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Study of Plant population Density on Recently Released Soybean (*Glycine max*. L.) Varieties in Jimma, South Western Ethiopia

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Abstract: *In Ethiopia, Soybean (Glycine max. L.) is one of the most prominent pulse crop recently and in the study area in particular. However, its yield is low due to a lack of appropriate plant densities, lack of improved varieties and unavailability of other modern crop management inputs. Therefore, a field experiment was conducted during 2020-2022 for three main cropping seasons in Karsa and Omonada woreda, southwestern Ethiopia to determine the effects of plant densities on growth, yield and yield components of Soybean varieties. The experiment consisted of two varieties soybean Clark-63k (prostrated type) and Nyala (compacted type) and four plant population densities (666,667, 500,000, 400,000 and 333,333plants ha^{-1}). A 2 X 4 factorial arrangement and laid out in a randomized complete block design with three replications. The combined locations analysis was done using SAS 9.3 software. The agronomic parameters showed that /highly/ significant effect (P<0.01) for both the main effects of plant densities and varieties. Neither varieties nor plant population densities showed an interaction (P>0.05) effect on plant height, pod height, number of pods per plant, number of seeds per pod, grain yield and above ground biomass and harvest index of soybean. Soybean varieties did not show a significant effect on grain yield across locations and cropping seasons. The highest grain yield (3496.55 kg ha^{-1}) was obtained from a plant density of 666,667 plants ha^{-1}while the lowest grain yield (2853.07 kg ha^{-1}) was obtained from a plant population of 333,333 plants ha^{-1}. The highest plant density of 666,667 plants ha^{-1} gave the highest above ground biomass of 12.63 ton ha^{-1} while the lowest above ground biomass of 7.81 ton ha^{-1} was recorded from 333,333 plants ha^{-1}. The mean grain yield, and above ground biomass accumulation of soybean were increased with increased planting density. Partial budget analysis revealed that the maximum net benefit of 70765 ETB ha^{-1} with a Marginal rate return of 527% was obtained from plant density of 666,667 plants ha^{-1} (30 x 5cm). Hence, the economic optimal plant density of 666,667 plants ha^{-1} with clark 63k or Nyala variety resulted in enhanced grain yield of soybean with acceptable economic benefit and recommended for farmers in the study area and adjacent woreda' with similar agro-ecologies.*

Keywords: *C Grain yield, Plant density, Soybean, Varieties*

1. INTRODUCTION

Soybean (*Glycine max. L.*) is one of the most important and widely grown legume crops worldwide due to its multipurpose use particularly in the animal feed industries and human nutrition. Its high quality protein and balanced amino acid profile in ration formulation and human diets are the driving forces of soybean production (Shea *et al.*, 2020). In 2020, world production of soybeans was over 353 million tones, led by Brazil (122) and the United States (113) combined with 66% of the total. Production has dramatically increased across the globe since the 1960s, but particularly in South America after a cultivar that grew well in low latitudes was developed in the 1980s (Cattelan and Dall'Agnol, 2018). Large-scale commercial and small scale farmers have the respective share of 80% and 20 in global soybean production (Voora *et al.*, 2020). The rapid growth of the industry has been primarily fueled by large increases in world wide demand for meat products, particularly in developing countries like China, which alone accounts for more than 60% of imports (OEC, 2020).

Soybean was introduced to Sub-Saharan Africa through Chinese traders in the 19th century for the first time. It was cultivated as a commercial crop in early 1903 in South Africa (Khojely *et al*., 2018). According to Yechalew *et al* (2020) world share of global soybean in sub-Saharan countries is very low. However, soybean production and productivity in sub-Saharan Africa counter indicate increasing trends in the past ten years and expected to increase in the future both in production and productivity.

In Ethiopia, soybean has been cultivated since 1950s expanding into different agro-ecologies accompanied by increasing domestic demand as food and feed yet with low grain yield (Hailu and Kelemu, 2014). 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, and poultry meal, for soil fertility improvement and more importantly as income for the country. Soybean is known for its wide adaptability coupled with its higher productivity per unit area than other grain legumes. Soybean grows in altitudes ranging from 1250-2200 m.a.s.l but performs well between 1300-1700 m.a.s.l. and can also be grown in an area receiving 450 to 1500 mm annual rainfall (Mesfin and Abush, 2018). Ethiopia has huge potential for soybean production although the current production status is not comparable to the existing potential (Tesfaye *et al.*, 2018). In Ethiopia records obtained from 2019 data indicated that area production and yield of soybean from 64,720.12 ha of land was 149,454.6 tones with national average yield of 2.309 tons ha^{-1} (CSA, 2019). The demand of soybean is increasing from time to time. Currently soybean is one of the focus subsectors supported by government and nongovernmental organization. Soybean can be grown in different parts of Ethiopia notably in the western and south western parts of the country (Benishangul Gumuz, Gambela and parts of Oromia region). These areas have vast fertile land and a favorable agro- climate suited to growing soybean.

Despite its high production potential and economic importance, the level of adoption of improved soybean varieties and dissemination constrained by many factors (Abebe, 2018). Although Ethiopia started soybean research in the early 1950's, its productivity is below potential and far from other soybean producer countries. Promising progress has been recorded particularly in the breeding program focusing on the breeding objectives of grain yield, disease resistance, resistance of shattering and maturity (Getnet, 2019). Low productivity of the crop is always associated with lack appropriate production technologies (Adebayo *et al*., 2018). Use of improved soybean variety had a positive and significant effect on crop productivity.

