Research Article

Effects of Nitrogen Fertilizer Quantity and Time of Application on Sorghum (*Sorghum bicolor* (L.) Moench) Production in Lowland Areas of North Shewa, Ethiopia

Degu Temeche ⑩**, Elias Getachew, and Gtachew Hailu**

Amhara Regional Agricultural Research Institute, Debre Birhane Agricultural Research Center, P.O. Box 112, Debre Birhane, Ethiopia

Correspondence should be addressed to Degu Temeche; temeche12@gmail.com

Academic Editor: Vera Popovic

This research was conducted to assess the effect of rates and time of nitrogen fertilizer application on yield and yield components of sorghum in lowland areas of North Shewa. The treatments contained three rates of nitrogen (N) (46, 92, and 138 kg·ha^{-1}) and three times of N application (1/2 dose at sowing and 1/2 dose at tillering (timing one); 1/3 dose at sowing and 2/3 dose at tillering (timing two); and 1/3 dose at sowing, 1/3 dose at early tillering, and 1/3 dose at tillering (timing three) including one control. Days to 50% maturity, plant height, head length, head weight, and grain yield were significantly affected by treatment effect, while days to emergency, days to heading, and thousand kernel weight showed nonsignificant effect. The maximum grain yield was 5.060, 5.169, 5.836, and 5.555 t·ha^{-1} from T2, T5, T8, and T10, respectively, and statistically similar yield was recorded at combination of different rates in two split applications (1/2 dose at sowing and 1/2 dose at tillering). By considering the economic status of the farmers, the applications of 46 kg·N·ha^{-1} in two split doses (1/2 dose at sowing and 1/2 dose at tillering stage) gave 87,122 Birr·ha^{-1} with a MRR of 475.61%, which gave best economic benefit. Therefore, it can be concluded that use of 46 kg·N·ha^{-1} in two split applications (1/2 dose at sowing and 1/2 dose at tillering stage) can be recommended for farmers for production of sorghum in the study area and other areas with similar agroecological conditions.

1. Introduction

Sorghum (*Sorghum bicolor* (L.) Moench) is an important cereal crop belonging to the grass family Poaceae [1]. Sorghum is the world's fifth major cereal in terms of production and acreage. It covers an area harvested 18, 28182 ha yield with the production of 52, 65,580 tones [2]. Sorghum is among the most important grain crops in the world including Ethiopia. Because of its multiple purposes and its ability to cope up with unfavorable growing conditions, sorghum will continue to feed the world's increasing populations. Moreover, it will be the crop of the future due to the changing global climatic trends and increase in use of marginal lands for agriculture [3]. Sorghum is widely grown in the high lands, low lands, and semiarid regions of Ethiopia, especially in moisture stressed parts where other crops can least survive [4].

Sorghum is one of the most important cereal crops cultivated in Ethiopia. It is the third important cereal crop next to teff and maize. It is an economically, socially, and culturally important crop grown over a wide range of ecological habitats in the country, in the range of 400–3000 m.a.sl [5]. Sorghum is the single most important cereal in the lowland areas because of its drought tolerance [6].

In Ethiopia, during 2019/20 cropping season, 1,828,182.49 hectares of land area was covered by sorghum with the average yield productivity of 2.88 tone ha^{-1} [7]. It is known for its versatility and diversity and is produced over a wide range of agroecological zones. In Amhara region, sorghum was produced on 641,613.53 hectares of land with an average yield productivity of 2.83 tone ha^{-1}, and in North Shewa Zone of Amhara, sorghum was produced on 133,521.03 hectares of land in the year 2019/20 cropping season with an average yield of 3.01 tons ha^{-1} [7]. In the

study zone, the average yield of sorghum is above the national yield average, but as compared to other countries, the productivity is low. The low productivity of sorghum in developing countries including Ethiopia can be attributed to many biotic and abiotic factors, such as erratic rainfall, disease and pest, and low soil fertility. Low soil moisture or drought can reduce nutrient uptake by roots and induce nutrient shortage by decreasing the diffusion rate of nutrients from soil to root, creating restricted transpiration rates, and impairing active transport and membrane permeability [8]. This indicates that considering soil moisture or rainfall distribution of an area is very important to limit the amount of fertilizer to be applied. Low soil fertility, particularly nitrogen and phosphorus deficiencies, is among the major biophysical constraints affecting agriculture in sub-Saharan Africa. According to [9], soil fertility depletion in smallholder farmers' holdings is the fundamental biophysical root cause of declining per capita food production.

Nitrogen (N) is commonly the most limiting nutrient factor for crop production in the majority of the world's agricultural areas, and therefore, adoption of good N management strategies often results in large economic benefits to farmers. Fertilizer N has contributed more than any other fertilizer towards increasing yield of grain crops, including sorghum. Consequently, N has become the foremost input in relation to cost and energy requirement in advanced agricultural production systems [10]. Nitrogen is a major input in sorghum production, affecting both yield and quality through influencing those components which have great contribution in increasing grain yield of sorghum [11]. However, in North Shewa, farmers use this fertilizer (nitrogen/urea) as a blanket recommendation, $69 \, \text{kg·N·ha}^{-1}$, which is the same rate of fertilizer application without considering the soil moisture condition and the fertility status of the soil of an area even though soil moisture content and soil fertility status vary from place to place.

