

Research Article

Determination of Optimum Plant Population for Soybean Agronomic Productivity

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Abstract

The poor agronomic practices, such as seeding rate and inappropriate plant population are the major reasons for low productivity of soybean. A field study did to determine the appropriate row and plant spacings for Soybean productivity and profitability at Metema and west Armachiho districts. Treatments were arranged to five rows (30, 40, 50, 60 and 70 cm) with three plant spacings (5, 10 and 15 cm) comparing with the blanket recommendation (40 cm x 10 cm and 60 cm x 5 cm) and laid out in randomized complete block design with three replications. The Afgat variety was used as planting material and 121 kg ha^{-1} of NPS fertilizer was applied at sowing time. The combined results indicated that; days to 50% flowering, number of branches plant $^{-1}$, length of productive node, number of seeds pod $^{-1}$ were significant, whereas days to 90% physiological maturity, plant height, number of pods plant $^{-1}$, hundred seeds weight and grain yield were highly significant ($p < 0.01$) and affected by the interaction effects of inter and intra row spacings. The highest grain yield (3831 kg ha^{-1}) and net benefit (50,650 ETB/ha) were obtained from the combination of 40 cm row spacing with the 5 cm plant spacing. Whereas, the blanket recommendation (40 cm x 10 cm and 60 cm x 5 cm) gave 3556 kg ha^{-1} and 3519 kg ha^{-1} , respectively. Therefore, 40 cm the row with 5 cm plant spacing is suggested to be promoted for Soybean production on the low land areas of northwestern Gondar, Ethiopia.

Keywords

Afgat, Interaction, Competition, Lowland, Net Benefit

1. Introduction

Soybean [*Glycine max* (L.) Merrill] is the most important and widely grown legume crops worldwide due to its multi-purpose uses. It is also called a “miracle golden” bean of 21st century, because of its high quality protein and balanced amino acid profile in ration formulation and human diets are the driving forces of soybean production [1]. It is originated from South East Asia from where it spread into many parts of the world and has been cultivated by man since nearly 5000 years [2]. In the 2022/23 cropping season a production of

soybean was the total area of 136.54 million hectares with total production of 369.74 million metric tons and the average productivity of 2.71 t ha^{-1} in the world [3].

Soybean was emerged to Ethiopia in the early of 1950s; it has grown in diverse agro ecological areas of the country [4]. Its production is crucial in Ethiopia for addressing the issue of malnutrition particularly for smallholder farmers who cannot afford animal source proteins [5]. The crop is amenable to agronomic as well as genetic improvements, has a high yield

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potential under good conditions, and perform better in different cropping systems. In addition, it was introduced lately to Amhara region during the resettlement program in 1986. However, smallholder farmers in this region dominantly produce it and it becomes the main source of income and base of their livelihood to smallholder soybean producers [6]. The area covered by soybean production is 54,543 ha with total production of 125,623 ton [7] and the national average productivity of 2.30 t ha^{-1} which is lower than that of the world average productivity (2.71 t ha^{-1} and 3.72 t ha^{-1}) [3]. But the potential and attainable yield of the released soybean varieties are on average up to 6 t ha^{-1} and 2.9 t ha^{-1} , respectively [8]. Ethiopia faced serious lack of oil seed for the huge number of oil industries established recently and in turn could not secure food oil for consumption. The major reasons for low productivity of soybean in Ethiopia were low varietal stability, narrow genetic base of cultivar, insect pests and diseases, multi-nutrient deficiencies, low fertilization, limited access to improved soybean seed, and poor agronomic practices [9]. Among the agronomic management practices, row spacing and plant density are important factors that influence the components of production and consequently, the final productivity of the crop. Either higher or lower density of

plants than the optimum leads to the reduction in seed yield.

In Ethiopia, studies showed that inter and intra row spacings recommended to soybean production for early maturing varieties 40 cm row spacing with 10 cm plant spacing and for late maturing varieties 60 cm row spacing with 5 cm intra row spacing [10]. Establishment of an optimum plant density per unit area is a non-monetary input factor for enhancing the production of soybean. There is a considerable scope for increasing soybean yield by optimizing the plant population and plant geometry [11]. Other parameters, such as the dry matter of plant components, harvest index, grain yield per plant and per unit area of soybean varieties changed with variable plant density [12]. Since a number of factors such as fertility status of the soil, moisture availability, growth pattern of the varieties and cultural practices influence both row and plant spacing, optimum-planting density should be determined to specific area and to specific soybean varieties through conducting experiment. However, the blanket recommendation may not suit for the specific environmental conditions in western Gondar soybean production areas. Therefore, this study aims to identify optimum plant population for medium maturity soybean varieties for better productivity and profitability.

