



Effect of Plant Spacing on Yield Components and Yield of Soybean [*Glycine Max* (L.) Merrill] Varieties at Haro Sabu Research Center, Western Ethiopia

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Abstract: Soybean is an important crop in hot sub-moist agro-ecological zone of western Ethiopia. However, the yield of the crop is limited due to lack of recommendation on appropriate plant density for the varieties. Therefore, the experiment was conducted to determine the effect of inter and intra row spacing on growth, yield components and yield of soybean varieties in Dale Sedi District, western Ethiopia. Four inter row spacing (30, 40, 50 and 60cm) and two intra row spacing (5 and 10 cm) were evaluated on three soybean varieties (Nyala, Wello and Dhidhessa). The experimental design was randomized complete block design with three replications. Variety Nyala was earlier in attaining flowering (57.06 days), maturity (101.4days) and gave higher hundred grain weight (23.22g) than varieties Wello and Dhidhessa. The longest plant height (98.61cm), (82.19cm) and (80.14cm) were for variety Wello, from 30cm inter row and from 5cm intra row spacing, respectively. The interaction effect of variety and inter row spacing was highly significant on number of primary branches per plant, number of pods per plant and harvest index. The highest number of primary branches per plant (4.57) and number of pods per plant (65.6) was recorded from variety Wello at 60cm while the highest harvest index (43.6%) was recorded from variety Nyala at 40cm. The interaction effect of the variety and intra row spacing was highly significant on number of effective nodules and number of primary branches per plant, number of pods per plant and above ground biomass. The highest effective nodules (23.1) were recorded from variety Wello at 10cm, the highest number of primary branches (4.78) were recorded from variety Dhidhessa at 10cm intra row spacing, the highest number of pods per plant (61.49) was recorded from variety Wello at 10cm and the highest above ground biomass (12681kg ha⁻¹) was recorded from variety Wello at 5cm. The three way interaction of variety, inter and intra row spacing was highly significant on crop stand count percentage and total grain yield, where the highest crop stand count at harvest (99.77%) was from variety Nyala at 50cm inter row spacing and 5cm intra row spacing and the highest grain yield was recorded from variety Nyala (4127kg ha⁻¹) at 30cm×10cm, (3523kg ha⁻¹) and (2994kg ha⁻¹) from Wello and Dhidhessa at 40cm×10cm respectively. Therefore, 30cm×10cm is the best spacing in for high yielding of Nyala variety and 40cm×10cm is the most preferable spacing for the highest yield for Wello and Dhidhessa varieties.

Keywords: Dhidhessa, GrainYield, Inter-Row Spacing, Intra-Row Spacing, Nyala, Soybean, Wello

1. Introduction

Soybean [*Glycine max* (L.) Merrill] cultivation is originated in China around 1700-1100 B.C. Soybean is now

cultivated throughout East and South east Asia, North America, Brazil and Africa where people depend on it for food, animal feed and medicine. It is highly industrialized in developed countries, providing more than quarter of world's food and animal feed requirement in addition to protein [14].

It is grown in many parts of the world and is primary source of vegetable oil and protein for use in food, feed and industrial application. It can substitute meat and to some extent also milk. It is a crop capable of reducing protein malnutrition [12].

Soybean was first introduced to Ethiopia in 1950's because of its nutritional value, multi-purpose use and wider adaptability in different cropping systems [3]. It is a crop that can play major role as protein source for resource poor farmers of Ethiopia who cannot afford animal products. Besides, it can also be used as oil crop, animal feed, poultry meal, for soil fertility improvement and more importantly as income for the country [25]. In Ethiopia, soybean has adapted to diverse ecological niches and provided wider yield range [3].

The crop is amenable to agronomic as well as genetic improvements and has a high yield potential under good conditions and performs better in different cropping systems. Soybean production in Ethiopia was 38,166.04 ha from which 81241.833 tons produced with productivity of 2.129 tons ha⁻¹ and in Oromia region 14,626.78 ha was cultivated with production of 31,832.611 tons and a productivity of 2.176 t ha⁻¹ in 2015/2016 cropping season [6].

Though soybean can be grown in different parts of Ethiopia, the major areas currently growing the crop are situated in the western and south western parts of the country, notably Benishangul Gumuz, Gambela and parts of Oromia region. Oromia and Benishangul Gumuz regions account for the highest production of soybean in the country, 51% and 40%, respectively [29]. These areas have vast fertile land and a favorable agro-climate suited to growing soybean. Entry of large scale commercial farmers, including government sugarcane-soybean inter cropping programs, and research in soil fertility rehabilitation have made soybean a favorite crop [29]. Particularly in Kellem Wollega Zone, Dale Sedi district of the Oromia region, soybean has good potential. It is being widely used as supplementary meals, as bread combined with maize flour, *wot* (sauce) with peas, and milk for babies as well as for adults.