According t o Tufa *et al* (2019) reported that 61% of yield gain and income increment achieved for use improved varieties. According to Teshale (2019) revealed that soybean productivity increased by 15% for those farmers who adopted improved soybean variety. Soybean production in this area is projected to grow from about 1.5 million tons in 2010 to about 2 million tons in 2020, representing a growth rate of 2.3% per annum to meet the predicted demand (Abate *et al*., 2012). Oromia is one the potential regions of Ethiopia in soybean production. The crop is producing in Jimma, Ilu Aba boor and Buno Bedele administrative zones of the region. Although the region has untapped potential regarding soybean production, its production is below the existing potential due to lack of using improved soybean varieties with recommended agronomic packages (inappropriate seed rate, suboptimum plant density, poor soil fertility, insects, diseases and weeds, farmers' limited access to fertilizers, and low access to seeds of improved soybean varieties) for its utilization. Plant density is an important component of yield in soybean and hence, it is important to determine the optimum plant population density for different areas, since the areas have different potential for soybean growth, with some areas having the capacity to support high plant density without a compromise in yield (Masuda and Goldsmith, 2009). Studies by Taylor (1980) have shown that soybean respond differently to different environmental conditions and these environmental differences would lead to differences in yield between seasons. Rainfall and soil moisture must be optimized when considering effects of plant density on soybean yield (Bertram and Pedersen, 2004). Higher plant densities compared to lower plant density have consistently produced higher seed yields in Northern USA where indeterminate early maturing varieties are used (Ball *et al.*, 2000).

Increased seed rate influenced yield to a point, while yield will eventually reach a maximum at which addition of more seed will do nothing to increase yield (Ball *et al*., 2000). The study done in Ethiopia has revealed that different soybean varieties an increase in seed yield per unit area as row spacing (RS) decreased, but it did not identify optimum plant density for high yield, nodulation and weed control (Worku and Astatkie, 2011). Duncan (1984) also reported that plant density above critical density has a negative effect on yield per plant due to the effects of interplant competition for light, water, nutrients and other potential yield-limiting environmental factors. Because of this discrepancy, the establishment of required plant density is essential to get maximum yield since high plant density will deplete soil moisture and nutrients before the crop's maturity, whereas low plant density will leave nutrients unutilized (Chandrasekaran *et al*., 2010).

Released soybean varieties (Clarck-63k and Nyala) were well adopted varieties in the Jimma, South Western part of Ethiopia. However, optimum plant density has not been determined for Clarck-63k and Nyala soybean in the study area during the main season. In the absence of recommended optimum plant density for soybean varieties, the productivity will be affected, and difficult to apply proper farm management practices. Therefore, this research work was designed to answer "what is the optimum plant density of soybean varieties, under Jimma agroecology condition during main season. Therefore, the objectives of this research were (1) To evaluate the response of morphologically different Soybean varieties to plant population density. (2) to identify the economic feasibility of plant population density for soya bean production.

2. Materials and Methods

2.1 Description of the study area

The field experiment was conducted at Karsa and Omonada districts of southwestern Ethiopia under rain fed conditions during the main cropping season of 2020-2022. The two districts were selected purposively since they are the major soybean producers in southwestern Ethiopia. Karsa is located at latitude 7º42' N and longitude 36º 59'E and laid at an altitude of 1753 m.a.s.l. The average minimum and maximum temperature is 6ºC and 25.5ºC respectively and reliably receives good rains 1712 mm per annum during cropping season. Whereas, Omonada site is located at latitude 7º72' N and longitude 37º 26'E and laid at an altitude of 1751 m.a.s.l (GPS, 2022). The average minimum and maximum temperature is 6ºC and 25ºC respectively and reliably receives good rains 1446 mm per annum cropping season. The farming system of the study site is coffee and cereal crops dominated with coffee, maize, teff and sorghum also has warm and cold climate, also convenient topography is very suitable for all agricultural practices. It was situated in the tepid to cool humid-mid highlands of southwestern Ethiopia.

2.2 Experimental Materials

Two soya bean varieties, Clark 63k and Nyala were used for this study. The seeds of both varieties for this experiment were obtained from Jimma Agricultural Research Center.

Table1. *Description of the soybean varieties, maturity type, altitude, year of release and ecology of adaptation soybean varieties used for the study.*

Varieties	Year of release	Altitude (m a s l)	Rain fall (mm)	Maturity Type
Clark 63k (prostrated type)	1981/2	1000-1700	900-1300	Medium
Nyala (compacted type)	2014	1200-1800	900-1300	Medium

Source: MOANR (2016)

2.3 Treatment and Experimental Design

The treatments consisted of two soybean varieties (Clark 63k and Nyala) and four plant population densities (666,667, 500,000, 400,000 and 333,333 plants ha^{-1}) resulting in 8 treatments combinations. The experiment was carried out in 2 X 4 factorial experiment arranged in a RCBD with three replications. Thus, there were a total of 24 experimental units or plots (Table 2). The blocks were separated by 1.5 m wide space and each plot was separated by 1 m space. Following the specifications of the design, each treatment was assigned randomly to experimental units within a block. All data were determined in the center of a minimum of six rows of each plot. The plot had 8,9,11 and 15 rows based on inter-row spacing. The outermost rows at both sides of plots were considered as borders. As the inter spacing varied the net plot area also varied. Therefore, the net plot size of (0.6

m x 6) X 3 m = 10.8 m^2 , (0.5 m X 7) X 3 m = 10.5 m^2 , (0.4 X 9 m) X 3 m =10.8 m^2 and (0.3 m X 13) X 3 m = 11.7 m^2 , respectively were used.

