface runoff and denitrification making the nutrient unavailable during the critical stages of crop growth (Mathers et al., 2007) which reduces N use efficiency. According to Davidson and Ackerman (1993) available N losses due to leaching and runoff are in the order of 30%. Several other research results also reported 50% of the applied N remains unavailable to crop due to N loss (Dobermann, 2005; Jamal et al., 2006; Chien et al., 2009). Hence, Leaching of NO3-N is economically waste and environmentally detrimental (Sheibani and Ghadiri, 2012; Xing et al., 2016). In this part of the country, other factors that result in inefficient use of N fertilizer were unpredictable seasonal rainfall, dry spells, and inadequate availability of other nutrients, ammonia volatilization and continuous biomass removal in the cereal mono-cropping systems of the Ethiopian highlands. Moll et al. (1982) defined NUE as being the yield of grain per unit of available N in the soil. This comes down to developing appropriate recommendations that match crop nutrient requirements fertilizer additions and minimize nutrient losses from fields (Johnston and Bruulsema, 2014).

Enhancing the productivity in countries which did not benefit from the so called ‘green revolution’ will be required to develop crop management strategies and select genotypes that can grow under low N conditions (Delmer, 2005). Hence, several strategies have been developed to mitigate nutrient leaching and improve the NUE. Controlled release of fertilizers (CRFs) often referred to as enhanced efficiency fertilizers have also been used as a viable option for improving NUE through synchronization between N supply and crop demand (Chen et al., 2008). Nitrification inhibitors also been offered as a potential to reduce and mitigate oxidation of ammonium (NH4) to Nitrite and then to nitrate NO_3^- by from agricultural soil through N leaching (Constable and Rochester 1988; de Klien and Eckard, 2008) deactivating responsible enzymes (Amberger, 1989). In addition, incorporation of cereal straw residues which often have high C/N ratio, has been suggested as a measure to control N leaching due to immobilization of soil N in microbial biomass during the decomposition processes (Jensen, 1997). Conservation agriculture due to accumulation of crop residue has also been recommended to increase the availability of mineral nutrition (Marahata, et al., 2014). The above strategies can be effective in reducing leaching but the extra cost often makes them prohibitive for use by small holders in rain-fed environments.

Timeliness of fertilizer N application with the recommended rate is another low-cost strategy to reduce nutrient leaching. It is very important and crucial in crop production to synchronize nutrient supply with plant demand in time and space throughout the growing season (Montemurro and Diacono, 2016) to get good yield and quality product acceptable along the value chain. Split applications reduce the exposure of N in saturated soils where the potential for losses such as leaching and denitrification are increased. Increasing fertilizer use efficiency is very important, particularly in developing countries where the cost of fertilizer is very expensive and sky rocketing. Hence, Timing of N application has an important role in Optimizing fertilizer N use, achieving acceptable grain yield, and maintaining adequate grain protein (Kanampiu, 1997) and economical and appropriate method of application needs to be determined to enhance productivity and profit of the growers under given situation (Manzoor et al., 2006). Numerous studies have demonstrated that an increase of the N-fertilizer rate has a favorable effect since it produces an increase in the protein content (Garrido-Les-tache et al., 2005). However, with respect to the effect of a further splitting of this N rate in several applications including a late N amendment, very different results have been described regarding grain yield and quality (Borghi et al., 1997; Garrido-Lestache et al., 2004, 2005; Subedy et al., 2007; Fuertes-Mendizábal et al., 2010). Furthermore, the N intake from mineral fertilizers reduces when the rate is increased because the supply is generally higher than the plant needs, and consequently losses are observed (Fageria and Baligar, 2005).

Appropriate timing of N application and rates are crucial for meeting crop needs and indicate considerable opportunities for improving NUE. According to Hailu et al. (2012) optimum and efficient time of N application can increase the recovery of applied N up to 58-70% and hence increase yield and grain quality of a crop. Growth stage of plants at the time of application determines NUE. In Ethiopia, wheat is grown during the high rain-fall season and losses of applied N through leaching may be decreased through proper rate and timing of N application. Limited research has been done on the effects of time of application in relation to improving grain yield of wheat. Such studies may give a clue for enhancing grain yield of the crop through manipulating timings of N application. Hence, this study was initiated to study the different N time of applications on the yield and yield components of wheat, economic feasibility and NUE.

2. Materials and methods

2.1. Characteristics of experimental sites

The experiment was conducted for 2 years (2015 and 2016 main cropping seasons) at Holeta, West Shoa, in the central highlands of Ethiopia. Wheat is widely grown in this area. The environment is seasonally humid and the soil type was reddish brown Eutric Nitisol (IUSS Working Group WRB, 2006). Holeta is located between 09° 03 ′ N latitude and 38° 3 0 ′ E longitude, 30 km west of Addis Ababa, at an altitude of about 2400 m above sea level. The long- term average annual rainfall is 1100 mm, about 85% of which is received from June to September with the remainder from January to May. The average minimum and maximum air temperatures are 6.2°C and 22.1°C respectively.