Inadequacy of appropriate technologies including improved varieties, plant population, planting pattern and fertilizer recommendation are the major cultural responsible for low yield in most soybean growing areas of Ethiopia. Plant population is a production factor which affects light interception by plant canopy [5]. 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 [4]. Study on the responses of early and late maturing varieties of

soybean to planting density in South western Ethiopia resulted in higher yield and yield components per m² as plant density increased from 14 to 80 plants per m² [22]. On the other hand in *Fluvisols* of southern Ethiopia, harvest index was decreased from 0.46 to 0.37 as plant population was increased from 20 to 50 plants/m² [7].

Since a number of factors such as fertility status of the soil, moisture availability, growth pattern of the varieties and cultural practices influence both inter row and intra row spacing, optimum planting density should be determined to specific area and to specific soybean varieties through conducting experiment.

Therefore, the objective of this study was to assess the effect of inter and intra row spacing on growth, yield components and yield of soybean varieties.

2. Materials and Methods

2.1. Description of the Study Area

The study was conducted at Haro Sabu Agricultural Research Center (HSARC) during the main cropping season from June to November in 2016 and 2017. The Center is located in Kellem Wollega Zone of Oromia Region at 555 km away from Addis Ababa in the western part of Ethiopia. It is located at latitude of 8°52'51"N and longitude of 35°13'18"E and altitude of 1515masl.

Haro Sabu has a warm humid climate with average minimum and maximum temperatures of 12.44°C and 28.48°C, respectively, in 2016; 12.84°C, and 28.95°C in 2017, respectively. It received average annual rainfall of 1492 mm and 1456 mm in 2016 and 2017, respectively; and its distribution pattern is uni-modal. The rain periods cover from April to October. Pre-planting soil analysis of the experimental site showed that the soil texture to be sandy clay loam, soil pH of 5.55 (moderately acidic), organic matter content of 4.6% (medium), total nitrogen of 0.23% (high), phosphorus of 6.345ppm (medium), and cation exchange capacity of 39.657 cmol(+)/kg soil (high). The area is characterized by coffee dominant based farming system and crop-livestock mixed farming system in which coffee, maize, sorghum, finger millet, common bean, soybean, sesame, banana, mango and sweet potato are the major crops [30].

2.2. Experimental Materials

Three soybean varieties Nyala, Wello and Dhidhessa were used as planting material. These varieties were adapted at the study area and selected based on their maturity group and better performance in the area. The description of the varieties is indicated in Table 1.

Table 1. Description of soybean varieties used for the study.

Characteristics	Varieties		
	Dhidhessa	Wello	Nyala
Altitude (masl)	1200-1900	750-1850	800-1700
Rainfall (mm)	1000-1200	660-1025	900-1200
Planting date	Mid June	Early July	Mid June
Fertilizer rate (kg ha ⁻¹)	P ₂ O ₅ : 46; N: 27	P ₂ O ₅ : 46; N: 18	P ₂ O ₅ : 46; N: 18

Characteristics	Varieties		
	Dhidhessa	Wello	Nyala
Days of 50% flowering	57-72	62	50
Days of 90% maturity	137-145	121	110
Plant height (cm)	60	68-70	50
Growth habit	Indeterminate	Bush and half tailing type	Indeterminate
Maturity group	Medium	Medium	Early
Flower color	Purple	White	White
100 seed weight (g)	20	12.5	17.5
Yield in research field (kg ha ⁻¹)	2000-3300	1920-3200	1800-2400
Yield in farmer field (kg ha ⁻¹)	1400-2800	1700-2200	1000-1600
Year of release	2008	2012	2014
Breeder/Maintainer	BARC/OARI	SRARC/ARARI	HwARC/SRARI and PARC/EIAR

Source: MoARD (2008); (2012); (2014)

Where ARARI, BARC, EIAR, HwARC, OARI, PARC, SRARC and SRARI are Amhara Regional Agricultural Research Center, Bako Agricultural Research Center, Ethiopian Institute of Agricultural Research, Hawasa Agricultural Research Center, Oromia Agricultural Research Institute, Pawe Agricultural Research Center, Sirinka Agricultural Research Center and South Region Agricultural Research Institute, respectively.

2.3. Treatments and Experimental Design

The treatments consisted factorial combination of three soybean varieties (Nyala, Wello and Dhidhessa); four inter row spacing (30cm, 40cm, 50cm and 60cm) and two intra row spacing (5cm and 10cm). The experiment was laid out in Randomized Complete Block Design (RCBD) and replicated three times per treatment. There were 6,7,9 and 12 rows on each plot for 60cm, 50cm, 40cm and 30cm inter row spacing, respectively, and there were 40 and 20 plants on each row for intra row spacing of 5cm and 10cm, respectively. The two outer most rows (one row from each side) of each plot and 10cm from the edge of the rows on both sides were considered as border rows. One destructive row from each plot was used for recording effective number of nodules and above ground dry biomass at physiological maturity. Thus, the net harvested plot sizes were 1.8m×1.8m (3.24m²), 1.8m×2m (3.6m²), 1.8m×2.4m (4.32m²) and 1.8m×2.7m (4.86m²) for 60 cm, 50cm, 40cm and 30cm inter row spacing, respectively.

