



Response of Soybean (*Glycine max.* L.) to Different Rates of NP Fertilizer and Plant Population Densities at Jimma Zone, South Western Ethiopia

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Abstract: Declining soil fertility status and poor agronomic practices, including minimum use of inorganic fertilizers and inappropriate plant population per hectare are the major reasons for low productivity of soybean. Therefore, the field experiment was conducted to evaluate the response of soybean to different rates of NP fertilizer and plant population density at Jimma South Western Ethiopia during 2015-2017 main cropping seasons. The experiment was laid out in RCBD with 4x4 factorial arrangements with four plant population densities; 333,333, 400,000, 200,000 and 166,666 plants ha⁻¹, and four NP fertilizer rates; 23/23, 23/46, 46/46, 69/69 kg ha⁻¹ N/P₂O₅. An interaction effect of plant population densities and NP fertilizer rates was observed for all parameters. The results indicated that as plant population density increased plant height, pod height, grain yield and above ground biomass significantly increased but number of pods per plant was decreased. As NP fertilizer rate increased slightly plant height, number of pods per plant, grain yield and significantly above ground biomass was increased. Significant highest mean grain yield of 3724 kg ha⁻¹ was obtained from the highest plant population density of 400,000 plants ha⁻¹ (50x5cm). Further research must be done to conclude the yield response of the crop to plant population density because the yield is significantly increasing up to 400,000 plants ha⁻¹. Regarding the effect of NP fertilizer rates, the highest grain yield of 3477 kg ha⁻¹ was obtained from 69/69 kg ha⁻¹ N/P₂O₅ which was statically at par with 46/46 kg ha⁻¹ N/P₂O₅ fertilizer. In conclusions, plant population density of 400,000 plants ha⁻¹ (50 cm inter row with 5 cm intra row spacing) with 46/46 kg ha⁻¹ N/P₂O₅ fertilizer rate were determined for optimum production of soya bean in Jimma area and similar agro-ecologies of the country.

Keywords: Plant Population, Fertilizer Rate, Grain Yield and Spacing

1. Introduction

Soybean (*Glycine max.* L.) is one of the most important oil crops in the world. It contains 18-22% oil and 40-42% protein [1]. Soybean cultivation is originated in China around 1700-1100 B.C. Soybean is now cultivated throughout East and Southeast 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 a quarter of world's food and animal feed requirement in addition to protein. 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 [2]. 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.

In Ethiopia, soybean has adapted to diverse ecological niches and provided wider yield range. 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. Entry of large scale commercial farmers, including government sugarcane-soybean intercropping programs, and research in soil fertility rehabilitation have made soybean a favorite crop.

The Ethiopian CSA [3] reported that the production of the

soybean on 64,720.12 hectares with 149,454.6 tons of grain yield ($2.31 \text{ tons ha}^{-1}$) which was low due to poor soil fertility [4]. Soil acidity associated with soil fertility problem is one of the most important soybean production constraints in south Western and Western Ethiopia where most soils with pH levels below 5.5 [5]. Higher plant densities compared to lower plant density have consistently produced higher seed yields in Northern USA where indeterminate early maturing varieties are used [6]. Increased seed rate will influence yield to a point, however, yield will eventually reach a maximum at which addition of more seed will do nothing to increase yield [6]. Only one plant density that is 333,333 plants ha^{-1} ($60 \text{ cm} \times 5 \text{ cm}$) and 46/46 kg ha^{-1} NP fertilizer rate were used for soya bean production irrespective of various agro-ecological zones with different soil fertility status. Therefore, the objective of this study was to determine the response of soya bean to plant population density and NP fertilizer rates on growth parameters, yield and yield components.

2. Materials and Methods

2.1. Description of the Experimental Site

The experiment was conducted at Kersa and Omonadaworeda of Jimma Zone South western Ethiopia under rain fed conditions during the main cropping season of 2015-2017. Kersaworedais located at about 318 km from Addis Ababa and 28 km East from Jimma town ($7^{\circ} 40' \text{ N}$ latitude and $36^{\circ} 50' \text{ E}$ longitude) at an altitude of 1740 m.a.s.l. The average annual maximum and minimum temperatures are 28.8°C and 11.8°C , respectively and the area receives an average rainfall of 1750 mm per annum. Omonada Woreda is located at about 281 km from Addis Ababa and 65 km East from Jimma town found on latitude $7^{\circ} 36' \text{ N}$ and longitude $37^{\circ} 15' \text{ E}$ and laid at an altitude of 1764 m.a.s.l. An average minimum and maximum temperature is 8°C and 28°C respectively and reliably receives annual average rainfall up to 1200 mm with agro-ecology characterized by humid mid altitude. The soil type of the experimental sites was Eutric-nitisols (reddish brown).

2.2. Soil Physico-chemical Properties

The soil of the experimental field was characterized by selected physico-chemical properties before the application of the treatments as described in Table 1. The average soil pH of the trial sites ranges from 5.07 to 5.17, which was strongly acidic [7] and ideal for the production of most field crops. At Kersa and Omonada woreda the soil total N of 0.167% and 0.14% respectively were found which was rated medium for crop growth and development [8]. The Bray II extractable available P for Kersa and Omonada woreda was 2.496 and 6.924 mg kg^{-1} respectively, which were below the critical level of 8 mg kg^{-1} for most crop plants as described by Tekalign and Haque [9]. Accordingly, the mean organic carbon and organic matter contents of the experimental areas of Kersa and Omonadaworeda were ranges from 1.82-2.644% and 3.13-4.558% respectively which were rated as medium for crop growth [8] with C:N ratio range of 13.0-15.83.

Table 1. Selected physico-chemical properties of the soil of the experimental sites before planting.

Soil characters	Location	
	Kersa	Omonada
pH (1:2.5)	5.07	5.17
Av P (mg kg^{-1})	2.496	6.924
TN (%)	0.167	0.14
OC (%)	2.644	1.82
OM (%)	4.558	3.13
C:N ratio	15.83	13.0

Where pH= hydrogen power, OC=Organic carbon, TN=Total Nitrogen, Av. P=Available Phosphorous, OM=Organic Matter. Values are the means of duplicated samples.

2.3. Experimental Procedures and Field 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 2015, 11 the June of 2016 and 13 the June of 2017. Before sowing the crop and the field was plowed with oxen three times to make a fine seed bed. The source of N and P was urea and NPS fertilizers respectively. Plant population was maintained by thinning. Harvesting was done manually when the crop reached harvest maturity.

