Productivity, Nitrogen Use Efficiency and Economic Benefits of Food Barley (Hordium vulgare L.) as Influenced by Stages of Nitrogen Split-Application in Central Highlands of Ethiopia

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Abstract
This experiment was initiated to evaluate the appropriate nitrogen fertilizer split application timing for food barley using for HB-1307 food barley variety. This experiment was done at Holeta Agricultural Research center, West Shoa, Ethiopia. The split nitrogen application times were ½ at planting + ½ at mid tillering, ½   at planting + ½ at anthesis, nil at planting + ½ mid tillering + ½ at anthesis, nil at planting + full at mid tillering, nil at planting + full at anthesis, ½ at planting + 2/3 at mid tillering, 1/3 at planting + 1/3 mid tillering + 1/3 at anthesis, nil at planting + 1/3 mid tillering + 2/3 at anthesis, 2/3 at planting + 1/3 mid tillering, 2/3 at planting + 1/3 at anthesis, full at planting and negative control. The experiment was laid out randomized complete block design with three replications. Timing of split nitrogen fertilizer applications has significant effect on the yield and yield component barley. 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 10.7 % 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: nitrogen fertilizer, split application timing, Nitisols, food barley
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1. Introduction

Barley one of the most important food crops predominantly grown from 1500 to 3500 m above sea level in Ethiopia (Lakew et al., 1996). It is the major food source in many North African countries. It is the staple food crops in Ethiopia. Barley assumes fourth position in total cereal production in the world after wheat, rice, and maize. In Ethiopia, It ranks fourth after tef, maize, and sorghum in terms of cereal area production. It covers an area of about 951, 993 ha, but its national average yield is still low at 2.1 ton ha^{-1} (CSA, 2018). Barley serves as a major animal fodder, base malt for beer and certain other distilled beverages.

Nitrogen (N) is the most important crop-yield limiting factor in the world, together with water (Mueller et al., 2012). Adoption of good N management strategies often result in large economic benefits to farmers. Among the plant nutrients, N plays a very important role in crop productivity (Amanullah et al., 2008a). N is frequently the most used and also the most costly mineral nutrient required for cereal production (Clark, 1990). Barley is very sensitive to insufficient N and very responsive to N fertilization. N is the key element in achieving consistently high yields in cereals. N is a constituent of many fundamental cell components such as nucleic acids, amino acids, enzymes, and photosynthetic pigments. Since N is a constituent of chlorophyll as well as the CO_2 fixing enzyme Rubisco (also called the photosynthesis machinery), N content is indirectly a determinant of the rate of photosynthesis , dry matter accumulation, and economic yield (Evans 1983). The rate of uptake and partition of N is largely determined by supply and demand during various stages of plant growth. Soil N supply, must be high at tillering, stem elongation, booting, heading and grain filling requiring a greater amount of the development and growth of its reproductive organs. However, it has been estimated that 50%–70% of the N provided to the soil is lost due to volatilization, runoff, denitrification and leaching (Hodge et al., 2000).

Excessive N causes excessive vegetative growth, resulting in greatly increased danger of lodging, delayed maturity and greater susceptibility to diseases and pests. N application at proper dose has the most important effect in terms of increasing crop production. N is a key factor in achieving an optimum yield in cereals and in their growing period requires lot amount of absorbed N. Proper dose of N increased leaf area, tillers formation, leaf area index and leaf area duration and this increase led to much greater production of dry matter and grain yield. In order to obtain greatest advantage from the fertilizer use the fertilizer should not only be applied in optimum quantity at recommended rate but also at right time as timely N application is one of the agronomic technique which has helped considerably in increasing the N use efficiency (NUE). It is now very well established that for most crops N must be applied in two or three split doses coinciding with the crop growth stages when its requirement is high therefore, it is high time to assess the effect of time of application of the recommended N fertilizer to increase the fertilizer use efficiency in food barley.

It is very important and crucial in crop production to nutrient supply is synchronized with plant demand in

time and space throughout the growing season 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 fertilizer is very expensive driven mainly by increases in the price of natural gas. Hence, splitting N fertilizer application in order to follow the N requirements by the crop throughout the growing season is probably the best strategy to achieve high grain yields. 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). Appropriate timing of N application and rates are crucial for meeting crop needs and indicate considerable opportunities for improving NUE. Limited research has been done on the effects of time of application in relation to improving grain yield of food barely. Hence, this study was initiated to study the different N time of applications on the yield and yield components of food barley, economic feasibility and agronomic N use efficiency.