Proper timing of application is the most important factor for N fertilizer management. Plant use efficiency of N depends on several factors including application time, rate of N applied, cultivar, and climatic conditions [12]. The management of N application time is essential to ensure sustained nutrition at the end of vegetative growth. Therefore, the total amount of N should be divided into suitable fractions to be applied to best satisfy the requirement of the growing sorghum crop. The aim is to avoid increasing early vegetative growth and to encourage the development of the upper most green parts directly involved in grain formation. Too late application may lead to N starvation, whereas too early supply may also increase tillering and vegetative growth. However, farmers in North Shewa lowland area apply N fertilizer in the form of urea at a blanket rate of $69 \, \text{kg·ha}^{-1}$ of N mostly one time at sowing or at a vegetative growth stage for sorghum production. Thus, there is lack of information on the response of sorghum to rate and time of N fertilizer application in North Shewa Zone. Choosing better N rate and N timing, as part of the major solution in this area, is thought to be the major step to minimize the coincidence of drought periods with sensitive crop growth stages that lead to significant yield losses. Therefore, the objective of this study was as follows:

(i) To determine the appropriate nitrogen rate and nitrogen timing for maximum yield of sorghum in the lowland of North Shewa

2. Materials and Methods

2.1. Description of the Study Area.
The experiment was conducted on farmers' fields at three locations, Shewa Robit, Ataye, and Alem Ketema (Jemma valley), under main growing season for two consecutive years (2019-2020). The geographical location of the experimental sites lies between $10°03'55''$ N to $10°17'52''$ N latitude and $38°59'11''$ E to $39°54'12''$ E longitude, and altitude ranged from 1365 to 1568 m.a.s.l (Figure 1).

The area has minimum and maximum average annual temperatures of 9.49°C and 21.02°C, respectively. The ten years' average annual rainfall is 1177.14 mm (data from Kombolcha Meteorological Station (KOMS)) (Figure 2). The major crops grown in the area are sorghum, teff, and mung bean, and from livestock, cattle and goat are dominant for the area. The soil type of the experimental site is clay with a proportion of 35% sand, 19% silt, and 46% clay (Table 1). Agroecologically, the research area is lowland to midland.

2.2. Experimental Materials.
The sorghum variety used in this experiment was Melkam. The variety is adapted to lowland areas, early maturing type, and widely produced in the study area. Urea (46% N) and triple superphosphate (TSP) with 46% P_2O_5 were used as source of nitrogen and phosphorus, respectively. Soil sampling and analysis: soil samples at a depth of 0–30 cm were taken from five random spots diagonally across the experimental field using an auger before planting from each experimental site. The collected soil samples were composited. After that, soil organic carbon, total N, soil pH, available P, and texture were analyzed at Debre Birhan Agricultural Research Center Soil Laboratory. The soil pH was measured in the supernatant suspension of a 1 : 2.5 soil to water ratio using a standard glass electrode pH meter [13]. The method in [14] was used to determine the organic carbon (%). Total N was determined using the Kjeldahl method as described in [15]. Available P (mg·kg^{-1}) was determined by employing the method in [16] using ascorbic acid as the reducing agent. The soil particle size distribution was determined using the Bouyoucos hydrometer method [17].