2.4. Experimental Design and Treatments

Clark- 63K soybean variety which was under production and dominant at the locations experiment was done. The experiment was carried out in 4×4 factorial experiment arranged in a RCBD with three replications. Four plant population densities; 400,000 plants ha^{-1} (50cm inter*5cm intra spacing), 333,333 plants ha^{-1} (60cm inter*5cm intra spacing), 200,000 plants ha^{-1} (50cm inter*10cm intra spacing), and 166,666 plants ha^{-1} (60cm inter*10cm intra spacing) and four levels of NP fertilizer rates; 23/23, 23/46, 46/46, 69/69 kg ha^{-1} N/P₂O₅. To increase the nitrogen use efficiency, it was applied at planting time and at 28-30 days after emergence. The gross plot size was 5m x 4m (20 m^2) and the distances between plot and replication were 1m and 1.5 m, respectively. All other agronomic and cultural practices were performed.

2.5. Data Collected

2.5.1. Plant Height

It was measured by centimeters from the ground to the top of the plant at 50% flowering from five randomly selected plants.

2.5.2. Pod Length

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

2.5.3. Number of Pods Per Plant

It was determined by counting the number of pods per plant of five randomly selected plants at harvest.

2.5.4. Number of Seeds Per Pod

It was determined as the total number of seeds per pod in each plot at the time of harvesting from the five randomly selected plants.

2.5.5. Above Ground Biomass (kg ha⁻¹)

It was determined by taking the total weight of the harvest including grain yield from each net plot area.

2.5.6. Grain Yield (kg ha⁻¹)

It was determined after threshing the seeds harvested from each net plot and adjusted to 10.0% moisture level.

2.5.7. Harvest Index

It was calculated as the ratio of grain yield to above ground biomass yield on dry weight basis [10].

$$HI(\%) = \frac{\text{Economic yield (kg/ha)}}{\text{Total biological yield (kg/ha)}} \times 100$$

2.6. Statistical Analysis

The collected data's were subjected to analysis of variance (ANOVA) appropriate to factorial experiment in RCBD over years and locations after confirmation of homogeneity of error variance using SAS software program 9.3 version. The means were compared using the least significant differences (LSD) test at 5% level of significance.

2.7. Partial Budget Analysis

The partial budget technique as described by CIMMYT [11] was used to investigate the economic feasibility of the applied fertilizer and seed rates. All costs and benefits were calculated on a per hectare basis in Ethiopian Birr (ETB). The marginal rate of return (MRR%) were calculated as changes in net

benefit divided by changes in total variable cost. The minimum acceptable MRR of 100% was used, which is suggested to be realistic. To select potentially profitable treatments from the range that was tested the dominance analysis was done.

3. Results and Discussions

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 NP fertilizer rates and plant population densities didn't show significant ($P > 0.05$) interaction effect on plant height, pods per plant, pod height, grain yield and aboveground biomass (Table 2). But, highly significant ($P < 0.01$) interaction effect was observed on harvest index. Plant height, grain yield, aboveground biomass and harvest index were highly significantly ($P < 0.01$) influenced by NP fertilizer rates (Table 2). Whereas, pods per plant was significantly ($P < 0.05$) and pod height was not significantly ($P > 0.05$) influenced by NP fertilizer rates. All parameters collected i.e. plant height, pods per plant, pod height, grain yield, aboveground biomass and harvest index were highly significantly ($P < 0.01$) influenced by rates of plant population densities (Table 2). Location and year were showed highly significant ($P < 0.01$) difference for plant height, pod height, grain yield and above ground biomass. Whereas pods per plant and harvest index were not showed significant ($P > 0.05$) difference over locations but both parameters were highly significantly ($P < 0.01$) affected by year difference (Table 2).

Table 2. Mean square from combined analysis of the effects of NP fertilizer rates and plant population densities on growth, yield attributes and yield of Soybean during 2015-2017 cropping seasons at Kersa and Omonadaworeda, Jimma zone Southwestern Ethiopia.

Parameter	Mean square for source of variation					
	Location (1)	Year (2)	NP (3)	PPD (3)	Rep (2)	PPD x NP (9)
Plant height (cm)	2647.0**	15866.5**	181.62**	467.99**	61.21 ^{ns}	54.21 ^{ns}
Pods per plant	295.8 ^{ns}	60553.7**	570.14*	2736.45**	2653.52**	194.14 ^{ns}
Pod height (cm)	408.85**	313.11**	6.59 ^{ns}	96.92**	109.24**	4.32 ^{ns}
Grain yield (kg ha ⁻¹)	5546339**	33742479**	5031543**	17745777**	1576136*	802857 ^{ns}
AGB (t ha ⁻¹)	43.85**	1410.58**	84.34**	241.50**	26.94**	7.17 ^{ns}
Harvest index	0.0001 ^{ns}	0.1858**	0.0048**	0.0054**	0.0001 ^{ns}	0.0039**

*Numbers in parenthesis = Degrees of freedom; NS=Not significant difference; *= Significant ($P < 0.05$) difference; ** = Highly significant ($p < 0.01$) difference; AGB= Above ground biomass; PPD=Plant population density; Rep=Replication; MS=Mean square; ha = Hectare.

Table 2. Continued.

Parameter	Mean square for source of variation					
	Location x NP (3)	Location* PPD (3)	Year x PPD (6)	Year x NP (6)	Location*year * PPD*NP (18)	MS of Error (48)
Plant height (cm)	10.32 ^{ns}	65.7 ^{ns}	66.0 ^{ns}	44.37 ^{ns}	92.3**	40.02
Pods per plant	99.1 ^{ns}	199.7 ^{ns}	162.6 ^{ns}	129.8 ^{ns}	116.7 ^{ns}	168.04
Pod height (cm)	2.63 ^{ns}	2.80 ^{ns}	27.76**	4.72 ^{ns}	19.17**	6.15
Grain yield (kg ha ⁻¹)	107308 ^{ns}	514406 ^{ns}	2631160**	1033395*	563309 ^{ns}	435405
AGB (t ha ⁻¹)	2.02 ^{ns}	6.69 ^{ns}	33.33**	8.31 ^{ns}	7.40**	4.495
Harvest index	0.0005 ^{ns}	0.0003 ^{ns}	0.0081**	0.0023*	0.0021**	0.0009

*Numbers in parenthesis = Degrees of freedom; NS=Not significant difference; *= Significant ($P < 0.05$) difference; ** = Highly significant ($p < 0.01$) difference; AGB= Above ground biomass; PPD=Plant population density; Rep=Replication; MS=Mean square; ha = Hectare.