Prior to sowing soil samples (0–20 cm depth) were taken from the experimental sites. A total of 25 samples were taken and combined into one composite per site for analysis. Soil samples were analyzed for pH using a ratio of 2.5 ml water to 1 g soil (Peech, 1965); for available P using Bray-II method (Bray and Kurz, 1945); for organic C content using Walkley and Black (1954) method; for total N content using Kjeldahl method (Bremner and Mulvaney, 1982) at the soil and plant analysis laboratory of Holeta Agricultural Research Center.

2.2. Experimental set-up and procedure

The experiment was laid out randomized complete block design with three replications. The timings of N application were adjusted according to Zadoks decimal growth stage for wheat (Zadoks et al., 1974) at the time when moisture is available for nutrient dissolution and absorption. Accordingly, treatments were comprised of eleven different times of N fertilizer application and a negative control T_1 = ½ at sowing + ½ at mid tillering, T_2 = ½ at sowing + ½ at anthesis, T_3 = nil at sowing + ½ mid tillering + ½ at anthesis, T_4 = nil at sowing + full at mid tillering, T_5 = nil at sowing + full at anthesis, T_6 = ½ at sowing + 2/3 at mid tillering, T_7 = 1/3 at sowing + 1/3 mid tillering + 1/3 at anthesis, T_8 = nil at sowing + 1/3 mid tillering + 2/3 at anthesis, T_9 = 2/3 at sowing + 1/3 mid tillering, T_{10} = 2/3 at sowing + 1/3 at anthesis, T_{11} = full at sowing and T_{12} = negative control (No input)). The same rate of N, 60 N kg ha^{-1}, was splitted and used in all cases. Sowing took place at the onset of rainfall, with a recommended seeding rate of 150 kg ha^{-1} at the third week of June. In each plot wheat was sown at inter row spacing of 20 cm by drilling with a depth of at about 2-4cm. Urea was used as the source of N. The recommended phosphorus fertilizer amount (69 kg P ha^{-1}) was uniformly applied as triple super phosphate (TSP) to all plots at sowing. N was applied after weeding and during the presence of light rainfall and moisture to avoid the potential loss of N into the atmosphere. Other agronomic practices were applied based on local research recommendations. Despite some incidence of shoot fly at the initial growth stage of wheat, insecticides were not applied in 2015. Bread wheat variety used was Hidase. The spacing between plots and blocks were 0.5 m and 1 m, respectively. Each plot consisted of 15 rows.

2.3. Growth and yield attributes

Plant parameters collected were grain yield, above-ground total biomass, harvest index, spike length, plant height, number of productive tillers, grain number per spike and 1000 kernels weight. Plant height was measured from the ground level to the tip of the spike excluding the awns at physiological maturity. The numbers of productive tillers per meter square was calculated at physiological maturity in each plot using 0.5 meter by 0.5 meter quadrant at two random places within the plot area and was converted into meter square basis. Spike length was measured from the base to the top of the spike excluding awns from ten randomly selected mother plants (main shoots). Thousand kernel weight was determined as the weight of 1000 seeds sampled from the harvested plot area using a sensitive balance. Grains per spike Number of grains from ten randomly selected spikes from the demarked area was counted using electronic grain counter and their average was taken as number of grains per spike. Aboveground biomass and grain yield was recorded after harvesting the aboveground biomass. The aboveground biomass was sun dried for 10-15 days and their plot weight was recorded and then converted to kg ha^{-1} for statistical analysis. This was followed by threshing, winnowing and recording of grain yield plot wise. Grain yield was determined by taking the grain yield of plants harvested from the whole plot area of 3 m x 3 m at maturity and converted to kg ha^{-1} for statistical analysis and then adjusted to 12.5 % moisture content and using the following formula.

$$Adjusted\ grain\ yield\ (kg/ha) = \frac{Actual\ yield\ (kg/ha)(100 - MC)}{100 - 12.5}$$

Where, MC was the measured grain moisture content; and 12.5 was the standard moisture content for cereals

Harvest index was calculated as the ratio of grain yield to the total aboveground biomass yield. The data were subjected to analysis of variance (ANOVA) using the general linear model procedure of SAS statistical package version 9.3 (SAS Inc., 2013). Means of treatments were separated using the least significant difference (LSD) at 5% level. Economic analysis was performed to investigate the economic feasibility of the time of N applications following the CIMMYT partial budget methodology (CIMMYT, 1988). The average open current market price (Birr 100 kg^{-1}) for wheat and the official prices of N and P fertilizers were used for economic analysis. The prevailing labor cost for sowing, weeding and harvesting for the area in Ethiopian Birr 30 per man day was assumed as total variable cost for the economic analysis. Agronomic NUE was calculated as extra kilogram of grain per extra kilogram of N applied (Hatfield and Prueger, 2004).