The seeds were planted by hand at a specified spacing by placing two seeds per hill on June 23, 2016 and on July 6, 2017 and thinning was done to one plant at each specific intra row spacing ten days after seedling emergence to achieve the desired plant density in each row. Uniform dose of recommended 100 kg ha⁻¹ diammonium phosphate (DAP) (46% P₂O₅ and 18% N) fertilizer was applied to all treatments during planting. All the other agronomic practices such as land preparation, sowing time, weeding were followed as per the recommendation for the crop.

2.4. Data Collected

2.4.1. Growth Parameters

Nodulation was assessed at 50% flowering stage (mid flowering stage) of the plants. Five randomly selected plants from destructive rows were carefully uprooted and the soil adhering to the roots was removed by gently washing with tap water. To determine effective number of nodules, the inside color of nodules was observed by cutting each with the help of sharp blade and the pink to dark-red colored nodules were considered as effective nodules, while green colored were considered as non-effective.

Number of primary branches per plant was determined by counting the total number of branches from randomly selected ten plants per net plot at physiological maturity. Similarly, plant height was measured at physiological maturity from the ground level to the tip of plant from randomly sampled ten plants from harvestable rows.

2.4.2. Yield Components and Yield

Number of pods per plant was determined based on ten randomly sampled plants in each net plot area at harvest. Number of seeds per pod was determined by counting total number of seeds in pods taken from the sample and divided by the total number of pods of the sample. Hundred grain weights (g) was determined by counting 100 seeds from each plot and weighting them using a sensitive balance. To determine the above ground dry biomass, 10 plants were randomly taken from the destructive rows of each plot and weighed after sun drying till a constant weight. The dry biomass per plant was then multiplied by the total number of plants per net plot and was converted in to kg ha⁻¹. This value was used to calculate the harvest index as well. Grain yield (kg ha⁻¹) was recorded from net plot area of each plot after sun drying for 10 days and the grain yield was adjusted at 10% moisture content. Harvest index was calculated by dividing grain yield by the total above ground dry biomass yield and multiplied by 100.

2.5. Data Analysis

All the recorded and measured data were subjected to analysis of variance using 18th edition Gen Stat statistical software procedure [13]. Fisher's Protected Least significant difference (LSD) test was used to compare treatment mean differences at the probability level of 0.05.

3. Results and Discussion

3.1. Crop Phenology

The soybean varieties showed highly significant ($P < 0.001$) difference for days to 50% flowering and for days to physiological maturity while the main effects of inter row and intra row spacing and the interaction effects were not

significant in both years (Table 1). Variety Nyala was the earliest to flowering and maturity while variety Dhidhessa was late (Table 2). The significant difference observed among the varieties might be attributed to the fact that days to flowering and maturity in soybean are considered to be varietal characteristics, which are genetically controlled. In

agreement with this result, previous reports also showed that variety Nyala to be earlier than varieties Wello and Dhidhessa [21, 19, 20]. Similarly, [31] reported variety Nyala to be earlier in days to flowering and days to maturity as compared to Gizo, Gishama, Awassa-95, Wegayen, Gozella and Crawford varieties.

Table 2. Main effects of variety, inter-row spacing and intra-row spacing on days to flowering (DF) and days to physiological maturity (DM) of soybean in 2016 and 2017.

Treatment	2016		2017	
	DF	DM	DF	DM
Variety				
Dhidhessa	71.17a	134.62a	66.69a	109.83a
Nyala	57.12c	115.58b	57.00c	87.29b
Wello	66.88b	133.58a	64.38b	106.79a
P	<0.001	<0.001	<0.001	<0.001
LSD (0.05)	1.307	2.361	0.667	3.456
Inter-row spacing (cm)				
30	64.17	127.39	62.72	99.72
40	65.94	129.28	62.61	103.28
50	65.06	128.17	63.00	102.33
60	65.06	126.89	62.42	99.89
P	0.147	0.327	0.504	0.201
LSD (0.05)	NS	NS	NS	NS
Intra-row spacing (cm)				
5	64.86	127.67	62.77	102.25
10	65.25	128.19	62.61	100.36
P	0.467	0.584	0.566	0.185
LSD (0.05)	NS	NS	NS	NS
CV (%)	3.5	3.2	1.8	5.9

Means in columns followed by the same letter(s) or no letter are not significantly different at 5% level of significant; P = Level of probability, LSD (0.05) = Least Significant Difference at 5% level probability, CV = Coefficient of variation, ns = non-significant.