2. Materials and methods

The experiment was conducted for 2 years (2015 and 2016 main cropping seasons) at Holeta Welmera wereda, West Shoa, on farmers field in the central highlands of Ethiopia 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.

2.1. 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 barley (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 planting + ½ at mid tillering, T_2 = ½   at planting + ½ at anthesis, T_3 = nil at planting + ½ mid tillering + ½ at anthesis, T_4 =nil at planting + full at mid tillering, T_5 = nil at planting + full at anthesis, T_6 = ½   at planting + 2/3 at mid tillering, T_7 =1/3 at planting + 1/3 mid tillering + 1/3 at anthesis, T_8 = nil at planting + 1/3 mid tillering + 2/3 at anthesis, T_9 = 2/3 at planting + 1/3 mid tillering, T_{10} =2/3 at planting + 1/3 at anthesis, T_{11} =full at planting and T_{12} = negative control (without input)). The same rate of N, 60 N kg ha^{-1}, was splitted and used in all cases. Urea was used as the source of N. Phosphorus at the rate of 69 kg ha^{-1} was applied to all plots at the time of sowing.

Sowing took place at the onset of rainfall, with a seeding rate of 125 kg ha^{-1} in early June. In each plot barley was sown at inter row spacing of 20 cm by drilling with a depth of at about 2-4cm. The recommended phosphorus fertilizer amount (69 kg P ha^{-1}) was uniformly applied as triple super phosphate (TSP) to all plots at planting. N was applied after weeding in the presence of moisture to avoid the potential loss of N into the atmosphere. Other agronomic practices were applied based on research recommendations. The data were subjected to analysis of variance 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. To assess the costs and benefits associated with different treatments the partial budget technique as described by CIMMYT (1988) was applied on the yield results. Economic analysis was done using the prevailing market prices for inputs during the period of the experiment applied at planting, tillering, anthesis and also for outputs at the time the crop was harvested. The economic analysis also considered components of the labor cost for land preparation, planting, weeding and harvesting. All costs and benefits were calculated on hectare basis in Ethiopian Birr (Birr ha^{-1}). 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 better compared with long-term average and 2015 (Figure 1). The rainfall amounts recorded for July and September were noticeably higher in 2016 than in 2015. When compared with a 30 year average, rainfall in July 2016 was elevated by 70 mm but lesser by 167 mm in 2015. Rainfall in September 2016 and 2015 was lesser by 9 and 69 mm, when compared with a 30 year average, respectively. Average moisture received in 2016 created conducive environment for food barley growth and development. On the contrary, since rainfall received in 2015 was much lower it was not suitable for growth and development of barley. Moisture deficiency in July seriously affects tillering while in September and October it critically affects grain filling.
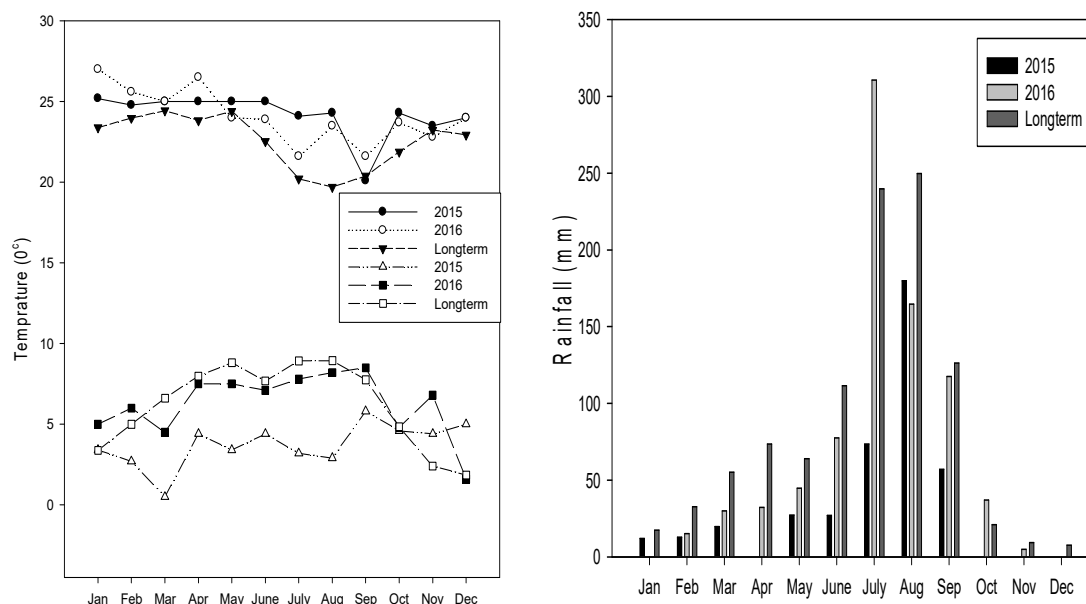
Figure 1. Mean monthly maximum, minimum air temperatures and monthly total rainfall for 2015 and 2016 cropping seasons, and the 30-year average rainfall at Holeta Research Center.