3. Result and Discussion

3.1. Weather

The total rainfall amount and precipitation pattern for 2016 was significantly higher compared with long-term average and 2015 (Figure 1). The rainfall amounts recorded for July and September were considerably higher in 2016 than in 2015. When compared with a 30 year average, rainfall in July 2016 was higher by 70 mm but lower by 167 mm in 2015. Rainfall in September 2016 and 2015 was lower by 9 and 69 mm, when compared with a 30 year average, respectively. Which entails average moisture received in 2016 was conducive for wheat growth and development. On the contrary, since rainfall received in 2015 was much lower it was not suitable for growth and development of wheat. Moisture deficiency in July seriously affects tillering while in September and October it critically affects grain filling.

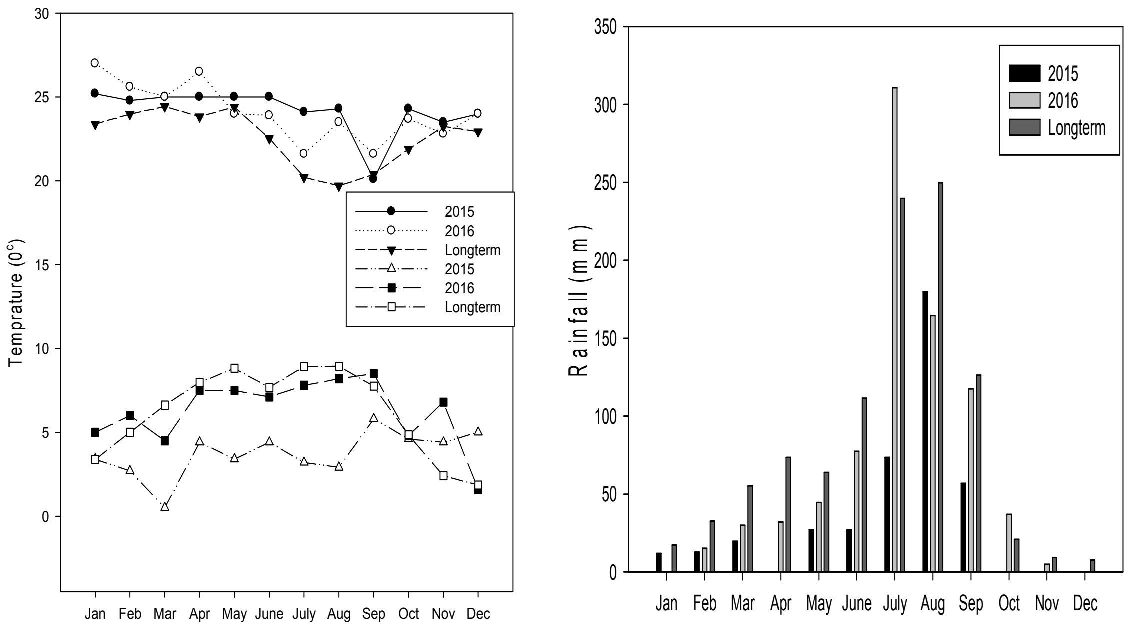

Figure 1. Mean monthly maximum, minimum air temperatures and monthly total rainfall for 2015 and 2016 cropping seasons, and the 30-year average rainfall at Holeta Research Center.

3.2. Physical and chemical properties of the experimental site

Physical and chemical properties of soils critically affect the growth and the development of wheat. The analytical results indicated the textural class of the soil was predominantly clay with strong acidic property

(Table 1).

Table 1: Physical and chemical soil characteristics of the experimental field

Parameter	Value
Clay	56.4
Silt	28.2
Sand	15.4
pH 1:2.5 H_2O	4.88
OC (%)	1.83
Total N	0.18
Available P (Bray II)	5.40

3.3. Yield and yield components of wheat

The responses of grain yield and yield components of wheat to time of N application, year and interaction of year by time of N application of the combined data of over two years are presented in Table 2. Results of ANOVA for two cropping seasons showed that grain yield and yield components of wheat were significantly affected by year and time of N application. ANOVA over two cropping seasons indicated that the year effect was highly significant ($P<0.001$, $P<0.01$and $P<0.05$) for grain yield, above ground biomass yield and yield components of wheat like plant height and number of productive tillers and 1000 kernel weight (Table 2). Year did not significantly affected spike length and number of seeds per spike. The year by time of N application interaction was significant ($P<0.001$ and $P<0.05$) for grain yield, above ground biomass yield and harvest index. The year by time of N application interaction effect was not significant for plant height, spike length, number of productive tiller, number of seeds per spike and 1000 kernel weight (Table 2). The highest mean grain yield (4410 kg ha^{-1}) was obtained in the year 2016 compared to the lowest (2463 kg ha^{-1}) recorded in 2015. The maximum above ground biomass yield, harvest index, plant height, spike length, productive tiller number, number of seeds per spike and 1000 kernel weight recorded in the same cropping season (Table 3 and 4).