2.3. Treatments and Experimental Design.
The experiment was laid out in randomized complete block design (RCBD) with three replications. Improved, early matured sorghum variety (Melkam) was used for the trial. The treatment consists three rates of nitrogen (46, 92, and $138 \, \text{kg·ha}^{-1}$) and three times of N application including one control. Therefore, we had 10 treatments. Timings of N application were adjusted as follows: APT1 (1/2 dose at sowing + 1/2 dose at tillering), APT2 (1/3 dose at sowing + 2/3 dose at tillering), and APT3 (1/3 dose at sowing + 1/3 dose at early tillering + 1/3 dose at late tillering) were applied as treatments. The gross size of experimental plot was $3.75 \, \text{m} \times 3 \, \text{m}$
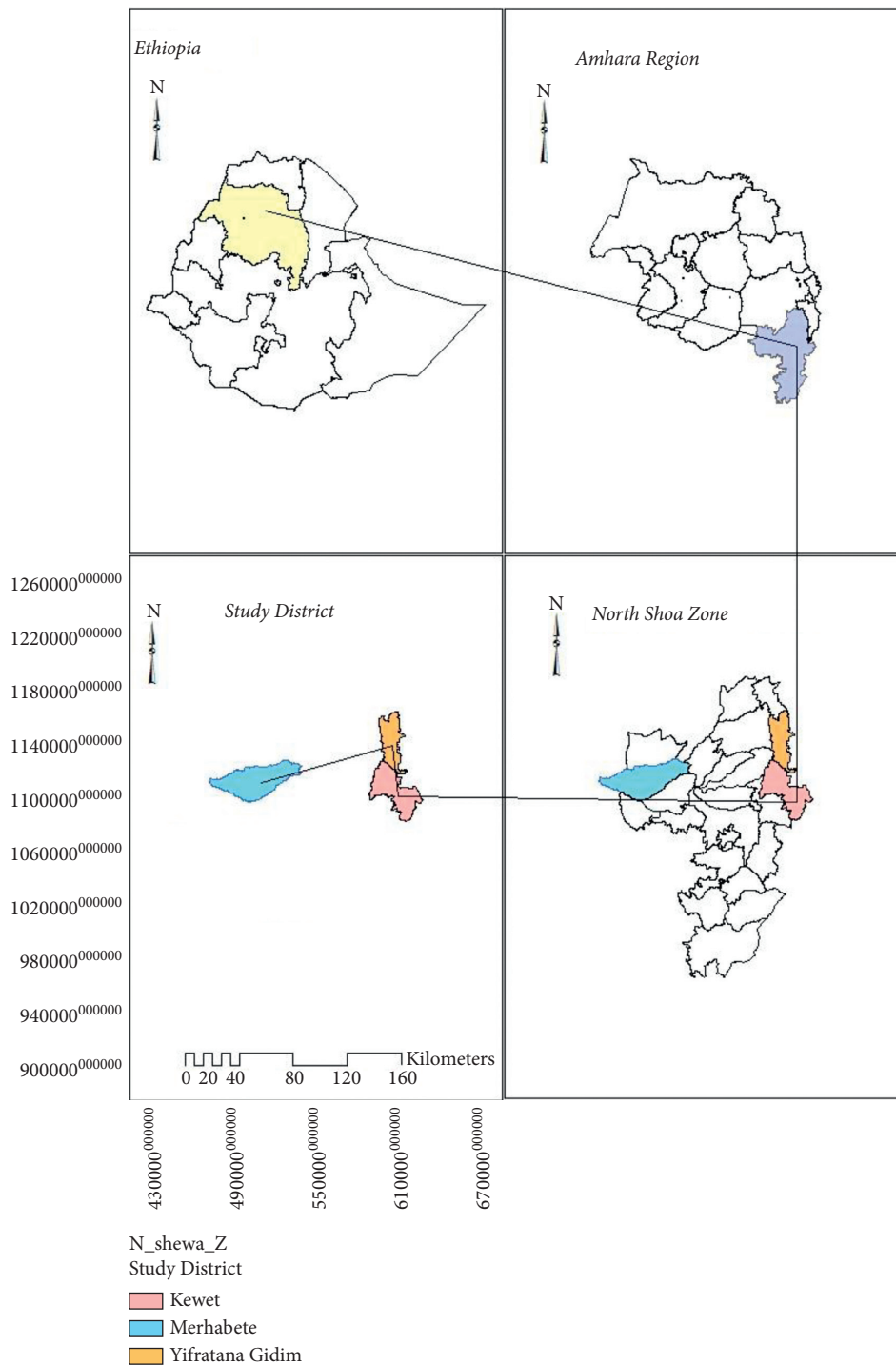
Figure 1: Location map of the study district.

(11.25 m^2) accommodating five rows of sorghum planted at a spacing of 75 cm between rows and 15 cm between plants. The net sampling plot size was 2.25 m × 3 m (6.75 m^2). The seeds were planted at a row spacing of 75 cm and plant spacing of 15 cm recommended for sorghum, and this is done by hand in the rows as uniformly as possible and covered with soil manually at a rate of two seeds per hill; after emergence, it was thinned to one seedling per hill. Sorghum was planted on first half of July. Nitrogen fertilizer in the form of urea (46% N) was applied as per treatment. The full dose of P (60 kg·P$_2$O$_5$·ha^{-1}) was applied uniformly in band application in the form of triple superphosphate (TSP) at planting time of sorghum for all experimental units. Hand weeding was done three times.
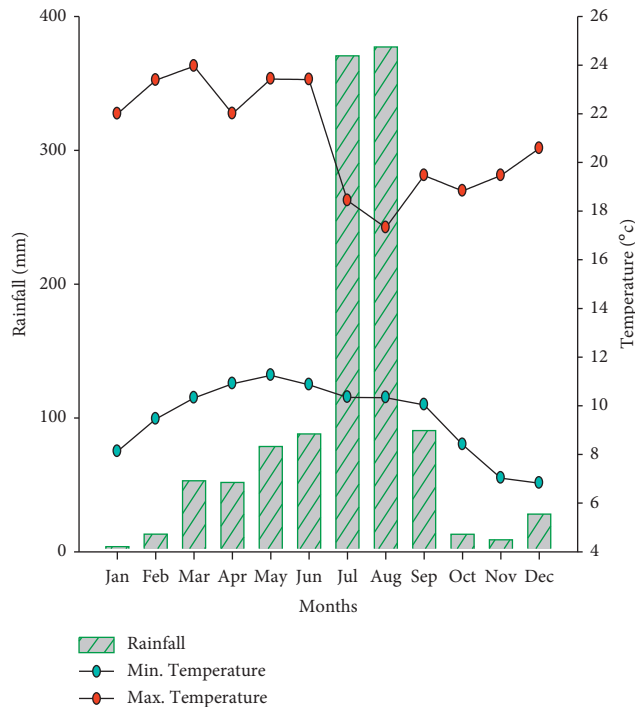
FIGURE 2: Ten years' mean monthly total rainfall and average maximum and minimum temperatures.