Table2. *Details of treatment combination of varieties and plant densities*

Varieties	Inter- row x Intra- row spacing (cm)	Plant density (ha^{-1})
	30 x 5	666,667
	40 x 5	500,000
	50 x 5	400,000
Clark 63k	60x 5	333,333
	30 x 5	666,667
	40 x 5	500,000
	50 x 5	400,000
Nyala	60x 5	333,333

2.4 Experimental Procedure and Crop Management

The land was ploughed, disked, and harrowed by oxen and seed was drilled per row and thinned after two weeks of planting on 10 the June of 2020, 11 the June of 2021 and 13 the June of 2022. Before sowing the crop and the field was plowed with oxen three times to make a fine seed bed. The outermost rows at both sides of plots were considered as borders. Fertilizers were applied at planting with the rate of 46 kg N ha^{-1} and 46 kg P_2O_5 ha^{-1}. The nitrogen fertilizer was applied as split, half of the nitrogen fertilizer together with 46 kg P_2O_5 ha^{-1} while the remaining half dose of N was applied four weeks after emergence. Then, all the remaining necessary agronomic practices and crop management activities were undertaken as recommended and in line with the practices followed by the Jimma Agricultural Research Center. Harvesting was done manually when the crop reached harvest maturity.

2.5 Data collection

2.5.1 Growth and yield parameters

Plant height (PH): Plant height was measured from the ground level to the tip of plants when the plant was reach at 90% physiological maturity stage.

Pod Length: It was measured from ground to where branching started at 50% flowering from five randomly selected plants.

Number of pods per plant (NPPP): were recorded from five randomly selected plants from the net plot area and the average was taken for the determination of number of pods per plant

Number of seeds per pod (NSPP): were determined from five pods taken from the five sampled plants.

Grain yield (GY): was determined from the net harvestable area and adjusted to 10% moisture level and grain yield obtained from the net harvestable area was converted to hectare basis.

Above ground biomass yield (AGB):five plants from the experimental unit was selected randomly, harvested at physiological maturity, weighed in kg after sun drying for seven days, multiplied by total number of plants per experimental unit, and converted to hectare basis

Harvest index (HI): was calculated by dividing grain dry weight to above ground biomass yield and multiplied by 100.

$$\text{Harvest index } \% = \left(\frac{\text{grain yield}}{\text{above ground dry biomass yield}}\right) \times 100$$

2.6 Statistical Analysis

Data were checked for the assumption of ANOVA before running the analysis. The collected data were subjected to Analysis of variance (ANOVA) using general linear model (GLM) procedure of SAS software version 9.3 software (SAS, 2014) to test the significance level at 5% probability level..

2.7 Economic Analysis

The economic analysis was performed by considering the cost of labor spent and seed rates as the main input and the mean grain yield obtained as the main output. The net benefit (NB) was calculated as the difference between the GFB and TCV CIMMYT, (1988). Grain yield was adjusted by 10% for management difference to reflect the difference between the experimental yield and the yield that farmers could expect from the same treatment (Getachew and Taye, 2005; CIMMYT, 1988). The dominance analysis procedure as detailed in CIMMYT (1998) was used to select potentially profitable treatments from the range that was tested. The discarded and selected treatments using this technique were referred to as dominated and undominated treatments, respectively. The undominated treatments were ranked from the lowest to the highest cost. For each pair of ranked treatments, the percent marginal rate of return (MRR) was calculated. The MRR (%) between any pair of un-dominated treatments was the return per unit of investment in both factors. It was calculated by dividing the change in a net benefit by the change in variable costs. If the MRR is 100%, it means for every 1 birr invested in labor cost and seed rates for plant population density and variety, farmers can expect to recover 1 birr and obtain an additional 1 birr (CIMMYT, 1988).

3. Results and Discussion

The homogeneity test of the error variances for locations indicated that the error variance was homogenous and hence combined analysis of variance was conducted. The plant densities and varieties didn’t show significant (P>0.05) interaction effect on plant height, pods per plant, pod height, seeds/pod, grain yield, aboveground biomass and harvest index.

3.1 Growth parameters

3.1.1 Plant height

The result revealed that the main effect of location and year had/ highly/ significant (P <0.01) on plant height but the interaction effects were non-significant (P >0.05) on the plant height of soybean (Table 3). The higher mean plant height (68.05 cm) was recorded at Karsa than Omonada (Table 3). During 2021 main cropping season the highest plant height of 71.47cm was obtained whereas the lowest plant height of 60.98 cm was obtained during 2020 main cropping season (Table 3). Plant height was highly significantly (P<0.01) affected by the main effects of variety. However, the main effect of plant densities and the interaction effect did not show significant effect (Figure 1). This might be due to less competition between crop plants for different growth resources especially light, moisture and nutrients. The result in contrary, Kayhan *et al.* (1999), who reported increase in plant height, leaf area index and light interception due to increased plant density in soybean and could be attributed to consequences of infrastructure development within and between plant communities.