In line with this result, [1, 18] reported non-significant effects of plant spacing on days to flowering and days to maturity on common bean. In contrast, [11] reported significant effect of intra row spacing on days to flowering on soybean varieties in which days to flowering were increased as intra row spacing increased from 5 cm to 15 cm. The reason for the higher days to physiological maturity in 2016 might be due different in sowing date and climatic factor fluctuation.

3.2. Growth Parameters

3.2.1. Plant Height

Plant height was significantly ($P < 0.001$) affected by the main effects of variety in both years, intra-row spacing in 2016 ($P = 0.002$) and inter-row spacing in 2017 ($P = 0.019$) (Table 2). The highest plant height of 84.7 cm in 2016 and 112.5 cm in 2017 were recorded for the variety Wello while the shortest height in both years was recorded for variety Nyala (Table 2). The significant difference in plant height

among the varieties might be due to the fact that early maturing variety Nyala with short duration for dry matter accumulation having the shortest plant height and the late maturing varieties achieving higher plant height. In conformity with this result, [23] reported that medium-maturing soybean variety Afgat had higher plant height (58.0 cm) than the early-maturing variety Awassa-95 (32.9 cm).

With respect to the effect of inter-row spacing, the plant height was increased as the inter row spacing was decreased in 2017 (Table 3). Likewise, the 5 cm intra-row spacing had taller plants than the 10 cm spacing. The increase in plant height with narrow spacing could be due to the lower amount of light intercepted by a single plant resulting into increased inter node length and also under higher plant density there might be comparatively low solar interception through crop canopy and plants become thinner and taller in search of solar radiation. In agreement with this result, [28] observed that increasing the density of plants led to enhances in plant height of soybean.

Table 3. Main effects of variety, inter-row spacing and intra-row spacing on plant height in 2016 and 2017 and on the number of effective nodules per plant of soybean in 2017.

Treatment	2016	2017	Number of effective nodules per plant
	Plant height (cm)	Plant height (cm)	
Variety			
Dhidhessa	76.69b	98.1b	4.1 (16.8)
Nyala	42.3c	53.5c	3.8 (14.4)
Wello	84.7a	112.5a	4.3 (18.4)

Treatment	2016	2017	Number of effective nodules per plant
	Plant height (cm)	Plant height (cm)	
P	<0.001	<0.001	0.359
LSD (0.05)	3.137	5.68	NS
Inter-row spacing (cm)			
30	70.49	93.9a	4.0 (16.3)
40	66.79	88.9ab	4.1 (16.8)
50	67.58	84.1b	3.8 (14.5)
60	66.73	85.2b	4.3 (18.5)
P	0.137	0.019	0.563
LSD (0.05)	NS	6.56	NS
Intra-row spacing (cm)			
5	69.99a	90.3	4.2 (18.1)
10	65.81b	85.8	3.9 (14.9)
P	0.002	0.056	0.138
LSD (0.05)	2.561	NS	NS
CV (%)	8	11.1	25

*Values in side bracket are original records while values outside the bracket are square root transformed.

Means in columns followed by the same letter(s) or no letter are not significantly different at 5% level of significant; P = Level of probability, LSD (0.05)= Least Significant Difference at 5% level of probability, CV= Coefficient of variation, NS= Non-significant.

Table 4. Interaction effect of variety and intra row spacing on number of effective nodules per plant of soybean in 2016.

Variety	Intra-row spacing (cm)	Number of effective nodules per plant*
Dhidhessa	5	3.93 (15.47)b
	10	3.82 (14.58)b
Nyala	5	4.26 (18.18)ab
	10	3.42 (11.70)b
Wello	5	3.69 (13.62)b
	10	4.81 (23.1)a
P		0.005
LSD (0.05)		0.78
CV (%)		24.4

*Values in side bracket are original records while values outside the bracket are square-root transformed.

Means in columns followed by the same letter(s) are not significantly different at 5% level of significance; P=Level of probability, LSD (0.05) = Least Significant Difference at 5% level of probability, CV = Coefficient of variation.

3.2.2. Number of Effective Nodules

The main effects of variety, inter row spacing and intra row spacing were not significant on the number of effective nodules per plant in 2016 while the interaction effect of variety and intra row spacing was highly significant ($P=0.005$) in 2017 (Tables 3 and 4). The highest number of effective nodules per plant (23.1) was recorded for variety Wello at intra row spacing of 10 cm while the lowest number of effective nodules (11.7) was recorded for variety Nyala at intra row spacing of 10 cm (Table 4). Moreover, variety Wello recorded significantly higher effective number of nodules per plant than varieties Dhidhessa and Nyala at 10 cm intra row spacing while varieties Dhidhessa and Nyala revealed higher effective number of effective nodules at 5 cm intra row spacing. The increase in the number of effective nodules in response to the narrower spacing for varieties Dhidhessa and Nyala might be attributed to the requirement for uptake of more nutrients might have prompted the plants to produce more number of

effective nodules. However, at the lowest plant population, plants might have utilized the available soil or applied nitrogen than fixation of nitrogen. In line with this result, [9] reported higher numbers of effective nodules per plant (10.08) at intra row spacing of 5 cm as compared to lower (8.25) at 10 cm (wider) intra row spacing for variety Dhidhessa. Similarly, [23] obtained less numbers of effective nodules under wide inter row spacing as row spacing was increased from 20 cm 60 cm on soybean. The difference in nodulation among the varieties might be attributed to their genetic characters such as root system architecture and the distribution of roots.