3.1. Growth Parameters

3.1.1. Plant Height

At Omonada the highest plant height of 66.7cm was

recorded when compared with that of Kersa woreda of 61.3cm (Figure 1). During 2017 main cropping season the highest plant height of 72.1cm was obtained whereasthe lowest plant height of 54.2cm was obtained during 2015

main cropping season (Figure 2). Numerically the highest plant height of 65.5 cm was recorded from plant population density of 400,000 plants ha^{-1} while the lowest plant height was recorded from 200,000 plants ha^{-1} which was statically at par with 166,667 plants ha^{-1} (Table 3). This result was in agreement with Elmore [12] who reported increased plant height was associated with plant population, but only as final stands were lodging was not a significant problem with greater seeding rates. Regarding the NP fertilizer rate, 69-69 N- P_2O_5 kg ha^{-1} gave highest plant height of 64.9 cm which was at par with 46-46 and 23-46 N- P_2O_5 kg ha^{-1}

while the lowest plant height of 61.5cm was recorded from 23-23 N- P_2O_5 kg ha^{-1} fertilizer rate (Table 3). These results indicated as NP fertilizer rate and plant population density increased, plant height also increased and vice versa. This result is in line with that of Kayhan *et al.* [13], 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. Similar results were also reported by Manral and Saxena [14] and Starling *et al.* [15].

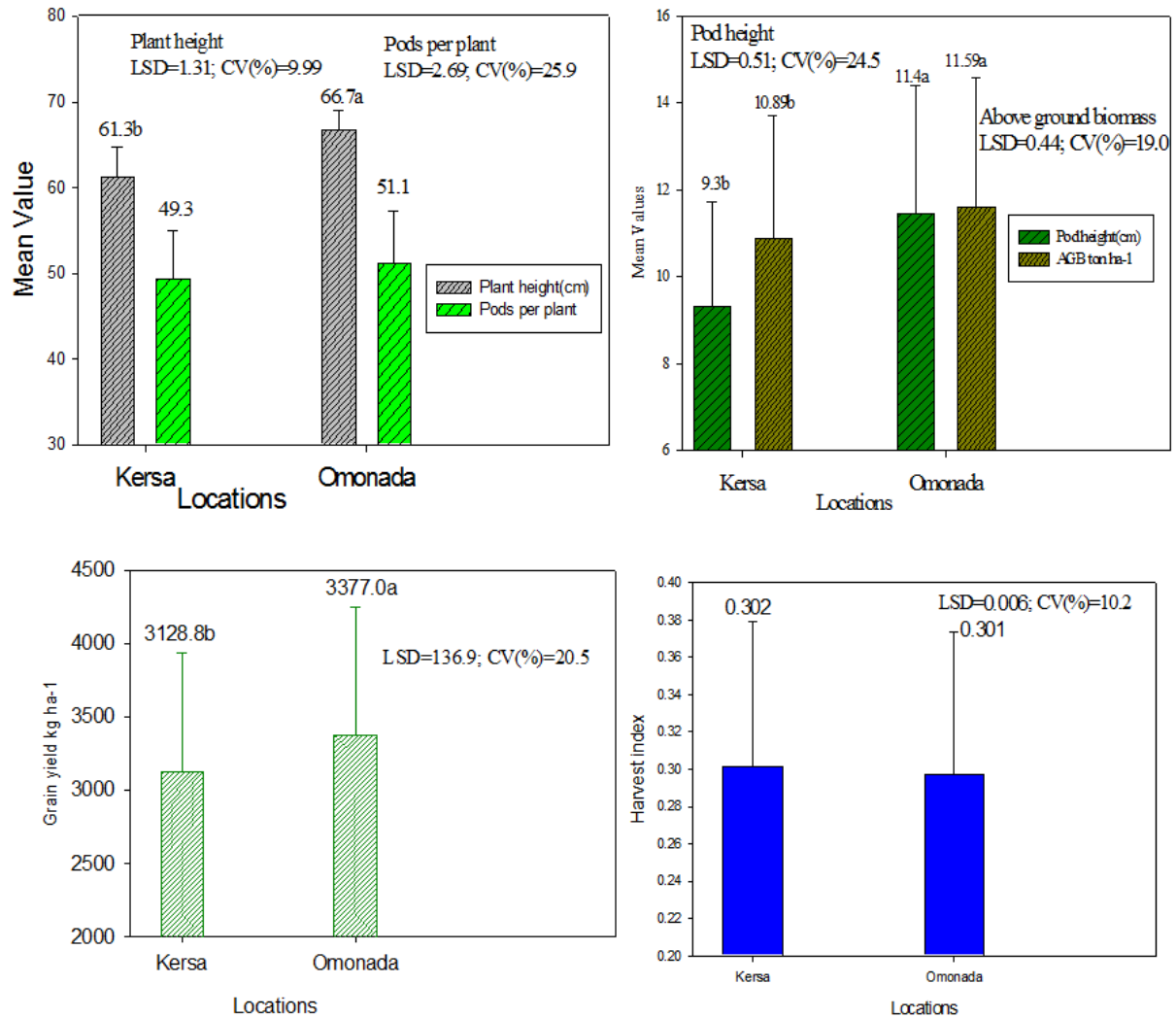


Figure 1. Effect of NP fertilizer and plant population density on growth, yield and yield related parameters of Soybean at Kersa and Omonada woreda.

3.1.2. Pod Height

The significant highest pod height of 11.4cm was obtained at Omonada than Kersa woreda (Figure 1). During main cropping season of 2016 the highest pod height was recorded whereas the lowest was recorded during 2015 cropping season (Figure 2). The plant population density of 400,000 plants ha^{-1} (50cm inter spacing*5cm intra spacing) was gave the highest pod height of 11.1cm, while the lowest pod height of 9.0cm was recorded from the lowest plant population density of 166,667 plants ha^{-1} (60cm inter spacing*10cm

intra spacing) (Table 3). The results were indicated as plant population density increased the pod height also increased and vice versa.