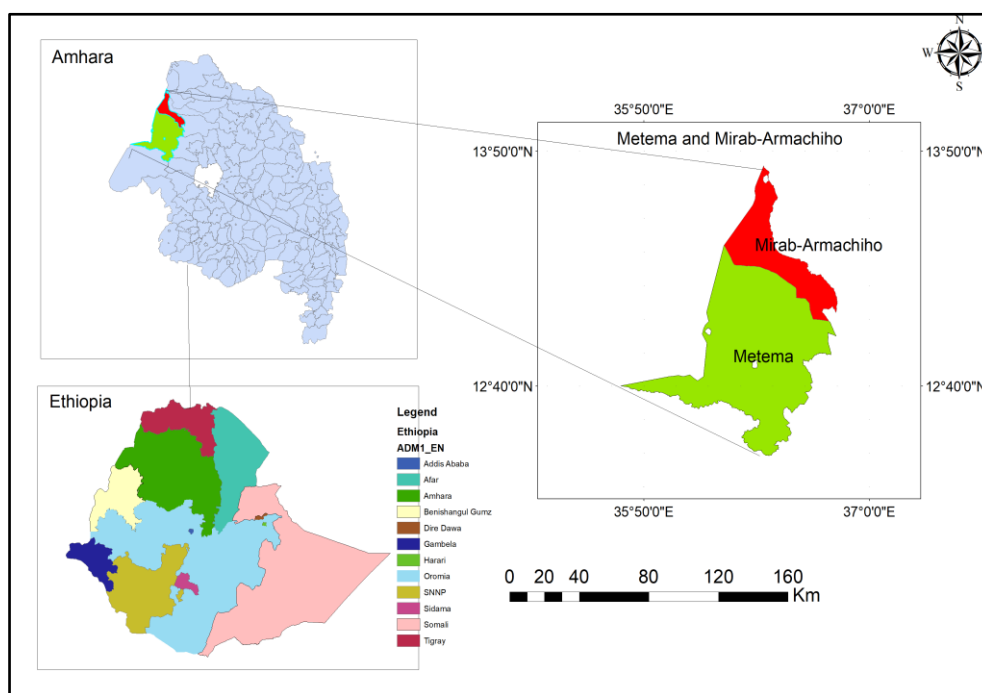


Figure 1. Map of study areas.

2. Materials and Methods

2.1. Description of Study Areas

The experiment was conducted on farmers' fields on ver-

tisols under rain fed condition from June to November in the 2021 to 2022 cropping seasons at Metema and west Armachiho districts of northwestern Gondar, Ethiopia. The two locations are situated and the representative of the major Soybean growing areas of low land areas of northwestern Gondar and are suitable for high quality and quantity soybean production to the local and international market. Sesame,

Sorghum and Cotton are dominant precursor crops for Soybean in that area. Metema district is characterized with (rain fall 1030.2-1037.3 mm, temperature 19.5-35.9 °C, relative humidity 53.1-58.3, altitude 710 to 898 m. a. s. l, 12°24'48" to 13°09'71" N latitude and 36°15'19" to 36°64'71" E longitude). Whereas, west Armachiho district is characterized with (rain fall 900-1800 mm, temperature 22.1-36.3 °C, relative humidity 45.1-47.2, 570 to 860 m. a. s. l, 13°10'09" to 13°70'36" N latitude and 36°31'29" to 36°77'16" E longitude) in the northwestern Gondar, Ethiopia. The areas are characterized with mono-modal type of rainfall distribution pattern in which the rainy season commences in late May to end of September.

2.2. Treatment and Experimental Design

Treatments were consisted of factorial combinations of five levels of inter rows (30, 40, 50, 60 and 70 cm) and three levels of intra rows (5, 10 and 15 cm) spacings comparing with the blanket recommendation of spacings (40 cm x 10 cm and 60 cm x 5 cm). The design was laid out in randomized complete block design with three replications at each district in 2021 to 2022 cropping seasons. The gross plot size was 4.8 m x 3.5 m = 16.8 m²; however, the harvestable plot sizes were arranged differently depend on the width of inter row spacings. As per the treatments, there was 14, 10, 8, 6 and 5 the harvestable number of rows for 30, 40, 50, 60 and 70 cm inter-row spacings, respectively. A number of plants in each row were 68, 33 and 22 for intra row spacings of 5, 10 and 15 cm, respectively. The outer most one row and one plant on both sides of the row and plant spacings were left to avoid border effects for all plots. In addition, the spaces between plots and replications were maintained 1 m and 1.5 m, respectively.