Table 2: Effects of year, time of N application and their interaction on yield and yield components of wheat 2015 and 2016

Parameters	**Year (Y)**	**Time of N application (TN)**	**Y x TN**
Grain yield	***	***	***
Above ground Biomass yield	***	***	***
Harvest index	**	***	*
Plant height	***	***	ns
Spike length	ns	ns	ns
Productive tiller number	***	***	ns
Number of seeds per spike	ns	ns	ns
1000 kernel weight	*	*	ns

Notes. Significant at *P<0.05, **P <0.01, *** P <0.001; ns, not significant

Grain yield (kg ha^{-1}): This research work clearly indicated positive effects of time of N application on wheat yield in this part of the country with a significant effect of cropping year. Inconsistency in cropping season's rainfall amount and its distribution has brought about significant differences in yield and yield components. Results have indicated that the amount of seasonal rainfall received and in the growing season greatly impacts the response to time of N application in increasing productivity of wheat (Table 2). In 2015, lower yield and yield components were recorded due to insufficient amount of rainfall in trial sites during the seedling and tillering stages in the month of June and July and grain filling stage in September and October (even there was total absence of rainfall in October) (Figure 1). The amount of precipitation received in June 2015, July 2015, September 2015, October 2015 were one fourth, one third, half and total absence when compared to the precipitation received in 2016, respectively (Figure 1). Wheat yield in 2015 was about 79% lower than in 2016 (Table 2). Drought stress and associated reduction in soil moisture can reduce plant nutrient uptake by reducing nutrient supply through mineralization (Fierer and Schimel, 2002; Agegnehu et al., 2006; Sanaullah et al. , 2012), but also by reducing nutrient diffusion and mass flow in the soil (Lambers et al., 2008). Precipitation and the resulting soil water dynamics strongly regulate N cycling in terrestrial ecosystems (Aranibar et al., 2004).

Moisture stress is known to reduce biomass, tillering ability, grains per spike and grain size at any stage when it occurs. Substantial losses in wheat grain yield have been reported due to water deficiency depending on the developmental stages at which crop plant experiences stress. Crop uptake of nutrients is affected by soil and climatic conditions. One of the constraints is low soil moisture that restrict uptake of plant nutrients. According to (Jones et al., 2011) low nutrient uptake early in a plant's growth lowers nutrient quantity for the seed affecting yield in the contrary. Similar to present findings Kimurto et al. (2003) has reported that water stress at tillering or at booting significantly affected the formation of tillers in wheat. Our results were in line with the findings of Karim et al. (2000) and Baque et al. (2006) who reported that water stress reduced grain yield by reducing productive tillers per plant, fertile spikelet per plant, number of grains per plant and individual grain weight. The grain filling stage is a crucial stage not only for grain formation but also for the N absorption and transport in the plant. Osaki et al. (1991) reported that grain N was partly derived from the N accumulated in the stem and leaves and partly redirected from the root system after flowering. Hence, the changes in crop production related climatic variables will possibly have major influence on regional as well as global food production (Abraha and Savage, 2006). This indicates that N application timing considerations are usually site specific being impacted by the local environmental conditions.

This research work also showed clear effects of N fertilizer application time on yield and yield components of wheat in the central Ethiopian highlands. Results of ANOVA for grain yield was significantly ($p<0.001$) affected by different timings of N application during both the years of research (Table 3). Significantly maximum grain yield was recorded by N application 1/3 at sowing + 2/3 at mid tillering though it did not show significant difference with 1/2 at sowing + 1/2 mid tillering, 1/3 at sowing + 1/3 at mid tillering + 1/3 at anthesis (figure 2). N application time 1/3 at sowing + 2/3 at mid tillering exhibited a grain yield advantage of 13.3%, 7.4% and 22.9% over the recommended N application time (1/2 at sowing + 1/2 at mid tillering), 1/3 at sowing + 1/3 at mid tillering + 1/3 at anthesis and full at sowing, respectively. The grain yield analysis indicated that wheat require more of their N to be applied at mid tillering than at sowing. Applying the entire N at sowing wheat yielded lesser yield than the split applications of 1/3 N at sowing + 2/3 at mid tillering which suggests that applying the entire N for wheat at was not the most efficient. It is evident from data analysis that grain yield increased progressively with split application of N being maximum in treatment receiving larger quantity of N applied at mid tillering than at sowing. It may be due to efficient utilization and arresting volatilization or leaching down of N. Most of the investigations on time of N fertilizer application are geared towards split-applications to synchronize timing of fertilization according to the crop demand and increase grain yield. This finding is in line with the findings of numerous authors (Tanner et al., 1992; Ramos, 1995; Gelato *et al.*, 2008; Mohammad et al., 2011;) who reported higher grain yields due to one third and two third split applications of N at sowing and mid tillering, respectively, relative to applications of urea all at sowing and mid tillering crop stage, especially when rainfall is heavy and continuous during the growing season. This N application timing might have enhanced uptake of N during these stage and there by increased crop performance and ultimately grain yield.