3.2. Yield and Yield Related Parameters

3.2.1. Number of Pods Per Plant

At Omonada woreda the highest number of pods per plant of 66.7 was obtained than at Kersa woreda (Figure 1). During 2017 main cropping season the significant highest number of pods per plant of 72.1 was recorded while the lowest number

of pods per plant of 30.5 was recorded during 2016 cropping season (Figure 2). The fertilizer rate of 69-69 kg ha⁻¹ and plant population density of 166,667 plants ha⁻¹ were gave maximum number of pods per plant of 52.8 and 55.3 plants ha⁻¹ respectively (Table 3). While fertilizer rate of 23-23 kg ha⁻¹ and plant population density of 400,000 plants ha⁻¹ were gave the lowest number of pods per plant of 47.1 and 46.1 plants ha⁻¹ respectively (Table 3). These findings were indicated as plant population density increased the number of pods per plant

decreased (by 19.7%) whereas as NP fertilizer rates increased the number of pods per plant also increased (by 12%) and vice versa. This is due to availability of more resources increase in number of pod per plant to plants on account of low population density. These findings are in agreement with Tola [16] who indicated that increasing levels of nitrogen fertilization increased the number of pods per plant. These findings are also in parallel with Shafshak *et al.* [17] who said that increased plant populations decrease pod number per plant.

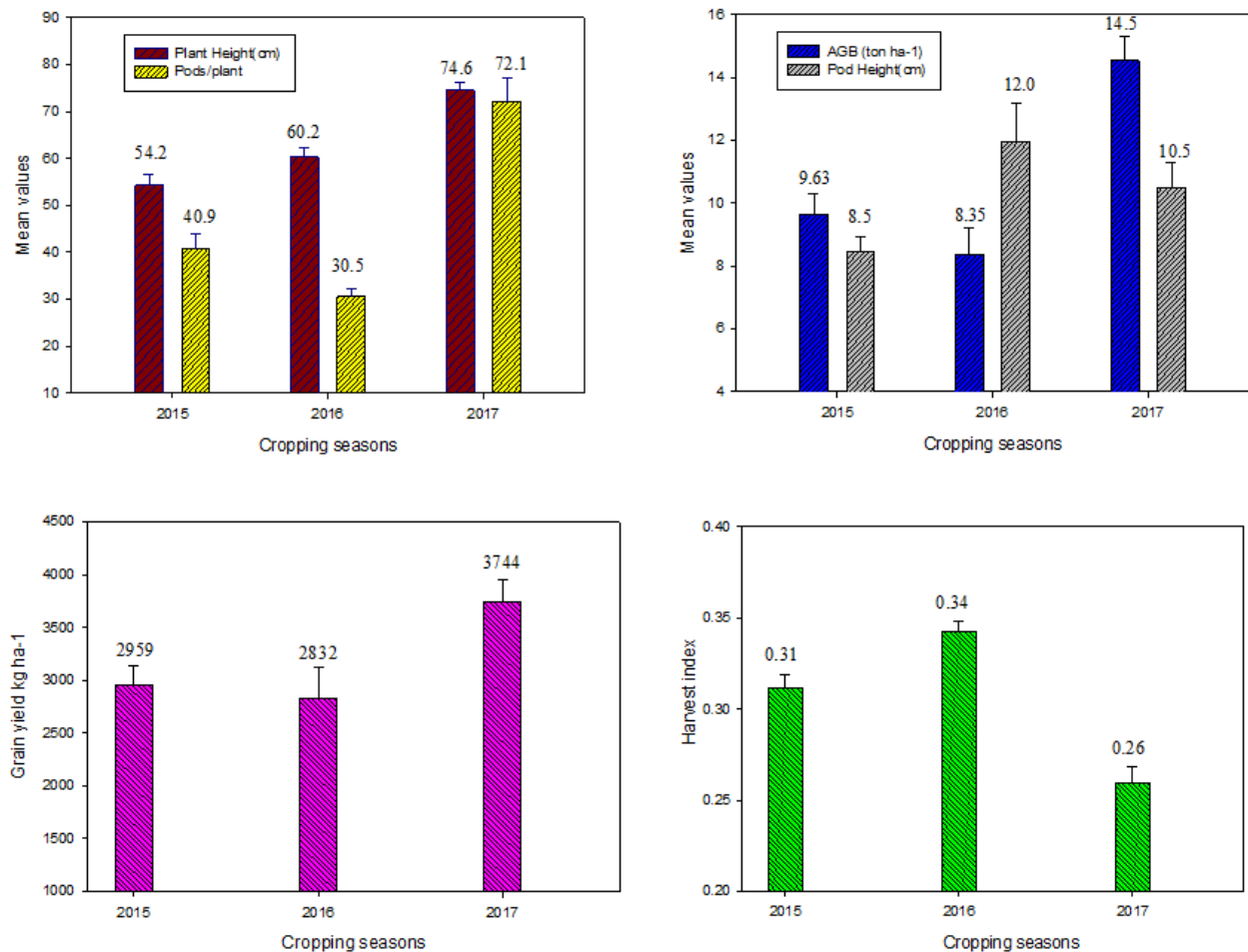


Figure 2. Effect of NP fertilizer and plant population density on growth, yield and yield related parameters during 2015-2017 cropping seasons.

Table 3. Plant height, first pod height and number of pods per plant of soybean as affected by NP fertilizerrates and plant population densities at Kersa and Omonadaworedaduring 2015-2017 main cropping seasons.

Treatments	Plant height (cm)	Podheight (cm)	Pods per plant
N-P ₂ O ₅ fertilizer rates (kg ha ⁻¹)			
69-69	64.9 ^a	10.4	52.8 ^a
46-46	63.5 ^b ^a	10.2	50.9 ^{ab}
23-46	63.4 ^{ab}	9.8	48.9 ^{bc}
23-23	61.5 ^b	10.0	47.1 ^c
Plant population Densities (Plants ha ⁻¹)			
400,000 (50cm*5cm)	65.5 ^a	11.1 ^a	46.2 ^b
333,333 (60cm*5cm)	64.8 ^a	10.7 ^a	47.6 ^b
200,000 (50cm*10cm)	61.0 ^b	9.4 ^b	53.7 ^a
166,667 (60cm*10cm)	61.8 ^b	9.0 ^b	55.3 ^a
Mean	63.3	10.1	49.9
LSD	1.8	0.7	3.68
CV (%)	9.99	24.5	25.9

*LSD= Least significant difference; CV=Coefficient of variation; Values followed by the same letter within a column are not significantly different at P< 0.05.