2.3. Experimental Materials and Management

The experiment was conducted using Afgat variety as a planting material and all the recommended NPS fertilizer (121 kg ha⁻¹) was applied at sowing time. The experimental sites were ploughed three times using oxen, all years at planting times, harrowed and levelled were done by human labours to fine tilt soils. The seeds were planted on June 20/2021 and June 18/2022 by placing a single seed per hole on an intra-row spacing. Weeding was done three times during the growth period of the crop. The first weeding was done 15 days after emergence; the second weeding was done 20 days after the first weeding and the third weeding was done 20 days after the second weeding. All other necessary agronomic management practices were done frequently throughout growing period of the crop accordingly.

2.4. Data Collection and Analysis

The standard procedures were followed to collect all the data on growth and yield parameters. Phenological parameters such as days to 50% flowering and days to 90% physiological maturity were taken from the whole plot area. Ten purposively

and randomly selected plants were used for data sampling from each plot on the harvestable plots and parameters were measured including the plant height, a total number of branches per plant length of productive node per plant, total number of pods per plant and a total number of seeds per pods. The central rows of harvestable plots were harvested to estimate hundred seeds weight and grain yield on each plot. At maturity, to avoid marginal effects, two rows and plants (one row and plant from each side) of each plots were discarded for all treatments, respectively. Harvesting was done 10 days after 90% physiological maturity from harvestable plot at full ripening when the leaves, stems and all pods (95%) became yellow. Drying was done by setting the harvested stems with pods in bags until all pods dried by sun and threshed by hand beating properly the pods until all seeds were dropped out from the pods. The hundred seeds were weighed after a moisture content of 10% on wet bases with a moisture tester. After threshing, the grain yield was cleaned. In addition, weighed with sensitive balance measurement in gram plot⁻¹ and changed to kg ha⁻¹. The statistical analysis of the generated data on each agronomic parameter was carried out on the combined mean values over three replications and six locations. The statistical methods adopted were as follows; collected data were subjected to the statistical analysis of variance by using SAS statistical software version 9.4 and R-software. Significant pairs of means were separated by using the least significant difference test at 5% and 1% levels of significance. In addition, used for mean separation for all agronomic parameters.

2.5. Partial Budget Analysis

It was carried out by using the methodology described in [13] which prevailing market prices of input (for seed cost), on planting costs (row making costs) and on cultivation (weeding cost) were used. All costs and benefits were calculated on hectare basis in Ethiopian birr. The concepts used in the partial budget analysis were the mean grain yield of each treatment. Actual grain yield was adjusted downward to adjust grain yield by 10% to reflect the difference between the experimental yield and the yield farmers could expect from the same area. Gross benefit / (GB/ETB ha⁻¹) / was computed by multiplying farm gate price that farmers receive for the crop when they sell it as adjusted grain yield. GB = AGY × P (farm gate price for the crop). Total variable cost (TVC ETB ha⁻¹) is a summation of operational costs that vary with changes in scale of operation includes, seed cost (64 ETB kg⁻¹) and labor costs (150 ETB for each) (for row making and weeding costs) for all treatments. The net benefit (NB) was calculated as the difference between the gross benefit and the total variables cost (TVC) that vary among treatments using the formula, NB = (GY × P) - TVC. Where, GY × P = Gross Benefit (GB), GY = Adjusted grain yield per hectare and P = Field price per unit of the crop. Following this, the dominance analysis procedure, as per CIMMYT guide-

lines, was employed to identify potentially profitable treatments, categorizing them into dominated (D) and non-dominated (ND) groups.

3. Result and Discussion

3.1. Response of Soybean to Row and Plant Spacings on Crop Phenology

3.1.1. Days to 50% Flowering

Plant density affects the phenological traits of soybean. It was flowered early at the narrowest inter and intra row spacings and late flowering on the widest inter and intra row spacings. That is, the shortest day (50) and longest day (52.1) to 50% flowering were recorded from the plants grown with 30 cm x 5 cm and 70 cm x 15 cm spacings, respectively (Table 1). This showed that in the narrowest inter row and plant spacings due to competition for nutrients; moisture and space the crop growth and development were fast that accelerates flowering period. However, the shortest days to flower is best, especially in the case of shortage of rainfall and labours. [14]

reported a day to 50% flowering of chick pea was delayed (73 days) and hastened (67 days) with 40 x 20 cm and 20 x 5 cm inter and intra row spacings, respectively.