Table 3: Table of means for effect of time of N fertilizer application on yield and yield of components wheat in 2015 and 2016

Factor	Grain yield (kg ha^{-1})	Above ground Biomass yield (kg ha^{-1})	Harvest index (%)	Plant height (cm)
Year				
2015	2463	6412	35.6	76.7
2016	4410	12324	38.0	88.4a
LSD (0.05)	175	422	1.5	2.2
Time of N application				
T1=1/2 at sowing + 1/2 mid tillering	3803	9468	40.2	86.5
T2=1/2 at sowing + 1/2 at flower initiation	3045	8046	38.4	80.5
T3=nil at sowing, 1/2 at mid tillering + 1/2 at anthesis	2870	9132	32.6	81.0
T4=nil at sowing + full at mid tillering	3574	8958	40.0	83.3
T5=Nil at sowing + full at anthesis	2892	8472	35.2	79.2
T6=1/3 at sowing + 2/3 at mid tillering	4313	10792	41.1	86.9
T7=1/3 at sowing + 1/3 at mid tillering + 1/3 at anthesis	4014	10406	39.5	84.0
T8=Nil at sowing + 1/3 at mid tillering + 2/3 at anthesis	3017	8222	36.0	80.6
T9=2/3 at sowing + 1/3 at mid tillering	3357	9336	36.7	85.2
T10=2/3 at sowing + 1/3 at anthesis	3512	9090	37.3	84.4
T11=full at sowing	3510	9250	37.7	84.8
T12=Negative Control (No input)	1863	6125	30.7	74.5
LSD (0.05)	668	1541	4.5	5.0
CV (%)	17.4	14.9	9.3	5.0

According to Mercedes *et al.* (1993) split application N better matched the crop N needs during growing period and thus has increased the crop yield. Further splitting the same N dose by means of a late N application at anthesis did not increase grain yield of wheat. This finding is slightly varied from that of Hailu et al. (2012) who recommended that 25%, 25% and 50% should be applied at sowing, mid tillering and at anthesis, respectively to get higher yield in other part of the country. Therefore, it is reasonable to conclude that there should be location specific split N fertilizer application timing. According to Johnston and Bruulsema (2014) timing considerations are usually site specific being impacted by the local environmental conditions and management practice. Ayup et al. (2001) also reported that the highest wheat yield can be obtained by applying N in three equal parts. It is concluded that site specific split N fertilizer application time recommendations should be developed for different wheat growing areas of the country. The present N split-application recommendation could be used for wheat growing areas which have growing conditions similar to West Shoa, western Ethiopia.

Aboveground biomass yield (kg ha^{-1}): Aboveground biomass yield is an important factor because farmers are also interested in straw in addition to grain yield. The data regarding aboveground biomass yield under different timings of N application are given in (Table 3). It is evident from the ANOVA data that aboveground biomass yield was significantly (P<0.001) influenced by time of split N applications (Table 4). Significantly highest aboveground biomass yield (10792 kg ha^{-1}) was obtained when plants were supplied with N 1/3 at sowing + 2/3 at mid tillering (figure 2). This is however, showed statistical similarity with the applications of N with applications of 1/2 at sowing + 1/2 mid tillering, 1/3 at sowing + 1/3 at mid tillering +1/3 at anthesis, and 2/3 at sowing + 1/3 at mid tillering. The possible reason for increased aboveground dry biomass yield in these treatments were might be due to the cumulative effect of higher plant height, number of total productive tillers and grain yield (Table 3 and 4). This in turn might be may be due to adequate availability of nutrient which triggered physiological growth processes and produced more yield.