3.2.2. Above Ground Dry Biomass

Numerically the significant highest above ground biomass of 11.59 ton ha⁻¹ was recorded at Omonada woreda than at Kersa woreda of 10.89 ton ha⁻¹ (Figure 1). During 2017 main cropping season the highest above ground biomass of 15.5 ton ha⁻¹ was recorded while the lowest 8.35 ton ha⁻¹ was recorded during 2016 main cropping season (Figure 2). This may be due to the highest plant height, pods per plant and grain yield of soybean at Omonada woreda and during 2017 main cropping season. The highest plant population density of 400,000 plants ha⁻¹ gave the highest above ground biomass of 12.7 ton ha⁻¹ which was statistically at par with plant population density of 333,333 plants ha⁻¹ while the lowest above ground biomass of 9.7 ton ha⁻¹ was recorded from 200,000 plants ha⁻¹ which was statistically at par with plant population density of 166,667 plants ha⁻¹ (Table 4). These results were indicated there was 30.9% increase of above ground biomass when plant population density doubled to 400,000 plants ha⁻¹ which might be due to the higher plant height, pod height, pods per plant and grain yield. Concerning the effect of NP fertilizer rates, the highest above ground biomass of 12.2 ton ha⁻¹ was recorded from the highest NP fertilizer rate of 69-69 N-P₂O₅ kg ha⁻¹ while the lowest above ground biomass of 10.1 ton ha⁻¹ was recorded from 23-46 kg ha⁻¹ N-P₂O₅ fertilizer which was statistically at par with 23-23 kg ha⁻¹ N-P₂O₅ fertilizer (Table 4). There was 20.8% increase of above ground biomass at application of 69-69 N-P₂O₅ kg ha⁻¹ fertilizer rate when compared with 23-46 kg ha⁻¹ N-P₂O₅ fertilizer rate. This increase might be due to highest plant height, pod height, pods per plant and grain yield at 69-69 N-P₂O₅ kg ha⁻¹ fertilizer. In agreement with this study, Getachew *et al.* [18] reported increased dry biomass of faba bean with increased plant density. This result

was in line with Nebret [19] who said total dry matter production increased significantly due to increased nitrogen application from 40 to 120 kg N ha⁻¹ on common bean. The total above-ground dry biomass yield of faba bean significantly increased with increased rate of phosphorus fertilizer application [20].

3.2.3. Grain Yield

At Omonada woreda the significant highest grain yield of 3377 kg ha⁻¹ was obtained than at Kersa woreda of Jimma zone (Figure 1). During 2017 main cropping season the crop performed well and the highest grain yield of 3744 kg ha⁻¹ was obtained, while during 2016 the lowest grain yield of 2832 kg ha⁻¹ was obtained (Figure 2). Numerically the significant highest grain yield of 3724 kg ha⁻¹ was recorded from 400,000 plants ha⁻¹ while the lowest grain yield of 2826 kg ha⁻¹ was recorded from the lowest plant population density of 166,667 plants ha⁻¹ (Table 4). These results were indicated that as plant population density increased grain yield dramatically increased by 31.8% and soybean grain yield was responded more to plant population density than NP fertilizer rates (Figure 3). The reason for increased grain yield may be due to more number of plants harvested per unit areas rather than increased yield per plant and net crop assimilation rate. Increasing the population reduced yield per plant but increased yield per unit area [6]. One of the 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. These results are supported by Edwards and Purcell [21] who showed that as soybean population increases, yield increases rapidly until it becomes asymptotic per plants.

Table 4. Main effect of plant population densities and NP fertilizer rates on grain yield and above ground dry biomass of soybean at Kersa and Omonada during 2015-2017 cropping seasons.

Treatments	Grain yield (kg ha ⁻¹)	Above Ground biomass (ton ha ⁻¹)
N-P ₂ O ₅ fertilizer rates (kg ha ⁻¹)		
69-69	3477 ^a	12.2 ^a
46-46	3348 ^a	11.5 ^b
23-46	2988 ^b	10.1 ^c
23-23	2875 ^b	10.6 ^c
Plant population Densities (Plants ha ⁻¹)		
400,000 (50*5cm)	3724 ^a	12.7 ^a
333,333 (60*5cm)	3432 ^b	12.1 ^a
200,000 (50cm*10cm)	2904 ^c	9.7 ^b
166,667 (60cm*10cm)	2826 ^c	9.8 ^b
Mean	3221	11.2
LSD	187.5	0.6
CV (%)	20.5	19

*LSD= Least significant difference; CV=Coefficient of variation; Values followed by the same letter within a column are not significantly different at P< 0.05.

Concerning NP fertilizer rates the maximum grain yield of 3477 kg ha⁻¹ were realized from 69-69 kg ha⁻¹ N-P₂O₅ fertilizer rate which was statically at par with NP fertilizer rate of 46-46 kg ha⁻¹ N-P₂O₅ while the lowest grain yield of 2875 kg ha⁻¹ was obtained from 23-23kg ha⁻¹ N-P₂O₅

fertilizer rate (Table 4). These results were indicated as NP fertilizer rate increased to 46-46 kg ha⁻¹ N-P₂O₅ the grain yield per hectare was increased by 16.5% when it were compared with lowest NP fertilizer rate of 23-23 kg ha⁻¹ N-P₂O₅. Nitrogen influenced grain yield through source-sink

relationships resulting in higher production of photosynthesis. The combined NP fertilizer rates and plant population densities indicates, increasing the plant population densities and NP fertilizer rates increases grain yield of soybean (Figure 4). Asfaw and Angaw [22] observed that application of 120 kg P ha⁻¹ in faba bean provided three times

higher grain yield compared to the control. Seedyield of French bean increased significantly at 40 kg N ha⁻¹ compared to the control treatment as stated by Prajapati *et al.* [23]. Nebret [19] revealed that application of phosphorus influenced the seed yield of common bean significantly up to 60 kg P₂O₅ ha⁻¹.