3.1.2. Days to 90% Physiological Maturity

The shortest (91) and longest (100) days to 90%, physiological maturity were recorded the plants grown with the 30 cm inter row spacing with 5 cm intra row spacing and the 70 cm inter row spacing with 15 cm plant density, respectively (Table 1). The reason for this may be that in the widest inter and intra row spacings, there existed a lower competition for resources like moisture, light and essential nutrients than the narrowest row and intra row spacings for long mature of the crop. In addition, light would be intercepted better in the narrowest inter row spacing as compared to widest inter row spacing but free air circulation in the canopy of the widest spaced rows could have its own contribution for longest days for maturity period. However, the narrowest inter and intra row spacings had its own advantages for fast seed setting and maturity in the case of shortage of rain to harvest early.

Table 1. The interaction effects of row and plant spacings on growth phenological in combined over locations (Metema and west Armachiho) and years (2021 to 2022).

TRT	DF			DM		
Row Spacings (cm)	Plant spacings (cm)					
	5	10	15	5	10	15
30	50	51	51	91	96	96
40	51	51	51	99	97	97
50	51	51	51	96	97	98
60	52	52	52	97	99	99
70	52	52	52.1	98	99	100
Mean	51.4			97.3		
CV (%)	13			11		
LSD (0.05)	0.69*			1.0**		

3.2. Response of Soybean to Plant Population on Growth Parameters

3.2.1. Number of Total Branches per Plant

The highest (5.9) and the lowest (3.9) number of branches plant⁻¹ were recorded from the plants grown with the 60 cm inter row spacing with 10 cm plant spacing and the 30 cm

inter row spacing with 5 cm plant spacing (Table 2), respectively. This showed that more number of branches per plant were produced at the widest inter row and wider intra row spacings. The maximum number of branches plant⁻¹ under lower plant densities could be attributed to lower sunlight interception for photosynthesis. In contrast, the decreased number of branches plant⁻¹ in the narrower inter and intra row spacings might be due to exposed to higher

interception of sunlight and the high competition for the resources with the overlapped canopy of the plant. [15] Confirmed that the number of primary branches decreased with the increase in density of chickpea.

3.2.2. Plant Height

The plant height at maturity has indicated statistical variation on sesame (Table 2). The tallest (93) and the shortest (85) plant heights were recorded from the plants grown with the 40 cm inter row spacing with 5 cm plant spacing and the 70 cm inter row spacing with 15 cm intra row spacing, respectively (Table 2). This showed that inter and intra row spacings increased, the plant height decreased and visa-versa. This result might be because as the spacings between plants decreased the interplant competition for light and nutrients increased this

resulted tallest plant height. While sparsely, populated plants intercepted sufficient sunlight that enhanced the lateral growth, more branches per plant and shortest plant height. [16] Reported that the increasing the density of soybean plants led to significant increases in plant height.

3.2.3. Length of Productive Node

The length of productive node had influenced by the plant population. The tallest (72 cm) and the shortest (66) length of productive node was recorded from the plants grown with 40 cm x 5 cm and 70 cm x 15 cm spacings, respectively (Table 2). This showed that the narrower inter and intra row spacings are more advantageous for length of nodes than the widest inter and intra row spacings like that of plant height.

Table 2. The interaction effects of inter and intra row spacings on growth parameters of Soybean over locations (Metema and west Armachiho) and years (2021 to 2022).

TRT	NBPP			PH			LPN		
Row Spacings (cm)	Plant spacings (cm)								
	5	10	15	5	10	15	5	10	15
30	3.9	4.0	4.6	92	92	89	71	69	67
40	5.2	5.1	4.3	93	90	87	72	68	67
50	5.2	5.1	5.2	92	90	88	71	68	68
60	5.2	5.9	5.5	88	90	91	71	68	69
70	4.6	5.6	5.7	92	90	85	68	69	66
Mean	5			90			68.8		
CV (%)	19			8.3			11		
LSD (0.05)	0.76*			4.2**			4.2*		

3.3. Response of Soybean to Inter and Intra Row Spacings on Yield and Related Yield Components

3.3.1. Number of Pods per Plant

The average numbers of pods per plant were influenced by plant density. The maximum (73) and the minimum (38) number of pods per plant were recorded from the plants grown with 40 cm x 5 cm and 30 cm x 5 cm spacings, respectively (Table 3). For more number of pods per plant, the inter row spacing plays significant role than that of intra row spacing. That is number pods plant⁻¹ the intra row spacing is the same but inter row spacing is different.