3.2. Physical and chemical properties of the experimental site

Physical and chemical properties of soils critically affect the growth and the development of food barley. 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	57.1
Silt	27.2
Sand	15.7
pH 1:2.5 H_2O	5.21
OC (%)	1.87
Total N	0.20
Available P (Bray II)	5.50

3.3. Yield and yield components of food barley

The responses of the grain yield, above ground biomass yield, spike length and harvest index to time of N split fertilization combined data are demonstrated in Table 2. There were significant (P<0.05) differences between years in the parameters of grain yield, above ground biomass yield and spike length. Grain yield, biomass yield and spike size was better in the second year (2016). Time of N application had a significant (P<0.01) effect on grain yield, biomass yield and spike length and harvest index. Significantly higher grain and biomass yield was obtained by 1/3 at planting + 2/3 at mid tillering though it did not show significant difference with 1/2 at planting + 1/2 mid tillering.

N split application time 1/3 at planting + 2/3 at mid tillering gave 10.7% a grain yield advantage over the recommended N application time (1/2 at planting + 1/2 at mid tillering) which revealed that food barley require most of their N to be applied at mid tillering than at planting. Applying all the recommended N at planting brought about lesser yield than the split applications of 1/3 N at planting + 2/3 at mid tillering which suggests that applying the entire N for food barley was not the most efficient. Grain yield increased with split application of N being maximum in treatment receiving larger quantity of N applied at mid tillering than at planting. Increased grain yields due to split N application at appropriate growth stage of food barley could be attributed to increased biomass production and improved harvest index with split N fertilization at appropriate growth stage of barley. The higher grain yield under this treatment is as the result of growth and development through efficient assimilation and utilization of available nitrogen by the growing plants during the entire growth period.

The lowest yield were recorded under the T12 treatment, where nitrogen was not applied and followed by application of N full at the time of anthesis which was possibly due to reduced translocation of carbohydrates from source leaves and stem to sink.

Significantly higher above ground biomass yield was obtained by 1/3 at planting + 2/3 at mid tillering though it did not show significant difference with application of N 2/3 at planting + 1/3 mid tillering and full at planting. Significantly higher spike length was obtained by 1/3 at planting + 2/3 at mid tillering though it did not show significant difference with application of 1/2 at planting + 1/2 mid tillering which might resulted in higher grain yield of this treatment. Shortest length of spike was observed in T12 treatment where nitrogen was not applied.

Analysis of variance also 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 2). Significantly greater harvest index was obtained with the application of 1/3 at sowing + 2/3 at mid tillering though there was no significant statistical difference with split time of N applications of 1/2 at planting + 1/2 mid tillering, 1/2 at planting + 1/2 at flower initiation, nil at planting 1/2 at mid tillering + 1/2 at anthesis, nil at planting + full at mid tillering, Nil at planting + 1/3 at mid tillering + 2/3 at anthesis and 2/3 at planting + 1/3 at anthesis as shown in Table 2.

Table 2: Effect of time of N fertilizer application on yield and yield components of food barley