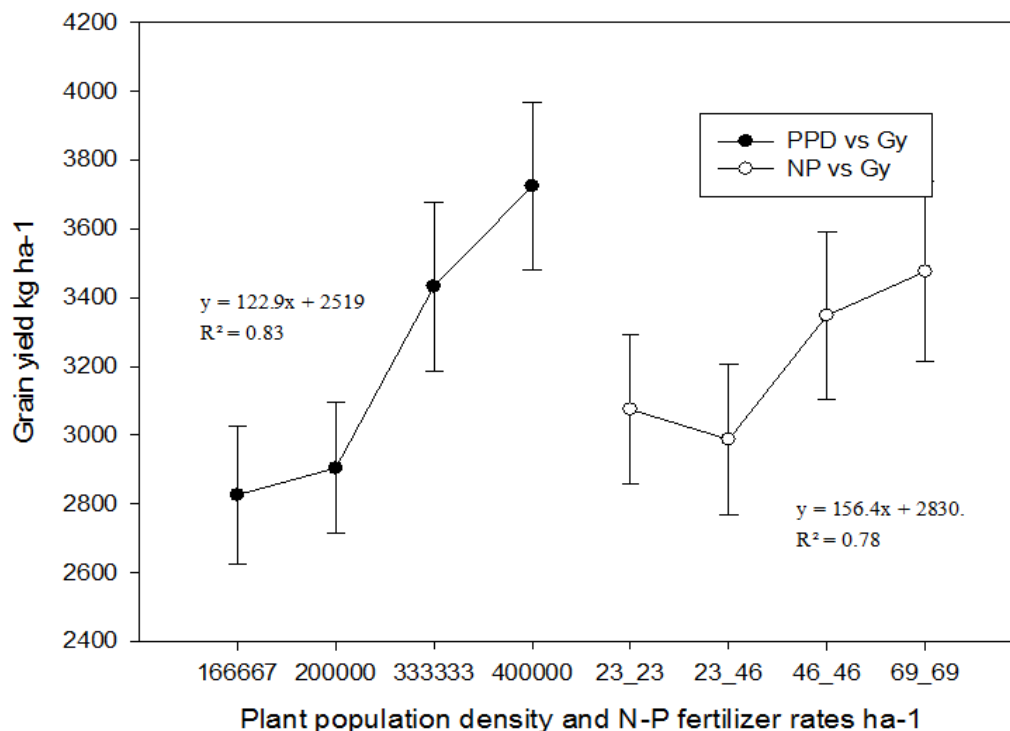


Figure 3. Over locations and cropping seasons relationship of grain yield of soybean with plant population densities and NP fertilizer rates.

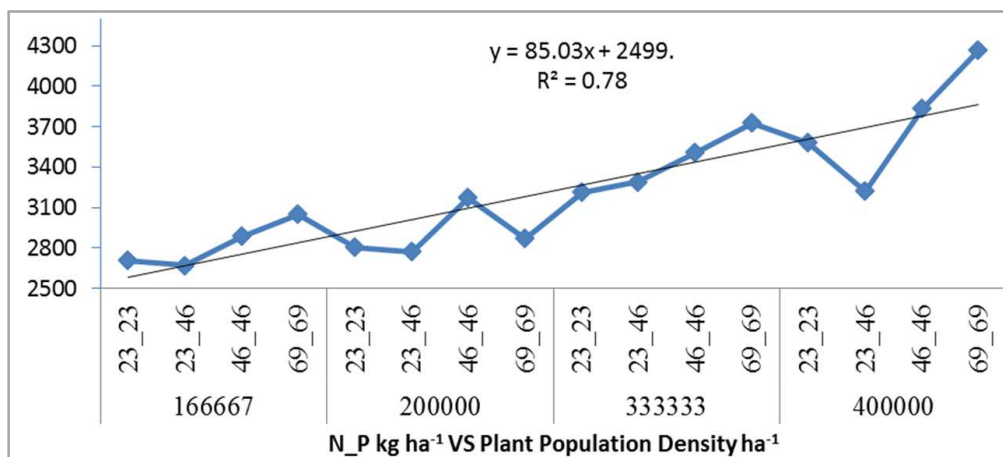


Figure 4. Over locations and cropping seasons grain yield of soybean response to combined NP fertilizer rates and plant population densities.

3.2.4. Harvest Index

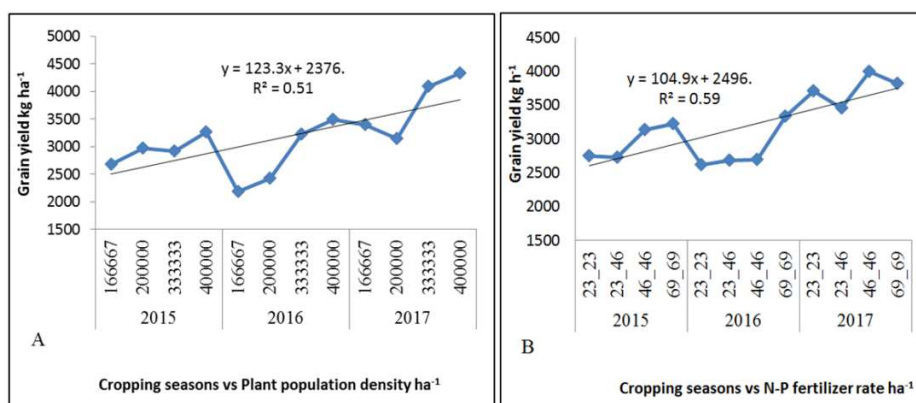
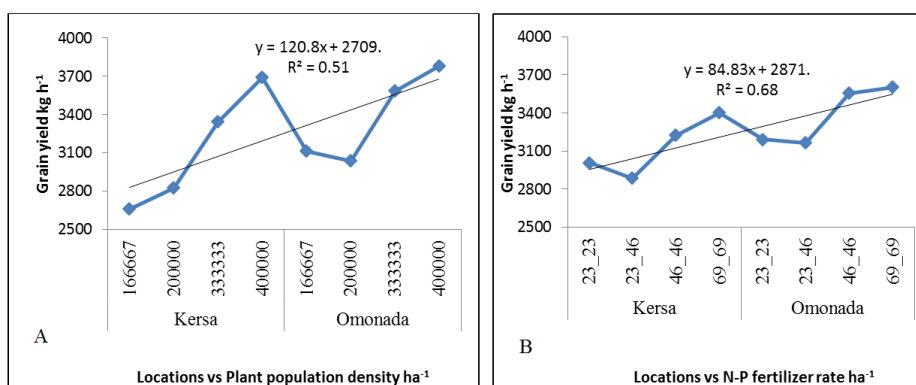
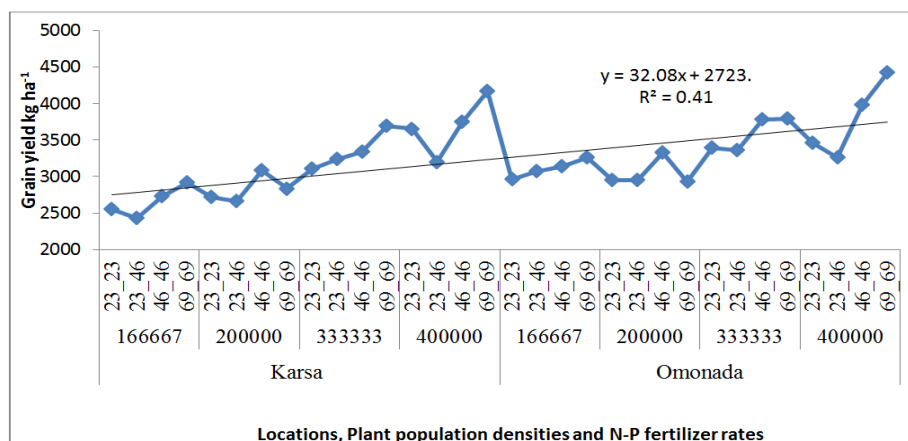
Numerically the highest harvest index of 0.34 was obtained during 2016 main cropping season where as the lowest harvest index of 0.26 was obtained during 2017 main cropping season (Figure 2). The average harvest index values were ranged from 0.269 to 0.321 over three main cropping seasons and locations (Table 5). The highest harvest index of 0.321 was obtained from 200,000 plants ha⁻¹ and 46-46 kg ha⁻¹ N-P₂O₅ fertilizer