TABLE 1: Selected physicochemical properties of the experimental soil before planting.

| Soil pH | %Organic carbon | %Total nitrogen | %Organic matter | Available phosphorus | Texture | | | Texture class |
					Sand	Clay	Silt	
6.63	1.68	0.14	2.89	36.55	35	46	19	Clay

2.4. Data Collection and Measurement

Days to 50% emergency: it was recorded as the number of days from planting to the date at which 50% of the plants emerged.

Days to 50% heading: it was recorded as the number of days from planting to the date at which 50% of the plants in a plot produced head.

Days to 50% maturity: it was recorded on the date at which 50% of the head per plot reached physiological maturity.

Plant height: it was measured at physiological maturity from the ground level to the tip of head from ten randomly taken plants and was averaged on per plant basis.

Head length: it is the length of the head from the node where the first head branches emerge to the tip of the head which was determined from an average of ten randomly taken heads per net plot.

Head weight (g): samples of ten heads were weighed after harvesting and sun drying to determine weight per head.

Thousand kernels weight (g): it was determined by counting 1000 grains and weighting them on a sensitive balance. The weight was adjusted to 12.5% moisture level.

Grain yield (kg): it was obtained from all plants of net plot area. It was determined using sensitive balance after the panicles were threshed, cleaned, and sun dried, and the yield was adjusted to 12.5% moisture level. Then, it was converted to tone ha^{-1} basis.

Data analysis: data collected were subjected to analysis of variance (ANOVA) using the SAS V.9.0 and tested for their significance, and whenever the effects of the treatments were found significant, the means were compared using least significance difference (LSD) test at 5% level of significance.

The economic analysis was carried out by using the methodology described in [18], in which market prices for inputs at sowing and for outputs at harvesting were used. In this paper, all costs and benefits were calculated in Ethiopian Birr per hectare (ETB·ha^{-1}) basis. The ideas used in the partial budget analysis were the mean grain yield of each treatment, the gross benefit ha^{-1} (the mean yield for each treatment), and the field price of fertilizers (urea and the time of application costs). Marginal rate of return, which refers to net income obtained by incurring a unit cost of fertilizer and its application, was calculated by dividing the net increase in yield of sorghum due to the application of each fertilizer's rate. Total variable cost was calculated by summing up the costs that vary, including the cost of urea

TABLE 2: Summary of probability values of combined analysis of variance over environments (year ∗ loc) and treatments (N rate ∗ N timing).

Source of variation	DF	Probability							
		DE	DH	DM	PHT	PL	HWT	GY	TKW
Year	1	<0001	<0001	0.0003	<0001	0.585	<0001	<0001	0.7231
Loc	3	0.3324	<0001	0.4783	0.2629	<0001	<0001	<0001	0.9154
Rep	2	0.012	<0001	0.1241	0.9606	0.0151	0.039	0.0031	0.2902
Tret	9	0.0369	0.7753	<0001	<0001	0.0102	0.0155	0.0007	0.0519
Year ∗ loc	3	<0001	0.0171	<0001	<0001	0.7666	<0001	<0001	0.705
Year ∗ tret	9	0.5803	0.3267	0.247	0.2998	0.9935	0.9156	0.1981	0.8894
Loc ∗ tret	27	0.0698	0.0842	0.6058	0.1429	0.0836	0.0582	0.0116	0.5568
Year ∗ loc ∗ tret	27	0.0072	0.3718	0.7329	0.002	0.0638	0.0447	0.0023	0.8389
CV		13.87	3.68	3.17	3.90	5.39	20.77	16.92	6.03

fertilizer (16.20 ETB or 0.41 \$·kg^{-1}) and for each time of application cost (4 persons, 200 birr/day or 5 \$ (USD)), and the average open price of sorghum price at Debre Birhan market was Birr 19.66 ETB or 0.5 \$·kg^{-1} in November 2020 during harvesting time.

Actual grain yield was adjusted downward by 10% to reflect the difference between the experimental yield and the yield farmers could expect from the same treatment. The dominance analysis procedure, as described in [18], was used to select potentially profitable treatments from the range that was tested. For each pair of ranked treatments, % marginal rate of return (MRR) was calculated. The treatment with highest net benefit and MRR > 100 was considered for recommendation.