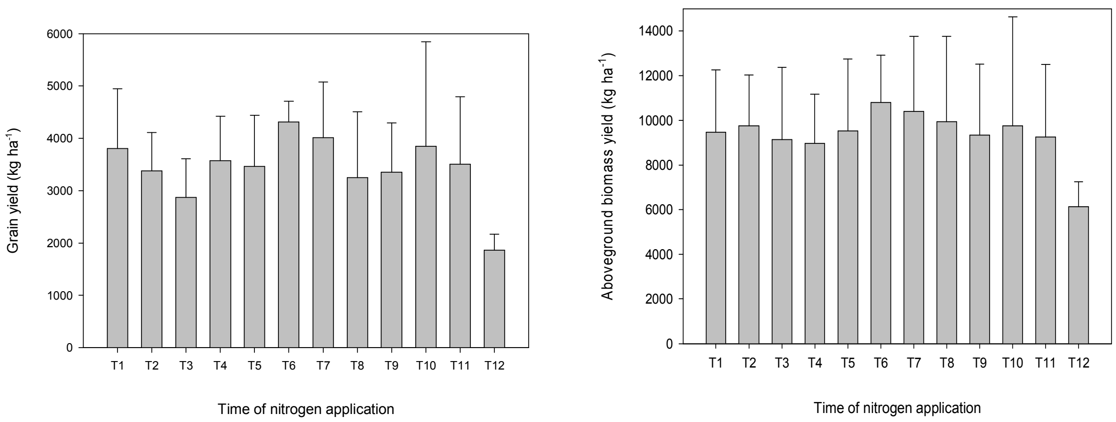

Figure 2: The effect of time of N application on grain and above ground biomass yield on bread wheat. Error bars with standard error.

Harvest index: Statistical ANOVA revealed that effect of time of split N applications on harvest index (The ratio of the economic yield to the biological yield) was highly significant (P < 0.001) (Table 3). Significantly greater harvest index was obtained with the application of 1/3 at sowing + 2/3 at mid tillering though it was statistically at parity with split time of N applications of 1/2 at sowing + 1/2 mid tillering, 1/2 at sowing + 1/2 at flower initiation, nil at sowing +full at mid tillering, 1/3 at sowing + 1/3 at mid tillering + 1/3 at anthesis, 2/3 at sowing + 1/3 at anthesis and full at sowing (Table 3). Dividing the N fertilizer into two applications resulted in a harvest index greater than treatments involving one or three applications.

Table 4: Table of means for effect of time of N fertilizer application on yield and yield components of wheat in 2015 and 2016

Factor / Year	Spike length (cm)	Productive tiller number (m^2)	Number of seeds per spike	1000 kernel weight (gm)
2015	6.1	177.1	51.8	39.0
2016	6.3	199.6	52.3	43.8
LSD (0.05)	Ns	6.8	ns	3.8
Time of N application				
T1=1/2 at sowing + 1/2 mid tillering	6.5	208.3	55	46.6
T2=1/2 at sowing + 1/2 at flower initiation	6.4	202.0	54	41.3
T3=nil at sowing, 1/2 at mid tillering + 1/2 at anthesis	6.4	200.0	47	38.4
T4=nil at sowing + full at mid tillering	5.9	196.7	53	39.7
T5=Nil at sowing + full at anthesis	5.7	182.0	53	41.
T6=1/3 at sowing + 2/3 at mid tillering	6.7	237.3	59	50.3
T7=1/3 at sowing + 1/3 at mid tillering + 1/3 at anthesis	6.6	230.0	57	47.0
T8=Nil at sowing + 1/3 at mid tillering + 2/3 at anthesis	5.9	186.7	48	39.7
T9=2/3 at sowing + 1/3 at mid tillering	6.6	198.0	56	41.0
T10=2/3 at sowing + 1/3 at anthesis	6.3	188.3	50	41.6
T11=full at sowing	5.9	205.3	48	39.3
T12=Negative Control (No input)	5.6	160.7	45	31.2
LSD (0.05)	0.84	26.9	ns	9.2
CV (%)	11.7	7.9	14.6	19.2

Plant height (cm): Results of ANOVA for plant height measured at physiological maturity indicated that plant height was significantly ($p<0.001$) affected by timing of N fertilizer application (Table 3) . Plants receiving split N applications in to 1/3 splits at sowing and 2/3 split at tillering stages (86.9 cm) were taller than those receiving N into two or more splits at other crop growth stages used in the study. However, it was statistically similar with the time of split N applications 1/2 at sowing + 1/2 mid tillering, 1/3 at sowing + 1/3 at mid tillering + 1/3 at anthesis, nil at sowing and full at mid tillering, 1/3 at sowing + 2/3 at mid tillering and 2/3 at sowing + 1/3 at anthesis. Ali *et al.* (2005) found that most of the bread wheat growth parameters like plant height were significantly affected by N application timings. Abdul *et al.* (2005) realized that plant height was reactive toward N applications. According to Ramu (2008) early applications of N fertilizer favored plant height and this was seen two equal splits resulted in taller plant than three splits. Similarly, Zewde *et al.* (1992) reported that early applications of N, either all at sowing or split applied increased plant height, while late applications resulted in shorter plant height. The enhancement in height in response to N applications was probably due to increased N availability at early stage. Plots in which split N applications was extended up to anthesis stage had relatively shorter height than the others. This indicated that applying N at very late stage contributed little increment in height. The shortest (81.67 cm) plants were obtained from plots provided with Nil at sowing + full at anthesis and control. The height difference between the tallest plants (86.9 cm) and with shortest height plants (74.5 cm) was 12.4 cm. This difference was lead to the evidence that magnitude of N fertilizer is indispensable in the early period of growth to get maximum plant height at harvesting time than later time of applications.