Statistically, Clark 63k was taller than the Nyala variety (Figure 1). The difference in plant height between the varieties may be due to the variation in the morphology of the varieties and their interaction with the environment. In agreement with this result, Dereje (2014), reported significant differences among the varieties of soybean for plant height and found that medium maturing soybean varieties were longer than early maturing soybean varieties.

3.1.2 Pod height

Pod height was significantly affected by cropping season and varieties. However, the main effect of plant densities, location and the interaction effect did not show significant effect (Table 3 and 4). In season 2020, soybean gave the tallest pod height (16.86 cm) while the lowest pod height (11.95 cm) was recorded in 2021 cropping season which is statistically par with 2022 cropping season (Table 3). Significantly a higher pod height (21.21 cm) was recorded from variety Clark 63k than variety Nyala (19.43) (Table 4). The significant effect of variety on pod height might be due to different growth habit between varieties.

3.1.3 Numbers of pods/plant

Pod number per plant was influenced by cropping season, varieties and plant density but location and their interaction effect was non-significant (P >0.05) effect on number of pods per plant (Table 3 and 4). In season 2022, soybean varieties had exhibited vigorous growth performances and resulted in good response to plant density. Significantly highest mean number of pod/plant (37.69) was obtained from 2022 cropping season while the least number pods per plant (11.82) was recorded in 2020 cropping season (Table 3). This could be related to the drought conditions during the first season. Different plant densities significantly affected the pod number per plant. Pod number per plant decreased while plant number of in unit area increased. The plant density of 333,333 plants/ha produced maximum (30 pods/plant).while the minimum pod number per plant (24 plant^{-1}) was recorded from 666,666 plant/ha (Table 4). The pod number per plant values generally concur with those of several earlier reports (Bullock *et al.*, 1998; Kutlu *et al*., 1991). This result was in line with Dereje (2014), who reported that higher number of pods per plant of soybean varieties at wider inter row spacing (60cm) and the lower pods per plant at narrower inter row spacing (30cm).

3.1.4 Number of seeds/pod

The main effects across location and cropping season had no significant effect on number of seeds per pod (Table 3). Soybean varieties and plant population did not affect the number of seeds per pod (Table 4). These results confirm what was reported by Agung and McDonald (1998) who revealed that for any given cultivar of faba bean, the average number of seeds per pod is a relatively stable character. Solomon *et al*. (2014); and Teshome *et al.* (2015), reported that number of seeds per pod was significantly not different due to the main effects of soybean varieties, plant densities and cropping system.

Table3. *The main effect of variety and plant density on growth and yield of soybean varieties at Kersa and Omonada woreda during 2020-2022 main cropping seasons.*

Year	Plant height cm	Pod height cm	Numbers of pods/plant	seeds/pod
2020	60.98^{c}	16.86^{a}	11.82^{c}	2.12
2021	71.47^{a}	11.95^{b}	33.95^{b}	2.29
2022	65.67^{b}	12.16^{b}	37.69^{a}	2.36
LSD (5%)	3.02	1.39	3.02	ns
Location				
Omonada	64.02^{b}	20.05	28.54	2.56
Karsa	68.05^{a}	20.59	27.10	2.09
LSD (5%)	2.47	NS	NS	ns

Values following by the same letter within treatments are not significantly different at 0.05 probability level.

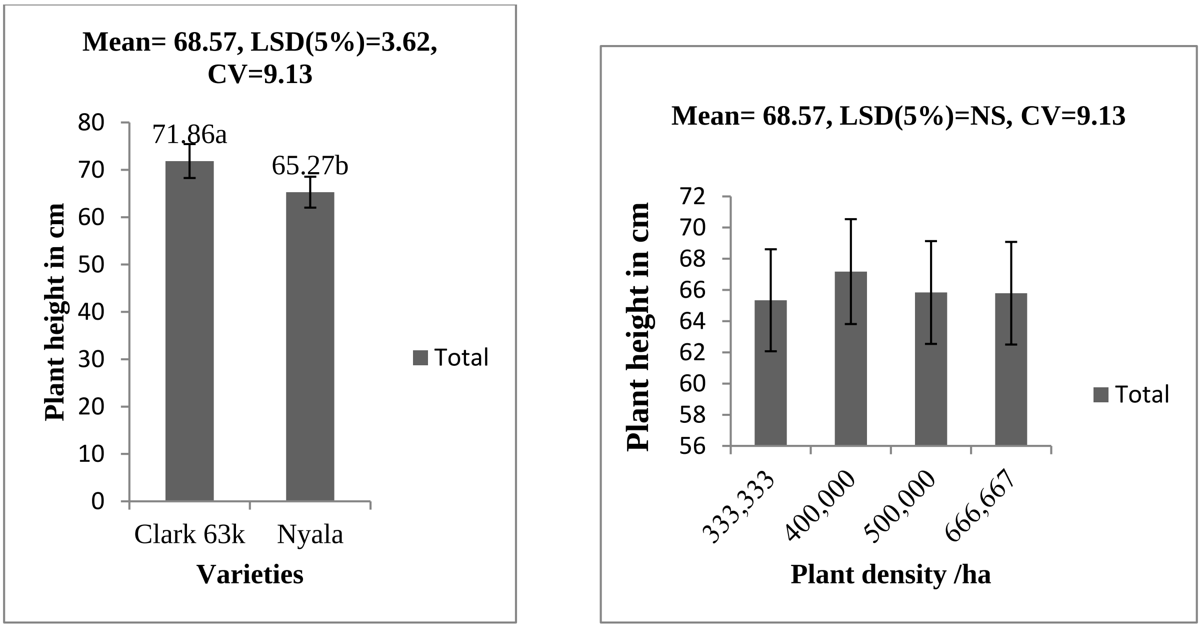

Figure1. *Effect of varieties and plant density on plant height of Soybean at Kersa and Omonada woreda from 2020-2022 cropping season.*