3. Results and Discussion

3.1. Soil Physicochemical Properties of the Experimental Site.
Selected physicochemical properties were analyzed for composite soil (0–30 cm depth) from the samples collected. The results indicated that texture of the soil in the experimental site was clay (Table 1). The composite soil sample had 2.89% soil organic matter which is rated as low according to [19] when soils having organic matter value in the range of 2-3% are considered low. The author of [20] has classified soil total N content of 0.12–0.25% as moderate. According to this classification, the soil samples were found to have moderate level of total N (0.14%). The analysis revealed that the available P of the soil was 36.55 mg·kg^{-1} (Table 1). Indicative ranges of available phosphorus have been established by Cottenie (1980) as >25 mg·kg^{-1} of soil (very high). Thus, the soils of the experimental site were considered as very high in available P content.

3.2. Phenological and Growth Parameters of Sorghum.
The analysis result showed that there was nonsignificant difference in days to emergence and days to heading, while days to maturity and plant height and head length showed significant difference between treatments.

Days to 50% physiological maturity was significantly ($P < 0.01$) affected due to treatments (Table 2). Treatments T9 and T10 statically similar to T8 significantly delayed maturity as compared to other treatments. The maximum days to 50% maturity (130.50 days) was recorded from

138 kg·N·ha^{-1} with three-time application, and the minimum (122.17 days) was recorded at a rate of 138 kg·N·ha^{-1} in all nitrogen application times (Table 3). Delay in days to maturity could be due to application of higher level of nitrogen that increased vegetative growth and delayed reproductive period as nitrogen boosts vegetative growth of the plants and make them stay green for long period of time. Similarly, Abrha [12] reported that maturity was more prolonged at the rate of 174 kg·N·ha^{-1}.

Plant height: treatments had significant ($P < 0.01$) effect on plant height (Table 2). However, except the control (unfertilized), the others showed statistically similar value. Treatments that have nitrogen increased plant heights than treatments without nitrogen (Table 3). The tallest plant (145.83 cm) was recorded from T7, and the shortest plant (124.85 cm) was recorded from T1 (Table 3). Similar result was observed in [21] that there is significant increase in plant height of sorghum when supplied with higher rates of N.

Head length: head length of sorghum was significantly affected ($P < 0.05$) by the treatment effect (Table 2). The highest head length (28.68 cm) was recorded from T8, and the minimum head length (26.38 cm) was recorded from T1 (Table 3). The increase in head length with respect to increased N application rate indicates maximum vegetative growth of the plants under higher N availability due to the increase in cell elongation as nitrogen is essential for plant growth process.

Head weight: the applied treatment showed significant effect on head weight ($P < 0.05$) (Table 2). The maximum head weight per head (91.62 g) was obtained from T8, whereas the minimum head weight (66.34 g) was recorded from T1. Head weight increased when nitrogen increased with any application time.

Thousand kernel weight: the result indicated that thousand kernel weight showed nonsignificant effect due to treatment difference.

Grain yield: the analysis of variance showed that treatment effect was significant ($P < 0.05$) on grain yield of sorghum (Table 2). The highest grain yield (5.836 t·ha^{-1}) was recorded from T8 (application of 138 kg·N·ha^{-1} in two split doses of 1/2 dose at sowing and 1/2 dose at tillering) statistically par with T10, T5,

TABLE 3: Mean tables for phenological and growth parameters of sorghum as affected by treatments.

Treatment code	Days to emergency	Days to heading	Days to maturity	Plant height (cm)	Head length (cm)
1	6.33	72.83	124.25[cd]	124.85[b]	26.38[d]
2	6.33	73.17	123.08[cd]	142.63[a]	27.02[cd]
3	6.08	73.08	122.17[d]	145.21[a]	27.20[b-d]
4	6.25	73.25	125.42[bc]	141.59[a]	27.00[cd]
5	5.83	74.08	123.67[cd]	145.14[a]	27.97[a-c]
6	5.83	72.67	123.33[cd]	144.83[a]	27.81[a-c]
7	6.00	72.75	122.25[cd]	145.83[a]	27.68[a-c]
8	5.83	73.83	128.17[ab]	145.80[a]	28.68[a]
9	5.50	74.50	129.75[a]	142.02[a]	27.97[a-c]
10	6.75	73.67	130.50[a]	143.19[a]	28.33[ab]
LSD (5%)	NS	NS	3.23	4.50	1.21
Mean	6.08	73.38	125.26	142.11	27.60
CV	13.87	3.68	3.17	3.90	5.39

LSD = least significant difference; CV = coefficient of variation; T1 = control with no fertilizer application; T2 = 46 kg·ha^{-1}·N with 1/2 at sowing and 1/2 at tillering application; T3 = 46 kg·ha^{-1}·N with 1/3 at sowing and 2/3 at tillering application; T4 = 46 kg·ha^{-1}·N with 1/3 at sowing, 1/3 at early tillering, and 1/3 at tillering application; T5 = 92 kg·ha^{-1}·N with 1/2 at sowing and 1/2 at tillering application; T6 = 92 kg·ha^{-1}·N with 1/3 at sowing and 2/3 at tillering application; T7 = 92 kg·ha^{-1}·N with 1/3 at sowing, 1/3 at early tillering, and 1/3 at tillering application; T8 = 138 kg·ha^{-1}·N with 1/2 at sowing and 1/2 at tillering application; T9 = 138 kg·ha^{-1}·N with 1/3 at sowing and 2/3 at tillering application; T10 = 138 kg·ha^{-1}·N with 1/3 at sowing, 1/3 at early tillering, and 1/3 at tillering application. Variable followed by the same letters are not significantly different according to the LSD test.