Spike length (cm): Spike length is one of the growth parameters of wheat that contributes to grain yield. Crops with higher spike length could have higher grain yield. Spike length recorded at physiological maturity was significantly ($P<0.05$) affected by the effects of timing of the N fertilizer application (Table 4). Significantly longest spike length (6.7 cm) was recorded in response to time split application of 1/3 splits at sowing + 2/3 split at tillering stages though this treatment was statically at par with most of the treatments except treatments of N application of Nil at sowing + full at anthesis and control. The lowest spike length of (5.6 cm) was obtained from the unfertilized negative control followed by N application Nil at sowing + full at anthesis (5.7 cm). The enhancement of spike length development of wheat receiving split applications might have been due to synchronization of N supply and demand which resulted in high uptake of N, resulting in cells expansion, enlargement and over and above the grain filling. Several reports indicated application of fertilizer has positive effect on spike length (Geleto et al., 1995; Haile et al.; 2012; Leta, 2013; Fana et al., 2012).

Number of productive tillers (m^2): Number of tillers per unit area is the most important component of yield. Results of ANOVA revealed that there was a significant ($p<0.001$) effect on the number of productive tillers at physiological maturity in response to time of N applications (Table 4). Significantly higher numbers of productive tillers (237) were recorded when N was applied in two splits, i.e. 1/3 at sowing + 2/3 mid tillering. However, it showed in statistically at par with treatments of time of N application 1/3 at sowing + 1/3 at mid tillering + 1/3 at anthesis. Minimum number of productive tillers (161) was noted in control treatment. Time of

N application is critical management decision, because it influences wheat tillering (Borghi *et al.,* 1995). The reason of increased number of productive tillers in plots receiving split application of N may be due to sufficient availability of N during tillering stage. This might be due to the effect of N split application in promoting and flourishing green vegetative growth and productive tiller. In the present study, the greater number of tillers production in fertilized plots can be attributed to the adequate N availability (Malhi *et al.,* 2006) which resulted in increased photosynthetic activities (Habtegebrial *et al.,* 2007), resulting in vigorous growth due to its immediate availability to the plant roots (Mohamed et al., 2012) ultimately increased the productive tillers. According to Lemma et al. (1992) early N applications is relevant for better productive tillers development and density. No other element has such an effect on promoting vigorous plant growth contributing to high above ground biomass yield. On the contrary, plots with nil N or received all the N at sowing resulted in less number of productive tillers due to less availability of the nutrient. Bulk N application at sowing may have resulted in leaching or volatilization of the nutrient that subsequently resulted in significantly lower number of productive tillers. Njuguna et al., (2010) concluded that N application increased the number of fertile tillers (m^2) and grain yield. Abedi et al., (2011) showed that nil N application decreased the number of productive tillers (m^2).

Number of seeds per spike: The potential of wheat spike is determined by the seeds per spike which is an important yield component of grain yield. Even though ANOVA showed that time of N applications did not show significant ($p>0.05$) effect on number of seeds per spike, application of N 1/3 at sowing + 2/3 at mid tillering gave maximum (59) number of seeds per spike (Table 4). In this respect, the split N application produced greater mean number of seeds per spike compared with the control and N application 1/2 at sowing + 1/2 mid tillering (Table 4). Minimum (45) number of grains per spike was recorded by control plots followed by treatment of nil at sowing, 1/2 at mid tillering + 1/2 at anthesis (47). Increased number of seeds per spike due fertilization can be attributed to improved crop performance in fertilized plots (Ayoub et al., 1994), or higher nutrient availability (Gurdip *et al*., 2001) as compared to control. Martre et al., (2003) also reported decreased grain numbers under N deficiency condition.

1000 kernel weight (gm): Results of ANOVA revealed that time of split N applications showed significant ($p<0.05$) effect on 1000 kernel weight (Table 4). Significantly higher 1000 kernel weight (50.3 gm) was obtained by plants nourished with N 1/3 at sowing + 2/3 at mid tillering. However, it is statistically similar with 1/2 at sowing + 1/2 mid tillering, 1/2 at sowing + 1/2 at flower initiation, 1/3 at sowing + 1/3 at mid tillering + 1/3 at anthesis and 2/3 at sowing + 1/3 at anthesis. Compared with the recommended N application time 1/2 at sowing + 1/2 mid tillering, three times N applications 1/3 at sowing + 1/3 at mid tillering + 1/3 at anthesis and full at sowing, the two-time 1/3 split N application at sowing and 2/3 mid-tillering resulted in 7.9% and 27.9% higher 1000-kernels weight, respectively (Table 4). According to Campbell et al. (1993) the response of grain weight to time of N applications was environment specific because it depend on conditions that existed during grain filling as well as during earlier development stages of the crop. It could be concluded that grain filling was faster as a result of two separate N applications compared to a single or three N applications.