Table4. *The main effect of variety and plant density on growth and yield of soybean varieties at Kersa and Omonada woreda during 2020-2022 main cropping seasons.*

Treatments	**Pod height cm**	**Numbers of pods/plant**	**seeds/pod**
Clark 63k	21.21^a	32.63^a	2.25
Nyala	19.43^b	23.01^b	2.40
LSD(0.05)	1.14	2.46	ns
Plant densities ha^{-1}			
666,667	19.59	24.06^b	2.58
500,000	20.22	28.99^a	2.24
400,000	21.14	27.96^a	2.28
333,333	20.34	30.28^a	2.18
Mean	20.32	27.82	2.32
LSD (5%)	1.23	3.48	ns
CV	16.95	26.75	39.20

3.2 Yield parameters

3.2.1 Grain yield

Main effect of plant densities had highly significant (P <0.01) effect on grain yield of soybean while varieties and their interaction was non-significant (P >0.05) effect on grain yield across two location and three cropping season (Figure 2). At Omonada woreda the significant higher grain yield of 3237.86 kg ha^{-1} was obtained than at Kersa woreda of Jimma zone (Figure 2). During 2022 main cropping season the crop performed well and the highest grain yield of 5031.12 kg ha^{-1} was obtained, while during 2020 the lowest grain yield of 783.89 kg ha^{-1} was obtained (Figure 2). Over season and site mean indicated that at highest plant population density (666,666 plant/ha) gave highest mean grain yields (3496.55 kg/ha) while the minimum (2853.07 kg ha^{-1}) grain yield was obtained from a plant population of 333,333 plants ha^{-1} (Figure 3). The grain yield increased by about 22.55% in the 66667 plants ha^{-1} treatment as compared with that of treatments 333,333 plants ha^{-1} (Figure 3). The grain yield was not influenced by varieties (Figure 3). This might be due to similar response of soy bean varieties and found with the same maturity group and performed similar. The main difference of grain yield of the interaction effect might be due to response of different varieties of the same crop to different plant spacing because of their growth habit, number of branches per plant and plant height affected by inter row spacing. Yield increase to emanating from plant density in unit area was mainly due to increased number of seeds per area rather than increased yield per plant. Other benefits of higher plant density is contribution to earlier canopy closure which makes weed control easier by increasing competition between the crop and weeds. The higher grain yield was possibly due to higher plant and pod height and biomass yield. Increasing plant density may increased light interception. The result was in line with (Ball *et al*, 2000; Andrade *et al.*, 2002; Caliskan *et al.*, 2007) reported that increasing the population reduced yield per plant but increased yield per unit area. The results also are supported by Edwards and Purcell (2005) who showed that as soybean population increases, yield increases rapidly until it becomes asymptotic per plants.

3.2.2 Above Ground Dry Biomass

Above ground dry biomass were significantly influenced by the main effects of location, cropping season, varieties and plant densities (P<0.01) but non-significant due to their interaction effect of varieties and plant densities (P>0.05) (Figure 2 and 4). Numerically, the higher above ground biomass of 11.73 ton ha^{-1} was recorded at Karsa woreda than at Omonada woreda of 7.64 ton ha^{-1} (Figure 2). During 2022 main cropping season the highest above ground biomass of 15.62 ton ha^{-1} was recorded while the lowest 4.55 ton ha^{-1} was recorded during 2020 main cropping season (Figure 2). The difference in above ground dry biomass with cropping season may be due to the occurrence of rust during 2020 cropping season and poor stand count at harvest. The highest plant density of

666,667 plants ha^{-1} gave the highest above ground biomass of 12.63 ton ha^{-1} while the lowest above ground biomass of 7.81 ton ha^{-1} was recorded from 333,333 plants ha^{-1} which was statistically at par with plant density of 400,000 plants ha^{-1} (Figure 4). Above ground dry biomass increased by about 61.71% in the 66667 plants ha^{-1} treatment as compared with that of treatments which are recorded 7.81 ton ha^{-1} to above ground biomass. This might be due to the higher number of plant per unit area harvest and grain yield. Regardless of the variety, Nyala higher above ground biomass (10. 07ton ha^{-1}) than Clark 63k variety (9.30 ton ha^{-1}) (Figure 4). This might be due to variation growth habit and genetic variation between varieties. In general, the above ground biomass was increased by 61.71% at the highest plant population density as compared to the lowest plant population density. This might be due to more number of plants harvested per unit areas rather than increased biomass per plant and net crop assimilation rate. Similarly, higher plant density is contribution to earlier canopy closure which makes weed control easier by increasing competition between the crop and weeds. This is agreement with Getachew *et al*. (2006) reported increased dry biomass of faba bean with increased plant density. Similar results were reported by Coeiho and Pinto (1989),who observed that at the final harvest of faba bean, the dry matter yield of above-ground parts increased with increasing plant population.