TABLE 4: Mean tables for phenological and growth parameters of sorghum as affected by treatments.

Treatment code	Head weight (g)	Thousand kernel weight (g)	Grain yield (t·ha^{-1})
1	66.34[b]	33.07[a]	4.276[d]
2	74.92[b]	32.57[a-c]	5.060[a-c]
3	74.80[b]	32.79[ab]	4.764[b-d]
4	66.50[b]	32.00[a-d]	4.487[cd]
5	76.24[b]	31.46[b-d]	5.169[a-c]
6	78.93[ab]	30.84[d]	4.994[b-d]
7	75.24[b]	32.87[ab]	4.805[b-d]
8	91.62[a]	32.59[a-c]	5.836[a]
9	72.79[b]	31.24[cd]	4.780[b-d]
10	79.02[ab]	32.85[ab]	5.555[ab]
LSD (5%)	13.47	1.5	7.95
Mean	75.64	32.2	4.972
CV	21.99	5.73	19.73

LSD = least significant difference; CV = coefficient of variation; T1 = control with no fertilizer application; T2 = 46 kg·ha^{-1}·N with 1/2 at sowing and 1/2 at tillering application; T3 = 46 kg·ha^{-1}·N with 1/3 at sowing and 2/3 at tillering application; T4 = 46 kg·ha^{-1}·N with 1/3 at sowing, 1/3 at early tillering, and 1/3 at tillering application; T5 = 92 kg·ha^{-1}·N with 1/2 at sowing and 1/2 at tillering application; T6 = 92 kg·ha^{-1}·N with 1/3 at sowing and 1/2 at tillering application; T7 = 92 kg·ha^{-1}·N with 1/3 at sowing, 1/3 at early tillering, and 1/3 at tillering application; T8 = 138 kg·ha^{-1}·N with 1/2 at sowing and 1/2 at tillering application; T9 = 138 kg·ha^{-1}·N with 1/3 at sowing and 2/3 at tillering application; T10 = 138 kg·ha^{-1}·N with 1/3 at sowing, 1/3 at early tillering, and 1/3 at tillering application. Variable followed by the same letters are not significantly different according to the LSD test.

and T2. On the other hand, the lowest grain yield (4.276 t·ha^{-1}) was obtained from T1 (0 kg·N·ha^{-1}) (Table 4). Grain yield increased with the increase in the rate of nitrogen with two-time application, statistically par result from 46 kg·N·ha^{-1} up to 138 kg·N·ha^{-1} nitrogen (Table 4). Sorghum yield increases with increase in the rate of nitrogen application, but significant difference was observed between control and other rates under two times (1/2 at sowing and 1/2 at tillering). To elaborate the treatment effect, we display Figure 3. In line with this result, Limaux et al. [22] reported that supplying N in two or three applications is a good recommendation to increase N use efficiency in sorghum.

Partial budget analysis: the final goal of producers in applying fertilizer is not limited to increasing yield alone, but also to make profit out of it. In the study area, the demand and market price of sorghum are important. Because of this fact, increasing grain yield can increase farmers' income. As indicated in Table 5, the partial budget analysis showed that the highest net benefit of 97,632 Birr·ha^{-1} was obtained in the treatment that received 138 kg·N·ha^{-1} in two split applications (1/2 dose at sowing and 1/2 dose at tillering stage). However, the lowest net benefit 75,660 Birr·ha^{-1} was obtained from control treatment. The highest marginal rate of return (842.31%) was obtained from the plot that applied nitrogen fertilizer
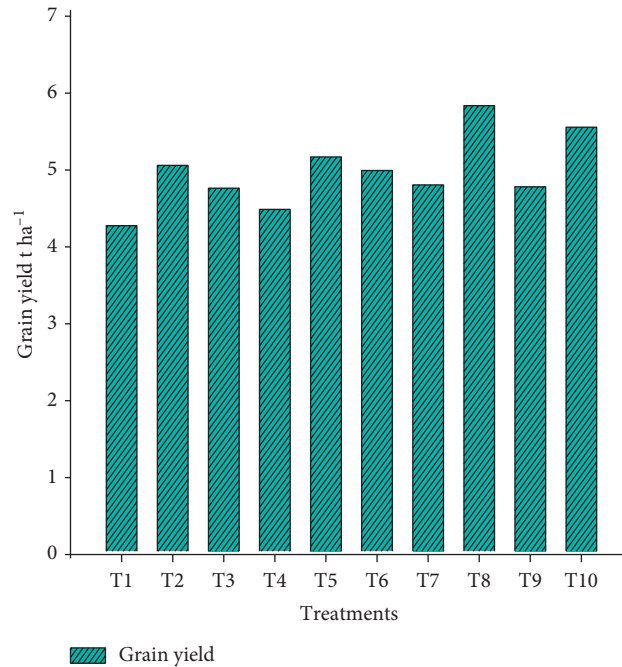
FIGURE 3: The effect of treatments on grain yield. T1 = control with no fertilizer application; T2 = 46 kg·ha^{-1}·N with 1/2 at sowing and 1/2 at tillering application; T3 = 46 kg·ha^{-1}·N with 1/3 at sowing and 2/3 at tillering application; T4 = 46 kg·ha^{-1}·N with 1/3 at sowing, 1/3 at early tillering, and 1/3 at tillering application; T5 = 92 kg·ha^{-1}·N with 1/2 at sowing and 1/2 at tillering application; T6 = 92 kg·ha^{-1}·N with 1/3 at sowing and 1/2 at tillering application; T7 = 92 kg·ha^{-1}·N with 1/3 at sowing, 1/3 at early tillering, and 1/3 at tillering application; T8 = 138 kg·ha^{-1}·N with 1/2 at sowing and 1/2 at tillering application; T9 = 138 kg·ha^{-1}·N with 1/3 at sowing and 2/3 at tillering application; T10 = 138 kg·ha^{-1}·N with 1/3 at sowing, 1/3 at early tillering, and 1/3 at tillering application.