Factor Year	Grain Yield (kg ha^{-1})	Biomass yield (kg ha^{-1})	Spike length (cm)	Harvest index (%)
2015	2761b	7365b	5.8b	37.3
2016	2907a	8239a	6.2a	35.5
LSD$_{0.05}$	196.2	470.6	0.18	ns
Time of N application				
T1=1/2 at planting + 1/2 mid tillering	3623ab	8946a	6.5ab	40.5ab
T2=1/2 at planting + 1/2 at flower initiation	2723dc	7208cd	5.9cd	39.6abc
T3=nil at planting 1/2 at mid tillering + 1/2 at anthesis	2681d	7625bc	5.9cd	37.5abc
T4=nil at planting + full at mid tillering	2967dc	8193abc	5.9cd	36.8abc
T5=Nil at planting + full at anthesis	2001e	6402d	5.7d	31.9dc
T6=1/3 at planting + 2/3 at mid tillering	3984a	9228a	6.8a	43.5a
T7=1/3 at planting + 1/3 at mid tillering + 1/3 at anthesis	3189bc	8657ab	6.2bc	36.9abc
T8=Nil at planting + 1/3 at mid tillering + 2/3 at anthesis	2998cd	7630bc	6.2bc	40.0ab
T9=2/3 at planting + 1/3 at mid tillering	3002cd	8875a	6cd	34.4bc
T10=2/3 at planting + 1/3 at anthesis	2696d	7361cd	6cd	36.7abc
T11=full at planting	3034dc	8972a	6.2cd	34.2bc
T12=Negative Control (No input)	1113f	4528e	4.5e	25.0d
LSD$_{0.05}$	480	1153	0.43	8.0
Significance level	***	***	***	**
CV (%)	14.6	12.7	6.2	18.7

, * Significant at P < 0. 01 and P < 0. 001; ns =not significant

Economic advantage was also obtained by time of N split-applications. The economic analysis showed that split 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 2). Time of N split application of 1/3 at sowing + 2/3 at mid tillering gave a 10% and 29% monitory advantage in Ethiopian Birr over the recommended N application of 1/2 at sowing + ½ at mid tillering and 1/3 at sowing + 1/3 at mid tillering + 1/3 at anthesis, respectively. Application of 1/3 N at sowing + 2/3 at mid tillering was more economically beneficial than other-split-applications. N Use Efficiency (NUE) expressed as grain production per unit of N applied, indicated that food barley had the highest NUE when the N was applied in split of 1/3 at sowing + 2/3 at mid tillering (Table 3).

Table 2: Economic analysis for split application N fertilizer on food barley

No.	Treatments	Grain Yield (kg ha⁻¹)	Total variable cost	Gross profit	Net benefit
T1	1/2 at sowing + 1/2 mid tillering	3623	4000	28984	24984
T2	1/2 at sowing + 1/2 at flower initiation	2723	4000	21784	17784
T3	nil at sowing, 1/2 at mid tillering + 1/2 at anthesis	2681	3700	21448	17748
T4	nil at sowing + full at mid tillering	2967	3700	23736	20036
T5	Nil at sowing + full at anthesis	2001	3700	16008	12308
T6	1/3 at sowing + 2/3 at mid tillering	3984	4300	31872	27572
T7	1/3 at sowing + 1/3 at mid tillering + 1/3 at anthesis	3189	4300	25512	21212
T8	Nil at sowing + 1/3 at mid tillering + 2/3 at anthesis	2998	4000	23984	19984
T9	2/3 at sowing + 1/3 at mid tillering	3002	4000	24016	20016
T10	2/3 at sowing + 1/3 at anthesis	2696	4000	21568	17568
T11	full at sowing	3034	4000	24272	20272

Table 3: Agronomic N Use Efficiency food barley as affected by split N fertilizer applications

No.	Treatments	Agronomic N Use Efficiency
T1	1/2 at sowing + 1/2 mid tillering	36.4
T2	1/2 at sowing + 1/2 at flower initiation	23.3
T3	nil at sowing, 1/2 at mid tillering + 1/2 at anthesis	22.7
T4	nil at sowing + full at mid tillering	26.9
T5	Nil at sowing + full at anthesis	12.9
T6	1/3 at sowing + 2/3 at mid tillering	41.6
T7	1/3 at sowing + 1/3 at mid tillering + 1/3 at anthesis	30.1
T8	Nil at sowing + 1/3 at mid tillering + 2/3 at anthesis	27.3
T9	2/3 at sowing + 1/3 at mid tillering	27.4
T10	2/3 at sowing + 1/3 at anthesis	22.9
T11	full at sowing	27.8

3.4. Conclusion and recommendations

Food barley growth yield and yield components were significantly affected by time split N fertilizer application. From the present study it is evident that time of split N applications generally improved grain yield of food barley. Time of split N fertilizer application 1/3 at sowing and mid tillering stage brought about the higher of spike length, grain yield, and aboveground biomass yield and harvest index when compared with other split N time applications. Application of N fertilizer 1/3 at sowing plus 2/3 at mid tillering gave the highest grain yield of food barley. Further investigations should be done to know the climatic effect.

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