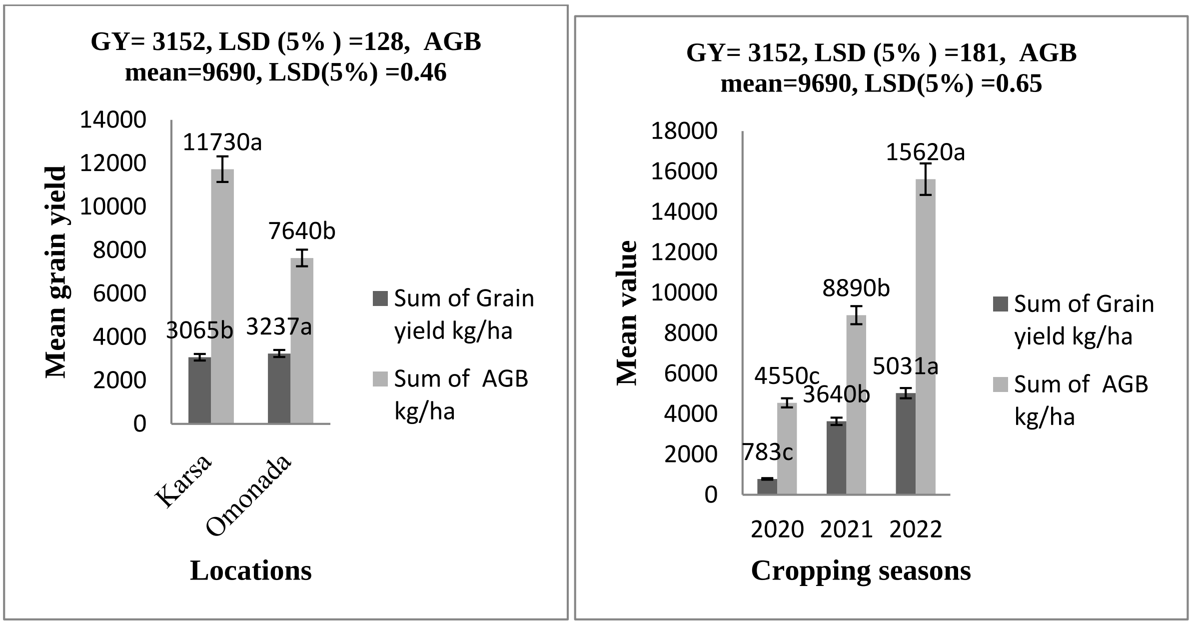

Figure2. *Effect of varieties and plant population density on grain yield of Soybean at Kersa and Omonada woreda during 2020-2022 cropping season.*

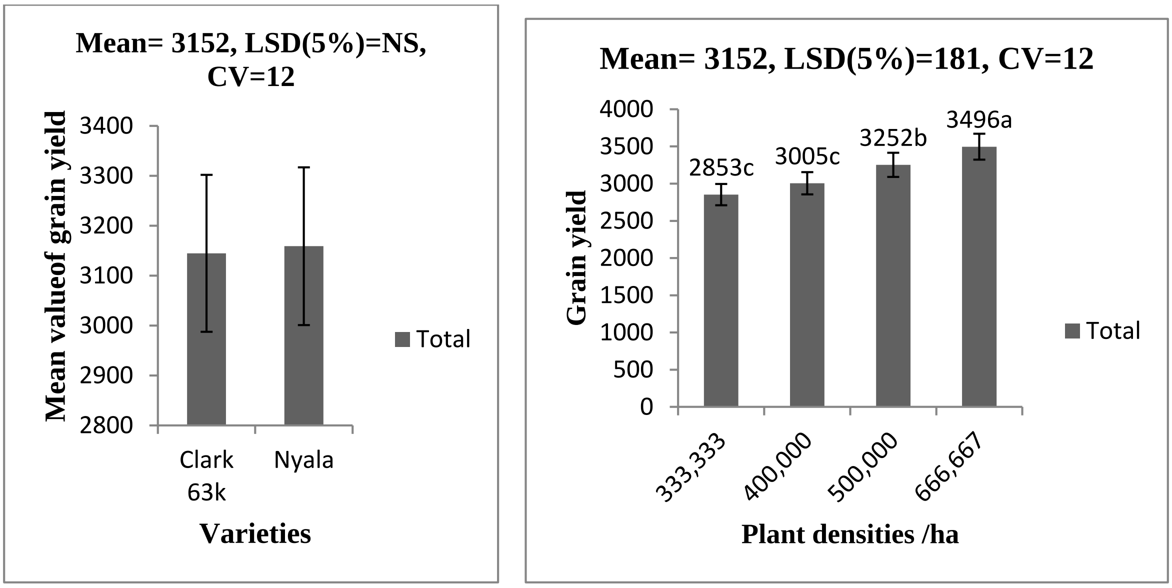

Figure3. *Grain yield of soybean as affected by varieties and plant population densities at Kersa and Omonada woreda during 2015-2017 main cropping seasons.*