TABLE 5: Partial budget analysis of sorghum yield as influenced by N fertilizer rates and time of application.

Treatment code	GY	AGY	GFB (ETB·ha^{-1})	TVC (ETB·ha^{-1})	NB (ETB·ha^{-1})	MC	MNB	MRR%
1	4.276	3.848	75660	0	75660	0	0.00	
2	5.060	4.554	89532	2410	87122	2410	11462.10	475.61
3	4.764	4.288	84294	2410	81884	0	D	
4	4.487	4.038	79393	2810	76583	400	D	
5	5.169	4.652	91460	4020	87440	1210	318.65	26.33
6	4.994	4.495	88364	4020	84344	0	D	
7	4.805	4.325	85020	4420	80600	400	D	
8	5.836	5.252	103262	5630	97632	1210	10191.90	842.31
9	4.780	4.302	84577	5630	78947	0	D	
10	5.555	5.000	98290	6030	92260	400	D	

Treatment code similar with Table 3. GY = grain yield; AGY = adjusted grain yield; GFB = gross field benefit; TVC = total variable cost; NB = net benefit; MRR = marginal rate of return; D = dominated treatments. Market price of sorghum = 19.66 ETB·kg^{-1}; cost of urea = 35 ETB·kg^{-1}; labour cost for application of nitrogen = 4 persons ha^{-1}, each 200 ETB·day^{-1} for one time application; ETB = Ethiopian birr.

(138 kg ha^{-1}) in two split applications (1/2 dose at sowing and 1/2 dose at tillering stage). For treatment to be considered as advisable to farmers, between 50% and 100% marginal rate of return (MRR) was the minimum acceptable rate of return [18]. Therefore, 475.61% was recorded from application of 46 kg·N·ha^{-1} in two split doses (1/2 dose at sowing and 1/2 dose at tillering stage) with better net benefit, and MRR is profitable and recommended for farmers in lowland areas of North Shewa area and other similar agroecological condition.

4. Conclusion

Among taken parameters, days to 50% maturity, plant height, head length, head weight, and grain yield were significantly affected by treatment effect, while days to emergency, days to heading, and thousand kernel weight showed nonsignificant effect. The maximum grain yield was 5.060, 5.169, 5.836, and 5.555 t·ha^{-1} from T2, T5, T8, and T10, respectively, and statistically similar yield was recorded at combination of different rates in two split applications (1/2 dose at sowing and 1/2 dose at tillering). The partial budget

analysis revealed that combined applications of $138 \, kg \cdot N \cdot ha^{-1}$ in two split doses (1/2 dose at sowing and 1/2 dose at tillering stage) gave the best economic benefit ($97,632 \, Birr \cdot ha^{-1}$) with a MRR of 842.31%, followed by applications of $46 \, kg \cdot N \cdot ha^{-1}$ in two split doses (1/2 dose at sowing and 1/2 dose at tillering stage), which gave $87,122 \, Birr \cdot ha^{-1}$ with a MRR of 475.61%. Therefore, it can be concluded that use of $46 \, kg \cdot N \cdot ha^{-1}$ in two split applications (1/2 dose at sowing and 1/2 dose at tillering stage) can be recommended for farmers for production of sorghum in the study area and other areas with similar agroecological conditions by considering low-income farmers.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Acknowledgments

References

[1] J. M. Poehlman and D. A. Sleper, *Breeding Field Crop*, Lowa State University Press, Ames, LO, USA, 4th edition, 1995.

[2] FAO (Food and Agriculture Organization), *Fertilizers and Their Use*, International Fertilizer Industry Association FAO, Rome, Italy, 4th edition, 2019.