rate while the lowest harvest index of 0.269 was obtained from lowest plant population density of 166,667 plants ha⁻¹ and highest NP fertilizer rate of 69-69 kg ha⁻¹ N-P₂O₅ (Table 5). The result indicates harvest index of soybean decreased with increasing NP fertilizer rates. These results agreed with Malik *et al.* [24] who reported N application has effect on harvest index of soybean. These results is also in parallel with results of Bullock *et al.* [25] who reported that harvest index decreased with increasing row width.

Table 5. Interaction effect of plant population densities and NP fertilizer rate on harvest index of soybean at Kersa and Omonada during 2015-2017 main cropping seasons.

N-P ₂ O ₅ fertilizer rates (kg ha ⁻¹)	Plant population Densities (Plants ha ⁻¹)			
	166,667 (60cm*10cm)	200,000 (50cm*10cm)	333,333 (60*5cm)	400,000 (50*5cm)
23-23	0.295 ^{a-d}	0.319 ^a	0.298 ^{abc}	0.315 ^{ab}
23-46	0.306 ^{abc}	0.315 ^{ab}	0.297 ^{abc}	0.286 ^{cd}
46-46	0.304 ^{abc}	0.321 ^a	0.297 ^{abc}	0.307 ^{abc}
69-69	0.269 ^d	0.286 ^{cd}	0.301 ^{abc}	0.313 ^{abc}
Mean	0.302			
LSD	0.027			
CV (%)	10.2			

*LSD= Least significant difference; CV=Coefficient of variation; Values followed by the same letter within a column are not significantly different at $P < 0.05$.

**Figure 5.** Soybean grain yield response to plant population densities (A) and NP fertilizer rates (B) during 2015 to 2017 main cropping seasons.**Figure 6.** Soybean grain yield response to plant population densities (A) and NP fertilizer rates (B) at Kersa and Omonadaworeda of Jimma zone.**Figure 7.** Soybean grain yield response to NP fertilizer rates and plant population densities at Kersa and Omonadaworeda of Jimma zone during 2015 to 2017 main cropping seasons.

3.3. Correlation Analysis

The relationship between grain yield with growth parameters and yield related traits was presented in (Figure 8). The results were showed that grain yield was positively and highly significantly ($P < 0.01$) correlated with plant height ($R^2 = 0.55$), pod height ($R^2 = 0.78$), above ground biomass ($R^2 = 0.93$) and

harvest index ($R^2 = 0.03$). While it was negatively and highly significantly ($P < 0.01$) correlated with number of pods per plant ($R^2 = 0.19$). This is due to as plant population densities increased number of pods per plant was decreased and plant population density had great impact on number of pods per plant to negatively correlate with grain yield.