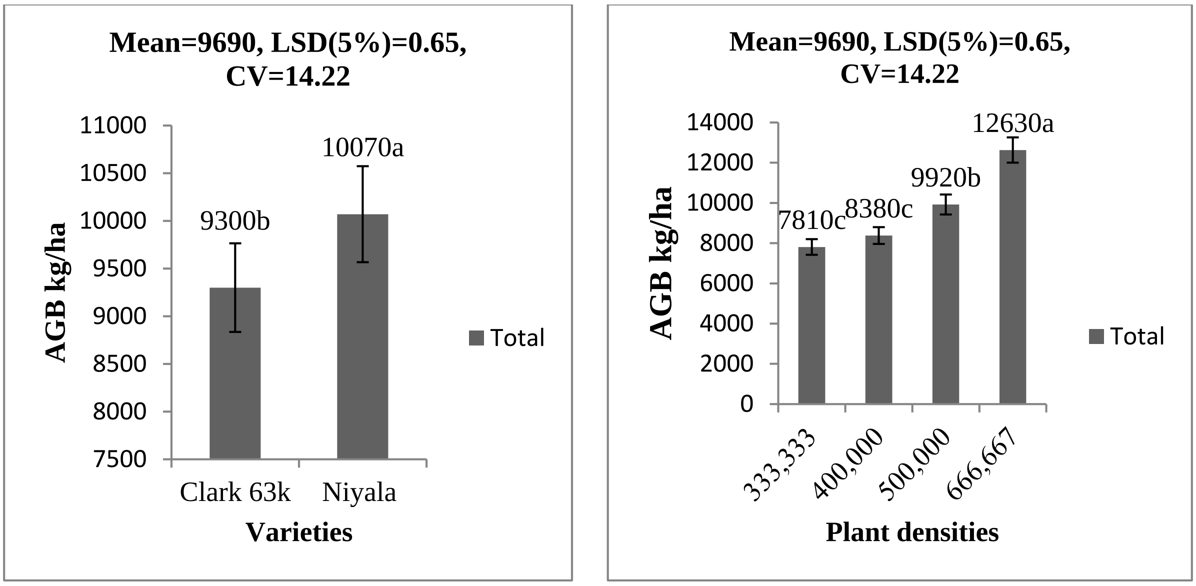

Figure4. *Above ground biomass yield of soybean as affected by varieties and plant population densities at Kersa and Omonada woreda during 2015-2017 main cropping seasons.*

3.2.3 Harvest index

The harvest index reflects the ability of the genotypes to partition their dry matter into seed and straw, and the ability to maintain the right balance between seed and straw yield. The Harvest index was influenced by varieties, location and cropping seasons (Figure 5 and Table 5). However, neither plant density nor interaction effect varieties, location, and cropping season significantly (Figure 5 and Table 5). Omonada woreda had a higher harvest index (39,80 %) than the Karsa woreda of the Jimma zone (Figure 5). Numerically the highest harvest index of 45.93% was obtained during the 2022 main cropping season where as the lowest harvest index of 18.12% was obtained during the 2020 main cropping season (Figure 5). Harvest index (HI) values ranged from 0.18 to 0.36 over 3 years for all treatment combinations across location and main cropping season. Plant density in both locations had no significant effect on harvest indices across three seasons. The variety Clark 63k produced a higher harvest index (36.21%) than Nyala the variety (34.42) (Table 6). It might be due to the difference in the genetic makeup of the two varieties for this trait. The Harvest index was relatively stable and was not affected by population (Ball *et al*., 2000).

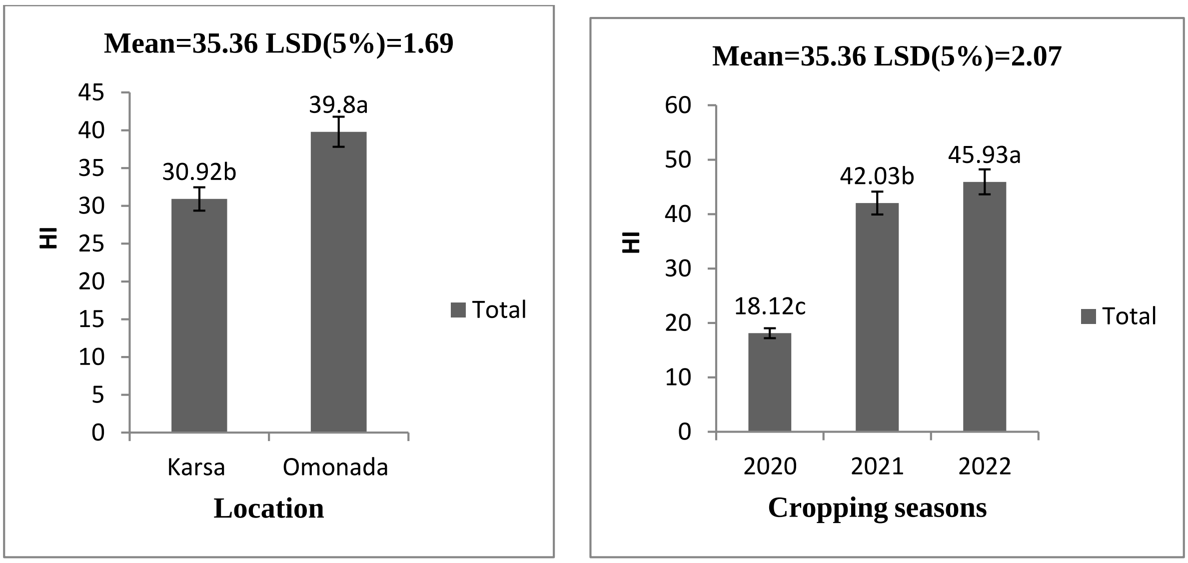

Figure5. *The effect of plant densities and varieties on the harvest index at Jimma zone (Karsa and Omonada) during 2020-2022 cropping seasons.*