[3] A. H. Paterson, J. E. Bowers, and F. A. Feltus, "Genomics of sorghum, a semi-arid cereal and emerging model for tropical grass genomics," in *Genomics of Tropical Crop Plants*, H. Paul and R. Moore, Eds., pp. 469–482, Springer Science + Business Media, New York, NY, USA, 2008.

[4] T. Tesso, I. Kapran, C. Grenier et al., "The potential for crop-to-wild gene flow in sorghum in Ethiopia and Niger: a geographic survey," *Crop Science*, vol. 48, no. 4, pp. 1425–1431, 2008.

[5] A. Teshome, D. Patterson, Z. Asfew, J. K. Torrance, and J. T. Arnason, "Changes of *Sorghum bicolor* landrace diversity and farmers' selection criteria over space and time, Ethiopia," *Genetic Resources and Crop Evolution*, vol. 54, no. 6, pp. 1219–1233, 2007.

[6] H. Kebede, P. K. Subudhi, D. T. Rosenow, and H. T. Nguyen, "Quantitative trait loci influencing drought tolerance in grain sorghum (*Sorghum bicolor* L. Moench)," *Theoretical and Applied GeneticsTheoretical and Applied Genetics*, vol. 103, no. 2, pp. 266–276, 1991.

[7] CSA (Central Statistical Agency), *Crop Production Forecast Sample Survey, 2019/20 (2012 E.C.). Report on Area and Crop Production Forecast for Major Crops (For Private Peasant Holding, Meher Season)*, Statistical Bulletin, Addis Ababa, Ethiopia, 2019.

[8] Y. Assefa, *Grain Sorghum in the Hybrid-Era*, pp. 1957–2008, Kansas State University, Manhattan, KS, USA, 2010.

[9] P. A. Sanchez, K. D. Shepherd, M. J. Soul, F. M. Place, R. J. Buresh, and A. M. N. Zac, *Soil Fertility Replenishment in Africa. Replenishing Soil Fertility Africa"*, SSSA, Special Publication 51. SSSA, Madison, WI, USA, 1997.

[10] B. M. Yousf, *The Response of Some Sorghum Cultivars to Nitrogen Fertilization at Two Sowing Dates*, Thesis of MSc, University of Gezira– Faculty of Agricultural Sciences, 1993.

[11] B. Wondimu, *Growth, Development and Yield Responses of Sorghum to Water Deficit Stress, Nitrogen Fertilizer, Organic Fertilizer and Planting Density*, Doctoral dissertation, University of Pretoria, Pretoria, South Africa, 2004.

[12] K. Abrha, *Growth, Productivity, and Nitrogen Use Efficiency of Maize (Zea mays L.) as Influenced by Rate and Time of Nitrogen Fertilizer Application in Haramaya District, Eastern Ethiopia*, MSc Thesis, Haramaya University, Haramaya, Ethiopia, 2013.

[13] J. D. Rhoades, *In Methods of Soil Analysis, Part 2*, A. L. P. Miller and D. R. Keeney, Eds., American Society of Agronomy, Madison, USA, 2nd edition, 1982.

[14] A. Walkley and I. A. Black, "An examination of the degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method," *Soil Science*, vol. 37, no. 1, pp. 29–38, 1934.

[15] S. R. Olsen, C. W. Cole, F. S. Watanabe, and L. A. Dean, *Estimation of Available Phosphorous in Soils by Extraction with Sodium Bicarbonate Circular 939*, US. Department of Agriculture, Washington, D.C, WA, USA, 1954.

[16] J. M. Bremner and C. S. Mulvaney, "Methods of soil analysis of total Nitrogen. Part 2-Chemical and microbiological properties," *Agronomy*, vol. 9, no. 2, pp. 595–624, 1982.

[17] G. J. Bouyoucos, "Hydrometer method improved for making particle size analyses of soils 1," *Agronomy Journal*, vol. 54, no. 5, pp. 464-465, 1962.

[18] CIMMYT (International Maize and Wheat Improvement Center), *From Agronomic Data to Farmer Recommendations: An Economics Training Manual*, CIMMYT (International Maize and Wheat Improvement Center), Veracruz, Mexico, 1988.

[19] EthioSIS (Ethiopia Soil Information System), *Soil Fertility Status and Fertilizer Recommendation Atlas for Tigray Regional State*, EthioSIS (Ethiopia Soil Information System), Tigray, Ethiopia, 2014.

[20] "Soil, plant, water, fertilizer, animal manure and compost analysis," *Working Document No. 13*, International Livestock Research Center for Africa, Addis Ababa, Ethiopia, 1991.

[21] M. Maral, K. M. Mohammad, A. Ebrahim, K. D. Reza, and R. B. Hamid, "Effects of nitrogen fertilizer and plant density management in corn farming," *Journal of Agricultural and Biological Science*, vol. 2, pp. 133–137, 2012.

[22] F. Limaux, S. Recous, J.-M. Meynard, and A. Guckert, "Relationship between rate of crop growth at date of fertilizer N application and fate of fertilizer N applied to winter wheat," *Plant and Soil*, vol. 214, no. 1/2, pp. 49–59, 1999.