Economic analysis: N split-application was also observed to be economically advantageous. The economic analysis revealed that N fertilizer application 1/3 at sowing + 2/3 at mid tillering was the appropriate time of N application due to the fact that it gave the highest net economic benefit (Table 5). N application of 1/3 at sowing + 2/3 at mid tillering gave a 23%, 7% and 22% monitory advantage in Ethiopian Birr over the recommended N application of 1/2 at sowing + ½ at mid tillering, 1/3 at sowing + 1/3 at mid tillering + 1/3 at anthesis and full at sowing, respectively. Application of 1/3 N at sowing + 2/3 at mid tillering was more economically beneficial than other-split-applications.

Nitrogen Use Efficiency: Nitrogen Use Efficiency expressed as grain production per unit of N applied, indicated that wheat had the highest NUE when the N was applied in split of 1/3 at sowing + 2/3 at mid tillering (Table 6). N fertilizer applications that exceed crop N requirements lead to environmental pollution including nitrate N leaching and N gaseous emissions. As a result, it is so essential to determine the plant response to N fertilization and its real N demand to develop rational practices for more NUE improving N application timing that may lead to achieve the highest yield with decline in environmental hazards. Several research reports noted the significance of split applications of N (one third at sowing and the two third at a later stage) in terms of apparent N recovery and other N use efficiency measures (Ortiz-Monasterio et al., 1997; Taa et al., 1999). Splitted N applications might have decreased the loss of N applied at due to denitrification, leaching and runoff and improved the agronomic NUE. Similar to this finding, numerous reports indicate increase in NUE with split N applications since leaching is one of the main challenges for N loss in especially in high rainfall areas (Chikowo, et al., 2004; Fageria and Baligar, 2005; Lopez-Bellido, 2006; Ali, 2010).

Table 5: Economic analysis for split application N fertilizer application

No.	Treatments	Grain Yield (kg ha^{-1})	Total variable cost	Gross profit	Net benefit
T1	1/2 at sowing + 1/2 mid tillering	3803	4000	30424	26424
T2	1/2 at sowing + 1/2 at flower initiation	3045	4000	24430	20430
T3	nil at sowing, 1/2 at mid tillering + 1/2 at anthesis	2870	4000	22960	18960
T4	nil at sowing + full at mid tillering	3574	3700	28592	24892
T5	Nil at sowing + full at anthesis	2892	3700	23136	19436
T6	1/3 at sowing + 2/3 at mid tillering	4313	4000	34504	30504
T7	1/3 at sowing + 1/3 at mid tillering + 1/3 at anthesis	4014	3700	32112	28412
T8	Nil at sowing + 1/3 at mid tillering + 2/3 at anthesis	3017	4000	24136	20136
T9	2/3 at sowing + 1/3 at mid tillering	3357	4000	26856	22856
T10	2/3 at sowing + 1/3 at anthesis	3512	4000	28096	24096
T11	full at sowing	3510	3700	28080	24380

Table 6: Agronomic N Use Efficiency wheat as affected by split N fertilizer applications

Treatments	Agronomic Nitrogen Use Efficiency
1/2 at sowing + 1/2 mid tillering	55.1
1/2 at sowing + 1/2 at flower initiation	44.1
nil at sowing, 1/2 at mid tillering + 1/2 at anthesis	41.6
nil at sowing + full at mid tillering	51.8
Nil at sowing + full at anthesis	41.9
1/3 at sowing + 2/3 at mid tillering	62.5
1/3 at sowing + 1/3 at mid tillering + 1/3 at anthesis	58.2
Nil at sowing + 1/3 at mid tillering + 2/3 at anthesis	43.7
2/3 at sowing + 1/3 at mid tillering	48.7
2/3 at sowing + 1/3 at anthesis	50.9
full at sowing	50.9

3.4. Conclusion

Timing of nitrogen fertilizer has significant effect on the yield and yield component wheat. According to our study, two split applications of the full N rate was the most effective method of supplying N to a wheat crop due to its positive effect on yield increment. Timing of nitrogen fertilizer one third at sowing plus two third at mid tillering gave the highest number of Harvest index, plant height, spike length, number of productive tillers, number seeds per spike and thousand kernel weight compared with other nitrogen timing. Application of nitrogen fertilizer one third at sowing plus two third at mid tillering gave the highest grain yield. Proper nitrogen management is important for rainfed agriculture. In rainfed wheat growing areas of West Shoa, and similar ecologies in western Ethiopia , farmers can apply uniform rates of N, with approximately 30% at sowing and 70% at the time of active tillering taking into consideration the spatial variability of soil moisture or rainfall distribution. Further investigations should be to know the climatic effect.

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