Innovative Systems Design and Engineering www.iiste.org
ISSN 2222-1727 (Paper) ISSN 2222-2871 (Online)
Vol 2, No 4, 2011

Selection of Planting Pattern and Plant Population Density (PPD) for Medium and Late Maturing Soybean Varieties (G*lycine Max* (L.) Merrill) in the Tropics

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The research is financed by agricultural research and training project (ARTP) and Southern Agricultural Research Institute (SARI).

Abstract

An experiment was conducted in the tropics at Awassa ($7^0$04'N, $38^0$31'E, 1700m a.s.l) from 2005-2006 in order to determine effects of planting patterns and plant density on growth and yield of soybean. Results showed that Belessa-95 variety had significantly ($p<0.05$) taller plants with lowest pod height, larger leaf area, greater leaf area index at R2 (stage 50% flowering) and taller plants at R7 (stage of physiological maturity). Similarly, grain yield per unit area was significantly higher ($p<0.01$) different from Belessa-95 than Awassa-95 variety. The yield performance of soybean was positively associated with hundred seed weight ($r=0.73$, $p<0.001$), seeds/pod ($r=0.56$, $p<0.001$), pods/plant ($r=0.53$, $p<0.001$, plant height ($r=0.73$, $p<0.001$) and harvest index ($r=0.63$, $p<0.001$). The number of branches/plant were significantly higher ($p<0.05$) in rectangular rows than either paired rows or equidistant rows. First pod height was significantly higher ($p<0.05$) due to equidistant rows than either paired rows or rectangular rows. Paired rows gave significantly higher ($p<0.01$) harvest index and grain yield/plant than equidistant rows. Grain yield/plant was comparable from rectangular and paired rows. Significantly greater ($p<0.05$) number of branches/plant, seeds/pod, pods/plant, hundred seed weight, harvest index and grain yield/plant were recorded due to 20plants/m2 than other plant densities. However, there was not significant difference due to 20 and 30 plants/m2 in number of branches/plant, pods/plant and hundred seed weight. But significantly higher leaf area index ($p<0.05$), first pod height ($p<0.05$) and grain yield/unit area ($p<0.01$) were obtained due to 50 plants/m2 than other plant densities. Leaf area index and first pod height due to 40 and 50 plants/m2 were not significantly different and grainyield/m2 due to 30, 40 and 50 plants/unit area were also comparable. Planting pattern x plant density interactions brought significant effect on most growth and yield related traits unlike variety x planting pattern and variety x plan density interactions. Similarly, the *interaction effect of planting pattern, plant density and variety was significant on harvest index, grain yield/plant and grain yield/unit area. Results indicated that grain yield/unit area was significantly higher (p<0.01) due to 30 plants/m2 grown in rectangular rows (60 cm x 5.5 cm) in Awassa-95 variety, but grain yield/m2 was significantly higher (p<0.01) due to 30 plants/m2 grown in rectangular rows (60 cm x 5.5 cm) and paired rows (90/30 cm x 5.5 cm) in variety Belessa-95. This study indicated that lower plant populations employed with rectangular or paired rows than are previously recommended for early and late maturing varieties provide way to optimize grain yield under sub-humid growing conditions of Awassa.*

Keywords: plant population density, planting pattern, R2, R5, R7, leaf area index, varieties