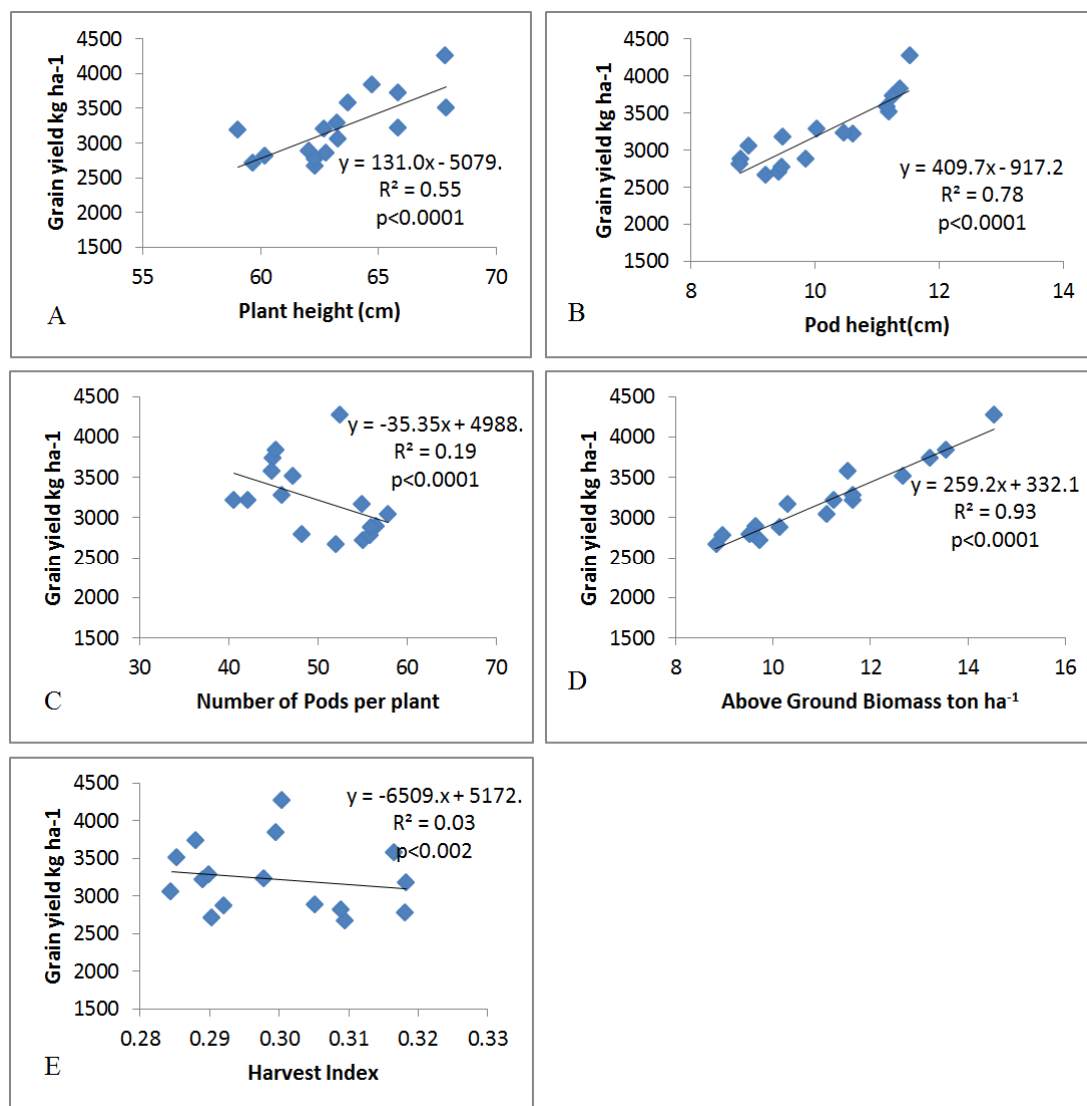


Figure 8. Relationships between grain yield with plant height (A), pod height (B), number of pods per plant (C), above ground biomass (D) and harvest index (E) at Kersa and Omonadaworeda of Jimma zone during 2015-2017 main cropping seasons.

3.4. Economic Analysis

Economic analysis was performed using partial budget analysis following the procedure described by CIMMYT [11] in which prevailing market prices for inputs at planting and for outputs at harvesting were used. All costs and benefits were calculated on hectare basis in Ethiopian Birr (ETB). The grain yield was adjusted by 10% for management difference. The total costs of fertilizers (NPS = 14.5 ETB kg⁻¹ and urea = 12 ETB kg⁻¹) were calculated based on store sale prices of Omaonada and Kersaworeda Cooperative and sale

of grain soya bean at at both locations open market average price (15 ETB kg⁻¹). The partial budget analysis revealed that the highest net benefit of 40,028 and 48,234 ETB ha⁻¹ was obtained from 46-46 kg N-P₂O₅ ha⁻¹ fertilizer rate and 400,000 plants ha⁻¹ respectively (Table 6). The highest marginal rate of return (MRR) of 276% and 1543% was also obtained from fertilizer rate of 46-46 N-P₂O₅ kg ha⁻¹ and plant population density of 400,000 plants ha⁻¹ respectively (Table 7). These results were indicated that as plant population density increases the MRR (%) also increased and vice versa (Table 7).

Table 6. Partial budget for the main effects of NP fertilizer and plant population density on soybean grain yield at Kersa and Omonadaworeda during 2015-2017 main cropping seasons.

Treatment	Grain yield (kg ha ⁻¹)	Adj. Grain Yield (kg ha ⁻¹)	GFB (ETB ha ⁻¹)	TVC (ETB ha ⁻¹)	Net Benefit (ETB ha ⁻¹)	Dominance
N - P ₂ O ₅ fertilizer rates (kg ha ⁻¹)						
23-23	2875.2	2588	38815	2,587	36,228	-
23-46	2987.5	2689	40331	3,880	36,451	U
46-46	3348.3	3013	45202	5,174	40,028	U
69-69	3476.5	3129	46933	7,761	39,172	D
Plant population densities (Plants ha ⁻¹)						
166,667 (60*10cm)	2826	2543	38151	2200	36951	-
200000 (50*10cm)	2904	2614	39204	2320	37884	U
333333 (60*5cm)	3432	3089	46332	2800	44532	U
400000 (50*5cm)	3724	3352	50274	3040	48234	U

*GFB = Gross field benefit; TVC = Total variable cost; D=Dominated treatments; U=Un-Dominated treatments; ETB = Ethiopian Birr.

Table 7. Partial budget with estimated MRR (%) for the main effects of NP fertilizer rates and plant population densities on soybean grain yield at Kersa and Omonadaworeda during 2015-2017 main cropping seasons.

Treatments	TVC (ETB ha ⁻¹)	Net Benefit (ETB ha ⁻¹)	MRR (%)
N-P ₂ O ₅ fertilizer rates (kg ha ⁻¹)			
23-46	3,880	36,451	17
46-46	5,174	40,028	276
Plant population Densities (Plants ha ⁻¹)			
200000 (50*10cm)	2320	37884	778
333333 (60*5cm)	2800	44532	1385
400000 (50*5cm)	3040	48234	1543

*TVC = Total variable cost; MRR=Marginal Rate of Return.

4. Conclusions

The experiment was conducted with objective to determine plant population density and NP fertilizer on growth, yield and yield components of Soybean at Kersa and Omonadaworeda of Jimma zone South Western Ethiopia during 2015-2017 main cropping seasons. The experiment was laid out in RCBD with 4*4 factorial arrangement of four different plant population densities; 166,666 (60*10cm), 200,000 (50*10cm), 333,333 (60*5cm) and 400,000 (50*5cm) plants ha⁻¹ and four levels of NP fertilizer rates; 23-23, 23-46, 46-46 and 69-69 kg ha⁻¹ N-P₂O₅ with three replications. The results indicated that at Omonadaworeda the crop performed well and the highest plant height, number of pods per plant, pod height, above ground biomass and grain yield was obtained than at Kersaworeda. During 2017 main cropping season the highest plant height, number of pods per plant, above ground biomass and grain yield was recorded than during 2015 and 2016 main cropping seasons. There was no interaction effect observed among plant population densities and NP fertilizer rate across locations and years for plant height, pod height, grain yield and above ground biomass except for harvest index. The crop responded more to plant population densities than NP fertilizer rates. As plant population density increased plant height, pod height, grain yield and above ground biomass significantly increased but number of pods per plant was decreased. The highest plant population densities gave highest mean grain yield of 3724 kg ha⁻¹ with highest net benefit of 48,234

ETB ha⁻¹ and Marginal rate of return of 1543%. Further research must also done to conclude the yield response of the crop to plant population density because the yield is significantly increasing up to 400,000 plants ha⁻¹. Concerning NP fertilizer effects, as NP fertilizer rate increased slightly plant height, number of pods per plant, grain yield and significantly above ground biomass was increased. The NP fertilizer rate of 46-46 N-P₂O₅ gave the highest net benefit of 40,028 ETB ha⁻¹ with highest MRR of 276%. Thus planting of soybean with plant density of 400,000 plants ha⁻¹ (50cm between rows and 5cm between plants) and 46-46 kg N-P₂O₅ ha⁻¹ fertilizer rate can be used for soybean production at Jimma area and similar agro-ecologies of the country.

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