Table5. *The main effect of variety and plant density on harvest index of soybean varieties at Kersa and Omonada woreda during 2020-2022 main cropping seasons.*

Treatments	Over season mean HI
Clark 63k	34.42^{b}
Nyala	36.21^{a}
LSD (5%)	1.69
Plant densities /ha	
666,667	34.47
500,000	34.89
400,000	36.02
333,333	36.06
Mean	35.36
LSD (5%)	ns
CV	14.43

3.3 Economic Analysis

The economic analysis was performed by considering the cost of labor spent and seed rate as the main input and the mean grain yield obtained as the main output. All costs and benefits were calculated on a hectare basis in Ethiopian Birr (ETB). The grain yield was adjusted by 10%for the management difference. The total costs of seed rate and labor were calculated based on store sale prices of Omonada and Kersa woreda Cooperative and the sale of grain soya bean at both locations' open market average price (24 ETB kg^{-1}). The inputs and/or concepts used in the partial budget analysis were the mean grain yield of each treatment, the field price of soybean grain (sale price grain yield minus the costs of seed, labor (planting, weeding, and harvesting), the gross field benefit (GFB) ha^{-1} (the product of field price of the mean yield for each treatment), the field price of seed rate kg ha^{-1} and labor wage, the total costs that varied (TCV) which included the sum of field cost of seed rate and its labor wage for planting, weeding and harvesting. The partial budget analysis revealed that the highest net benefit of 70765 ETB ha^{-1} was obtained from 666,667 plants ha^{-1} respectively (Table 6). These results indicated that as plant population density increases the net benefit also increased and vice versa.

Table6. *Partial budget with estimated MRR (%) for the main effects of plant densities on soybean grain yield at Kersa and Omonada woreda during 2020-2022 main cropping seasons.*

Plant density(ha^{-1})	Grain yield (kg ha^{-1})	Adjusted Grain yield (kg ha^{-1})	Gross field benefit (ETB ha^{-1})	TCV (ETB ha^{-1})	Net benefit (EB ha^{-1})	Value cost ratio	MRR (%)
333,333	2853.07	2568	61626	2240	59386	26.51	-
400,000	3005.09	2705	64910	3360	61550	18.32	193.18
500,000	3252.65	2927	70257	3920	66337	16.92	854.87
666,667	3496.55	3147	75525	4760	70765	14.87	527.17

Retail price of grain ETB = 24 kg^{-1} Wage rate ETB= 70 man-day^{-1}.

4. Summary And Conclusion

Soybean is one of the most important pulse crops but the yield of soybean in Ethiopia has been low due to several constraints, which could be suboptimum plant densities, poor agronomic and soil management practices, diseases, inadequate availability and lack of improved variety and lack of other modern crop management inputs. Therefore, an experiment was conducted to determine the effects of plant densities on growth, yield, and yield components of soybean varieties and to estimate the economic feasibility of variety by plant density for an enhanced yield of soybean production at Kersa and Omonada woreda of Jimma zone South Western Ethiopia during 2020-2022 main cropping seasons. The experiment was laid out in RCBD with a 2 x 4 factorial arrangement of two varieties (Clark-63k and Nyala) and four different plant densities (666,667, 500,000, 400,000 and 333,333 plants ha^{-1}). The plant densities had a significant effect on the growth, yield and yield components of soybean varieties. The main effects of varieties and plant densities on plant height, pod height, numbers of pods/plant, grain yield, above-ground biomass yield and harvest index were recorded. There was no interaction effect observed among plant densities and soybean varieties across locations and years for plant height, pod height, numbers of pods/plant, grain yield, above-ground biomass and harvest index. Neither plant densities nor varieties were affected by seeds/pods. Grain yield was not influenced by soybean varieties. Hence farmers can use either Clark-63k or Nyala for the study area. The crop responded more to plant densities than soybean varieties. As plant density increased grain yield and above-ground biomass significantly increased but the number of pods per plant and harvest index decreased. The highest plant density (666,667 plants ha^{-1}) gave the highest mean grain yield of 3496.55 kg ha^{-1} with the highest net benefit 70765 ETB ha^{-1} with a marginal rate of return of 527% for soybean production. Further research is needed to conclude the yield response of the crop to plant density because the yield is significantly increasing up to 666,667 plants ha^{-1}. Future research should also consider other factors such as nutrient management to maximize yield, yield components, N accumulation as well as weed control. In general, significantly higher grain yield and above-ground dry biomass yield were obtained due to closer spacing. Therefore, the use of either Clark-63k or Nyala variety with a plant density of 666,667 plant ha^{-1} in increased grain yield and economically feasible and therefore can be recommended for soybean production in the study area and other areas with similar agro ecologies.

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