3.3.2. Number of Seeds per Pod

The maximum (2.83) and the minimum (2.57) number of seeds per pod were recorded from the plants grown with the 40 cm inter row spacing with 5 cm intra row spacing and the 30 cm inter row spacing with 5 cm intra row spacing, respectively (Table 3). All inter row spacings with 15 cm intra row spacing gave the minimum number of seeds per pod compared to 5 cm and 10 cm intra row spacings except 30 cm inter row spacing. Due to low resource competition among plants for widest intra row spacing, the length of pod is decreased as result the number of seeds per pod decreased. [17] Found that plant densities significantly influenced the numbers of seeds per pod and seed yield per plant.

3.3.3. Hundred Seeds Weight

The plant population affected the hundred seeds weight. The maximum (15.2) and the minimum (14.5) hundred seeds weight were recorded from the plants grown with the 40 cm inter row spacing with 5 cm intra row spacing and the 50 cm plant spacing with 10 cm intra row spacing, respectively

(Table 3). In this case, the hundred seeds weight decreased with the increased in inter and intra row spacings from 40 cm to 50 cm and 5 cm to 10 cm, respectively. Because soybean is photoperiod sensitive crop, that gives advantage for seed filling time. This showed that narrower inter row spacing plays more role for seed weight than that of wider inter and intra row spacings.

Table 3. The interaction effects of different inter and intra row spacings on yield contributing parameters of Soybean over locations (Metema and west Armachiho) and years (2021 to 2022).

TRT	NPPP			NSPP			HSW		
Row Spacings (cm)	Plant spacings (cm)								
	5	10	15	5	10	15	5	10	15
30	38	48	54	2.57	2.78	2.74	14.8	14.8	14.6
40	73	58	63	2.83	2.80	2.79	15.2	14.9	14.8
50	71	66	68	2.82	2.76	2.72	14.9	14.5	14.6
60	58	69	68	2.78	2.82	2.76	15.2	14.8	14.9
70	60	70	68	2.77	2.73	2.71	15.0	14.9	14.0
Mean	58.9			2.75			14.85		
CV (%)	11			10			5.5		
LSD (0.05)	9.2**			0.16*			0.04**		

3.4. Grain Yield

Interaction effects of row and plant spacings had influenced grain yield of soybean across locations and years. Notably, the highest grain yield (3,831 kg ha⁻¹) was obtained with row and plant spacings of 40 cm x 5 cm, while the lowest yield of 3,205 kg ha⁻¹ was observed with 70 cm x 15 cm spacings (Table 4). The possible reason could be that, when inter and intra row spacings decreased, the number of plants per unit area increased, resulting in higher grain yield per hectare and vice-versa. On the other reason, for grain yield enhancement under narrower row and plant spacings there might be the attainment of sufficient leaf area index to produce maximum light interception and sufficient uses of growth factors during the grain formation. Moreover, the timing of the transition from vegetative to reproductive or floral development stages and the rate of physiological development are primarily influenced by the photoperiod. On the other way, the lowest grain yields on the widest inter and intra row spacings might be due to the total yield per unit area depends not only on the

performance of individual plant but also on the number of plants per unit area. In addition, the interaction effect of 30 cm and 70 cm row spacings with all plant spacings (5, 10 and 15 cm) gave less than average mean grain yield. Moreover, the grain yield was decrease as inter row spacing increased from 40 cm to 70 cm and intra row spacings increased from 5 cm to 15 cm across locations. The widest plant spacing (15 cm) gave less grain yield interacted with all inter row spacings (30 to 70 cm). The inter row spacing 40 cm with intra row spacing 5 cm gave 275 kg ha⁻¹ and 312 kg ha⁻¹ grain yield advantages over that of blanket recommendations (40 cm x 10 cm and 60 cm x 5 cm), respectively. [18] Confirmed that a soybean record yield of 10,414 kg ha⁻¹, with a planting density of 520,000 plants ha⁻¹. [19] Reported that the high population level ensured early canopy coverage and maximized light interception, greater crop growth rate and crop biomass, resulting in increased seed numbers and yield potential of soybean. Similarly, [20] obtained 6803 kg ha⁻¹ with higher plant populations. Moreover, [21] reported that the highest grain yield (3805 kg ha⁻¹) recorded for Nyala variety at 40 cm inters row spacing.