3.2.3. Number of Primary Branches Per Plant

The interaction effect of variety with inter-row spacing and intra row spacing were significant ($P=0.020$) and highly significant ($P<0.001$), respectively, in 2016 (Table 5). Varieties Wello and Dhidhessa gave significantly the highest number of primary branches of 4.6 and 4.2, respectively; at 60 cm inter row spacing while significantly the lowest numbers of primary branches per plant were recorded for all the varieties at 30 cm inter row spacing (Table 5). Similarly, significantly higher numbers of primary branches for all the varieties were recorded at the intra-row spacing of 10 cm (Table 5).

The interaction of inter row spacing and intra-row spacing and the main effect of variety were significant on the number of primary branches in 2017 (Table 6). Significantly highest numbers of primary branches per plant were recorded from inter-rows pacing of 40 cm and 50 cm spacing at 10 cm intra-row spacing (Table 6). The increased number of branches at the wider plant spacing could be attributed to more availability of growth resources such as light, soil moisture and nutrients per plant for lateral vegetative growth of the crop resulting in more number of primary branches per plant. In line with this result, [17] obtained higher number of branches (7.9) at the wider plant spacing (70 cm \times 20 cm) than narrower spacing (70 cm \times 5 cm) (5.5) for soybean and attributed this to more interception of sunlight for

photosynthesis, which may have resulted in production of more assimilate for partitioning towards the development of more branches. Similarly, [16] reported higher number of primary branches (8.56 and 7.68) of soybean at wider spacing (60 cm and 50 cm) than narrow spacing (40 cm and 30 cm) (6.67 and 5.67). [9] also obtained more number of branches per plant (5.95) of soybean in 60 cm inter row spacing than in 30 cm inter row spacing (4.47).

Among the varieties, Wello and Dhidhessa gave significantly highest numbers of primary branches per plant than variety Nyala (Table 6). The significant differences in number of primary branches among the varieties could be due to the differences in maturity since varieties Wello and Dhidhessa are medium maturing with higher vegetative growth resulting in more number of branches. Similarly, [9] reported 12.6% higher mean number of primary branches per plant for variety Dhidhessa than variety Boshe.

Table 5. Interaction effects of variety with inter row spacing and intra rows pacing on the number of primary branches per plant of soybean in 2016.

Inter-row spacing (cm)	Variety		
	Dhidhessa	Nyala	Wello
30	2.3f	2.6ef	2.3f
40	3.5bcd	2.8def	3.0def
50	4abc	3.3cd	4.1ab
60	4.2a	3.2de	4.6a
P		0.02	
LSD (0.05)		0.69	
Intra-row spacing (cm)			
5	2.2c	2.6c	2.6c
10	4.8a	3.3b	4.4a
P		<0.001	
LSD (0.05)		0.49	
CV (%)		17.8	

Means in the table followed by the same letter (s) are not significantly different at 5% probability level; P =Level of probability, LSD (0.05) = Least Significant Difference at 5% level, CV = Coefficient of variation.

Table 6. Interaction effect of inter row spacing and intra row spacing and main effect of variety on the number of primary branches per plant of soybean in 2017.

Inter row spacing (cm)	Intra row spacing (cm)	
	5	10
30	3.77c	5.29ab
40	5.1b	6.29a
50	5.7ab	6.22a
60	5.9ab	5.43ab
P	0.047	
LSD (0.05)	1.041	
Variety		
Dhidhessa	5.87a	
Nyala	4.64b	
Wello	5.88a	
P	<0.001	
LSD (0.05)	0.637	
CV (%)	20.1	

Means in the table followed by the same letter(s) are not significantly different at 5% probability level; P = Level of probability, LSD (0.05) = Least Significant Difference at 5% level, CV = Coefficient of variation.

3.3. Yield Components and Yield

3.3.1. Number of Pods Per Plant

The main effects of variety, inter row spacing and intra row spacing were highly significant ($P < 0.001$) on the number of pods per plant in both years. Moreover, the interaction effect of variety and inter-row spacing was also highly significant ($P = 0.005$) in 2016 while all the interactions were non-significant in 2017 (Tables 7 and 9). In 2016, the highest mean number of pods per plant (49.8) was recorded for variety Wello at 60cm inter row spacing while the lowest number of pods per plant (21.7) was recorded for variety Nyala at 30cm inter row spacing (Table 7).

Table 7. Interaction effect of variety and inter-row spacing on the number of pods per plant of soybean in 2016.