Table 4. The effect of spacing on grain yield of soybean over locations (Metema and west Armachiho) and years (2021 to 2022).

Treatment	Grain Yield (kg/ha ⁻¹)		
	Plant spacings (cm)		
Row spacings (cm)	5	10	15
30	3338	3593	3375
40	3831	3756	3553
50	3545	3517	3436
60	3519	3739	3419
70	3532	3527	3205
Mean		3514.2	
CV (%)		13	
LSD (0.05)		329**	

3.5. Partial Budget Analysis

The cost-benefit analysis was carried out to evaluate the economic performance of different inter row and intra row spacings. The result of partial budget analysis indicated that the use of inter and intra row spacings of 40 cm x 5 cm gave

the highest net benefit (50,650 ETB/ha⁻¹) followed by 40 cm x 10 cm resulting (45,616 ETB/ha⁻¹). The row spacing 40 cm with plant spacing 5 cm gave 8,606 ETB and 7,658 ETB monetary advantages over that of blanket recommendation (40 cm x 10 cm and 60 cm x 5 cm), respectively. Therefore, use of this spacing can be considered to have an economic advantage over the use of now farmers' used technology.

Table 5. Partial budget analysis of soybean in acceptable values of inter and intra row spacings.

Treatment (cm)	UAGY (kg/ha)	AGY (kg/ha)	TVC (ETB)	GB (ETB)	NB (kg/ha)	Dominance
40 x 5	3831	3448	18317	68967	50650	
50 x 5	3445	3101	19169	62018	42849	D
70 x 5	3532	3179	19671	63585	43914	D
30 x 5	3338	3004	19773	60080	40307	D
60 x 5	3517	3165	20372	63355	42983	D
40 x 10	3756	3380	22001	67617	45616	
30 x 10	3593	3234	24835	64683	39848	D
50 x 10	3517	3165	28695	63315	34620	D
60 x 10	3539	3185	30045	63711	33666	D
30 x 15	3375	3038	32737	60758	28021	D
40 x 15	3553	3198	33363	63963	30600	D
70 x 10	3527	3174	33446	63495	30049	D
50 x 15	3436	3092	39347	61840	22493	D
60 x 15	3419	3077	41834	61550	19716	D
30 x 5	3205	2885	47236	57698	10462	D

4. Conclusion and Recommendation

Ultimately, the findings of this study showed that the optimum plant density and uniform plant distribution could enhance the grain yield and profitability of Soybean. The two-way interactions of inter row and intra row spacings were highly significant on yield related components and grain yield of soybean. The interaction effect of 40 cm row spacing with 5 cm plant spacing gave the highest grain yield and the most profitable than the other spacings. Therefore, from the results of this study it can be conclude that, for higher productivity and profitability of soybean the 40 cm row spacing with 5 cm plant spacing (75 kg ha^{-1} or 500,000 plants ha^{-1}) is recommended and could be promoted for Soybean production in the study area and similar agro-ecologies.

Abbreviations

AGY	Adjusted Grain Yield
cm	Cent Meter
CV (%)	Coefficient of Variation
DF	Days to 50% Flowering
DM	Days to 90% Physiological Maturity
D	Dominance
ETB	Ethiopian Birr
GFB	Gross Field Benefit
LSD (%)	Least Significant Difference
LPN	Length of Productive Node
kg	KILO GRAM
ha	Hectare
PH	Plant Height
NBPP	Number of Branches per Plant
NPPP	Number of Pods per Plant
NSPP	Number of Seeds per Pod
ND	Non- Dominated
Ns	Non-Significant
GY	Grain Yield
TVC	Total Variable Cost
TRT	Treatment
HSW	Hundred Seeds Weight
UAGY	Unadjusted Grain Yield
%	Percentage
**	Highly Significant
*	Significant

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Author Contributions

Melaku Azanaw: original draft, proposal preparation, conceptualization, methodology, data collection, investigation data curation, formal analysis and manuscript writing

Fentahun Biset: experiments follow up and data collection

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Additional Information

No additional information is available for this paper.

Conflicts of Interest

The authors declare no conflicts of interest.

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