Inter-row spacing (cm)	Variety		
	Dhidhessa	Nyala	Wello
30	23.3g	21.7g	28.5ef
40	31de	25.8fg	33.1cde
50	34.3cd	30.2def	40.6b
60	36.7bc	29ef	49.8a
P	0.005		
LSD (0.05)	5.12		
CV (%)	13.8		

Means in the table followed by the same letter(s) are not significantly different at 5% probability level; P = Level of probability, LSD (0.05) = Least Significant Difference at 5% level, CV = Coefficient of variation.

In 2017, varieties Wello and Dhidhessa produced significantly highest number of pods per plant of 91.5 and 89.9, respectively, than variety Nyala (67.2) (Table 9) which might be due to more number of branches and higher plant height for the late maturing varieties. In agreement with this result, [26, 9] reported less number of pods per plant for soybean varieties with less number of branches per plant.

As the inter-row and intra-row spacing increased, the number of pods per plant also increased. The highest number of pods per plant (97.8) was recorded at the widest inter-row spacing of 60 cm while the lowest number of pods per plant (60.7) was recorded at the narrowest inter-row spacing of 30 cm. Likewise, wider intra-row spacing of 10 cm produced significantly higher number of pods per plant (92.4) than 5 cm spacing (73.4) (Table 9). The decrease in the number of pods per plant with increased plant density might be due to competition between the former and later emerged flowers that resulted in flower abortion. In wider inter and intra-row spacing, however, the growth resources (nutrient, moisture and light) for the plants might be easily accessible that retained more number of primary branches and more flowers contributing to higher number of pods per plant. In line with this result, [15] reported highest number of pods per plant of soybean varieties at lower plant population (166,667 plants per hectare) and the lower number of pods per plant at the highest plant population (400000 per hectare).

3.3.2. Number of Seeds Per Pod

The main effects of variety, inter and intra row spacing

as well as their interaction had no significant effect on number of seeds per pod in both years except the effect of intra-row spacing in 2016 which was significant ($P=0.025$) (Tables 8 and 9). The number of seeds per pod ranged from 2.00 to 2.22. The lack of significant difference in the number of seeds per pod among the treatments might be due the fact that the number of seeds per pod is primarily depends on type of legume species and is a relatively stable

character that typically does not respond to seeding rates or row spacing [10]. In line with this result, [16, 24 32, 11] reported non-significant effect of variety and plant spacing on number of seeds per pod of soybean varieties. In contrast, [23] reported significant difference among soybean varieties on the number of seeds per pod that ranged from 1.99 to 2.38 regardless of row spacing and interaction of variety and row spacing.

Table 8. Main effects of variety, inter-row spacing and intra-row spacing on yield components, yield and harvest index of soybean in 2016.

Treatment	NSPP*	HGW (g)	ADB (kg ha ⁻¹)	GY (kg ha ⁻¹)	HI (%)
Variety					
Dhidhessa	2.01	15.03b	7681.98b	2641.3b	36.08b
Nyala	2.08	19.91a	6921.34b	3072.0a	44.81a
Wello	2.06	13.26c	8857.27a	2892.1a	34.54b
P	0.24	<0.001	<0.001	0.004	<0.001
LSD (0.05)	NS	0.55	764.49	243.21	4.98
Inter row spacing (cm)					
30	2.00	16.40	8785.16a	2890.4	34.18b
40	2.04	15.98	8020.00ab	2892.7	37.43ab
50	2.08	16.00	7702.93b	2971.6	40.39a
60	2.10	15.88	6772.69c	2719.1	41.90a
P	0.228	0.369	<0.001	0.333	0.047
LSD (0.05)	NS	NS	882.75	NS	5.75
Intra row spacing (cm)					
5	2.01b	16.24	8241.03a	2833.2	36.00b
10	2.09a	15.89	7399.36b	2903.8	40.95a
P	0.025	0.128	0.009	0.478	0.018
LSD (0.05)	0.07	NS	624.202	NS	4.06
CV (%)	7.2	5.9	16.8	14.6	22.3

*NSPP=Number of seeds per pod, HGW=hundred grain weight, ADB= above ground dry biomass, GY= grainyield, and HI= harvest index
Means in the columns followed by the same letter(s) or no letter are not significantly different at 5% probability level; P= Level of probability, NS = Non-significant, LSD (0.05) = Least Significant Difference at 5% level, CV = Coefficient of variation.

Table 9. Main effects of variety, inter-row spacing and intra-row spacing on yield components and harvest index of soybean in 2017.

Treatment	NPP*	NSPP	HGW (g)	HI (%)
Variety				
Dhidhessa	89.9a	2.08	18.82b	30.28b
Nyala	67.2b	2.17	26.53a	39.99a
Wello	91.5a	2.22	17.57c	30.4b
P	<0.001	0.478	<0.001	<0.001
LSD (0.05)	10.55	Ns	0.664	4.655
Inter row spacing (cm)				
30	60.7c	2.18	21.37	29.89b
40	78.3b	2.08	20.83	31.92b
50	94.7a	2.22	20.92	34.85ab
60	97.8a	2.15	20.78	37.57a
P	<0.001	0.749	0.409	0.033
LSD(0.05)	12.18	NS	NS	5.375
Intra row spacing (cm)				
5	73.4b	2.12	20.69b	31.15b
10	92.4a	2.20	21.26a	35.97a
P	<0.001	0.386	0.039	0.014
LSD (0.05)	8.61	NS	0.542	3.8
CV (%)	21.9	18.0	5.5	23.9

*NPP=Number of pods per plant, NSPP = Number of seeds per pod, HGW=hundred grain weight, and HI=harvest index.
Means in the columns followed by the same letter(s) or no letter are not significantly different at 5% probability level; P= Level of probability, NS= Non-significant, LSD (0.05) = Least Significant Difference at 5% level, CV= Coefficient of variation.

3.3.3. Hundred Grains Weight

The main effect of variety was highly significant ($P<0.01$) on hundred grains weight of soybean in both years while the other effects were non-significant except the effect of intra-row spacing which was significant ($P=0.039$) in 2017 (Tables 8 and 9). Variety Nyala had significantly the highest hundred seed weight of 19.91g in 2016 and 26.53g in 2017 while variety Wello had the lowest hundred grains weight in both years (Tables 8 and 9). The significantly highest hundred grains weight for the variety Nyala might be due to the lowest number of pods per plant which might have resulted in less competition among the pods resulting in higher hundred grains weight. The highest hundred seed weight for variety Nyala in 2017 might be due to its highest adaptability and performance in the studied area. Inconformity with this result, [33] reported that inter row spacing did not significantly affect 100 grains weight of soybean genotypes across seasons and sites whereas genotype and season had significant influence on 100 grains weight. Similarly, [9, 23] reported significance difference among soybean varieties on 100 grains weight regardless of plant density.

3.3.4. Above Ground Dry Biomass Yield

The main effects of variety, inter-row and intra-row spacing were highly significant ($P<0.01$) on the above ground dry biomass yield while none of the interactions were

significant in 2016 (Table 8). On the other hand, the main effects of inter-row spacing, intra-row spacing and the interaction of variety and intra-row spacing were highly significant ($P < 0.001$) on the above ground dry biomass in 2017 (Table 10).

Table 10. Interaction effect of variety and intra row spacing and main effect of inter row spacing on above ground dry biomass (kg ha^{-1}) of soybean in 2017.

Variety	Intra-row spacing (cm)	
	5	10
Dhidhessa	11956.1b	10909.7b
Nyala	10835.39b	10014.44bc
Wello	15550.7a	8058.71c
P	<0.001	
LSD (0.05)	2509.1	
Inter-row spacing (cm)		
30	13223a	
40	12192ab	
50	10623bc	
60	8846c	
P	<0.001	
LSD (0.05)	2048.67	
CV (%)	27.2	

Means in the table followed by the same letter(s) are not significantly different at 5% probability level; P = Level of probability, LSD (0.05) = Least Significant Difference at 5% level, CV = Coefficient of variation.

In 2016, the highest above ground dry biomass ($8857.27 \text{ kg ha}^{-1}$) was recorded for variety Wello, for inter-row spacing of 30 cm ($8785.16 \text{ kg ha}^{-1}$) and intra-row spacing at of 5 cm ($8241.03 \text{ kg ha}^{-1}$) (Table 8). Similarly, in 2017, the highest above ground dry biomass ($15550.7 \text{ kg ha}^{-1}$) was recorded for variety Wello 5 cm intra-row spacing (Table 10). In general, the above ground dry biomass was increased with decreased inter-row and intra-row spacing which might be due to more number of plants per unit area. In line with this result, [33] reported that planting soybeans at an inter row spacing of 45 cm (narrower) accumulated more biomass (3383 kg ha^{-1}) than at inter row spacing of 75 cm (2424 kg ha^{-1}). Similarly, [23] obtained the highest total dry biomass of soybean at narrow row spacing (40 cm) than the widest row spacing (60 cm).

3.3.5. Grain Yield

In 2016, only the main effect of variety was highly significant ($P = 0.004$) on grain yield of soybean (Table 8) while in 2017 the three way interaction of variety, inter-row spacing and intra-row spacing was significant ($P = 0.024$) on grain yield (Table 11). The highest grain yield ($3071.97 \text{ kg ha}^{-1}$) was recorded for variety Nyala in 2016 while the lowest grain yield ($2641.3 \text{ kg ha}^{-1}$) was recorded for variety Dhidhessa (Table 8). In 2017, the highest grain yield ($5074.5 \text{ kg ha}^{-1}$) was recorded for variety Nyala at 30 cm inter and 10 cm intra row spacing followed by same variety at 40 cm inter and 5 cm intra-row spacing ($4697.05 \text{ kg ha}^{-1}$) (Table 11). This highest grain yield might be the result of hundred seed weight which leads to better performance and adaptation ability of the variety. In contrast, the lowest grain yield (1928.74) was recorded for variety Wello at 60 cm inter and 10 cm intra row spacing ($1928.74 \text{ kg ha}^{-1}$) (Table 11). The

highest grain yield for variety Nyala in both years could be attributed to its biggest seed size as compared to the other varieties. The increased grain yields in response to closer inter-row spacing in 2017 could be due to high population ensured early canopy coverage, maximized light interception resulting in greater crop growth rate and crop biomass thereby increased grain yield. In agreement with this result, [27] reported the highest grain yield (2.46 t ha^{-1}) of soybean for 40 cm \times 5 cm spacing. Similarly, [9] reported the highest grain yields of soybean (2533 kg ha^{-1}) at 40 cm \times 7.5 cm for variety Dhidhessa. [8] also reported that the increase in row from 38 cm-76 cm spacing can result in decreasing of soybean grain yield from 4641 kg ha^{-1} to 4393 kg ha^{-1} .

Table 11. Interaction effects of variety, inter-row spacing and intra-row spacing on grain yield (kg ha^{-1}) of soybean in 2017.

Variety	Intra-row spacing (cm)	Intra-row spacing (cm)	
		5	10
Dhidhessa	30	3414.03c-g	3315.21c-g
	40	3468.28c-g	3545.11c-g
	50	2876.93gh	3036.37g
	60	3104fg	3120.44fg
Nyala	30	4270.33abc	5074.5a
	40	4697.05ab	4078.78bcdef
	50	4147.55abcde	3288.95d-g
	60	3690.19c-g	3330.56c-g
Wello	30	3217.6efg	3395.18c-g
	40	4233.13abcd	1969.21h
	50	3564.19c-g	3755.29b-g
	60	3697.87c-g	1928.74h
P		0.024	
LSD (0.05)		981.324	
CV (%)		17	

Means in the table followed by the same letter(s) are not significantly different at 5% probability level; P = Level of probability, LSD (0.05) = Least Significant Difference at 5% level, CV = Coefficient of variation.

3.3.6. Harvest Index

Harvest index is a measure of the ability of a crop to convert the dry matter in to economic yield. The main effects of variety, inter row spacing and intra-row spacing were significant on harvest index of soybean while the interaction effects were non-significant in both years (Tables 8 and 9). Among the varieties, variety Nyala had the highest harvest index of 44.81% in 2016 and 39.99% in 2017 (Tables 8 and 9) which could be attributed to its early maturity which resulted in highest grain yield as compared to the biomass yield. In line with this result, [2] reported higher harvest index values (44.3%) with early maturing soybean cultivars relative to late maturing varieties (35.0%). Similarly, Dereje (2014) reported significant difference in harvest index between the varieties of soybean varieties with 40.3% for variety Dhidhessa than for variety Boshe (37.4%).

With respect to the effect of plant spacing, the harvest index was increased as both the inter-row and intra-row spacing increased in both years. As the inter row spacing increased from 30 cm to 60 cm, the harvest index was increased from 34.18% to 41.9% in 2016 (Table 8), and from 29.89% to 37.57% in 2017 (Table 9). Similarly, in both years, the wider intra-row spacing of 10 cm gave significantly

higher harvest index. The highest harvest index at the lowest plant density might be due to less interplant competition for growth resources such as nutrients, water and solar radiation which could have resulted in more partitioning of the biomass to the grain. In agreement with this result, [7] reported the highest harvest index (46%) of soybean from 20 plants/m² and the lowest harvest index (37%) from 50 plants/m². Likewise, [9] reported that soybean inter row spacing of 60 cm gave the highest harvest index (41.9%) than 30 cm (34.18%).

4. Conclusion

Soybean varieties, inter and intra row spacing showed significant differences for major crop growth parameters, yield components and yield in 2016 and 2017. Variety Nyala was earlier to initiate flower and to reach physiological maturity, gave higher hundred grain weight and main effect of inter row spacing revealed significant effect on days to 90% physiological maturity in both consecutive years. The interaction effect of variety and inter row spacing revealed highly significant on, number of primary branches per plant, number of pods per plant and harvest index. Likewise the interaction effect of variety and intra row spacing was highly significant on number of effective nodules, number of primary branches per plant, number of pods per plant, and above ground biomass. The three way interaction of variety, inter row spacing and intra row spacing was highly significant on crop stand count percentage at harvest and on grain yield. From the results of this study it can be concluded there was variety specific spacing which direct 30 cm x 10 cm is the best spacing in increasing the productivity of Nyala variety and 40 cm x 10 cm is the most preferable spacing for the highest yield Wello and Didhessa varieties.

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