1. Introduction

In Ethiopia, soybean has adapted diverse ecological niches and provided wider yield range (Amare, 1987). The most promising performance has been recorded in areas where starchy root and tuber crops, cereals and enset (*Ensete ventricosum*) have been dominant in the proportion of diet of the majority. As a result, production of pulses like soybean has been highly encouraged to supplement the carbohydrates with proteins (ARC, 2004). To this end, new varieties namely Awassa-95(G-2261) and Belesa-95(IP-149) were released recently in 2003/4 cropping seasons (ARC, 2004). However, the yield performance of these varieties could only be realized with proper management and timely performance of appropriate cultural practices. Past population density studies were undertaken on Crawford, Williams, Davis, Coker-240 and Clark-63K. The recommended plant spacing for early and late maturing varieties was 40 cm x 5 cm and 60 cm x 5 cm respectively. These findings were old and indicated that plant spacing experiments were undertaken using row pattern in Ethiopia (IAR, 1983). However, too old recommendations aggravate the adverse effect of competition as response of varieties to growth conditions change over time (Venkateswarlu, 1992). More over, the responses of soybean differ with equidistant and paired row pattern of planting (Herbek and Bitazer, 2004). Equi-distant planting gave highest yield when compared with traditional row planting in USA. In such arrangement, quadratic allocation of plants provides more efficient light interception, nutrient exploitation, advantage of border effects and judicious apportioning of other available resources (Egli, 1996). However, Bullock *et al.* (1996) obtained opposite result in southern USA. In Kentucky, skip row patterns gave consistently higher yields than traditional uniform rows for both Elf and Union varieties that had determinate and indeterminate growth habit respectively (Herbek and Bitazer, 2004). It was also shown that paired rows give higher productivity, gross return and moisture use efficiency than traditional rectangular arrangement across different seasons and crops in India. More over, a different pattern of planting several seeds per hill in a "check row" pattern of hills that were isolated a meter apart was adopted by Zambian formers instead of drilling seeds in narrow rows (Venkateswarlu, 1992). More over, planting pattern and population density vary greatly with soil moisture, soil fertility, soil type, seeding rate, variety, climate, weed control, seed size, time of planting, tillage practices, lodging behavior of the plant, quality of the seed, and method of sowing (Johnson, 1987; Olufajo and Pal, 1991; Norman *et al*., 1995). Hence the project was implemented with objectives of determining the effect of planting pattern and plant density on growth and yields of soybean, and identifies appropriate set of these treatments that gives maximum soybean yield.

2. Materials and methods

The study was conducted in Awassa Research Center, which is situated at 7^0 04\` N latitude, $38^0$ 31\` E longitudes and located at 1700 m a.s.l from 2005 to 2006. The treatments included factorial combinations of two varieties, three planting patterns and four plant densities. The soybean varieties were Awassa-95 (early type) and Belessa–95(late type); planting patterns were equidistant planting, paired row planting and rectangular row planting. The levels of plant densities were 200, 300,400 and 500 thousand plants per hectare, which are 20, 30, 40 and 50 plants/m^2, respectively. Factorial combination of treatments was laid in randomized complete block design with three replications. Fertilizer DAP was applied at the rate of 100Kg/ha uniformly for all plots. Plant height was recorded on five randomly sampled plants at 50% flowering (R2) and physiological maturity stages (R7). Same plants were taken for determination of leaf area at 50% flowering using punch method as described by Pal and Saxena (1976). Leaf Area Index at 50% flowering was calculated as the ratio of leaf area to area occupied by individual plants (Pal, 2004). At 90% physiological maturity, five competitive plants were randomly sampled from the net plot area for the determination of first pod height, number of branches/plant, number of pods/plant, number of seeds/pod (based on 20 randomly sampled pods), grain yield/plant and hundred seed weight (using sensitive electronic balance). Harvest index was computed as the ratio of grain yield to dry above ground biomass per plant. Grain yield per plot or per hectare was determined by harvesting the crop of entire net plot area (including those used for yield attributes determination). Grain yield was adjusted to 10% moisture content. All data was subjected to ANOVA (analysis of variance) (Gomez and Gomez, 1984).

3. Result and discussion

3.1 Phenology

The variety Awassa-95 flowered, filled its pods and matured earlier than Belessa-95. The productivity period (the period between R2 and R7 stage) was also highly significantly longer in Belesa-95 than Awassa-95 reaching about 23 days (Table 1). The long period from emergence to R2 means that Belessa-95 variety had higher opportunities to enhance adequate vegetative growth compared to Awassa-95. This result has been in accordance with characterization work on these varieties in different agroecologies of Ethiopia (Asrat *et al*., 2003). Most phenological dates were not significant due to main effects of planting pattern and plant density, and interaction effects of varieties with planting pattern and density.

3.2 Growth components

The effect of variety was significant on number of branches/plant, leaf area index, first pod height and plant height at R7. However, the main effect of variety was not significant on plant height at R2. Variety Belessa-95 produced significantly ($p<0.05$) larger leaf area, higher leaf area index, taller pod clearance and plant height at R7 than variety Awassa-95, but the number of branches/plant were significantly higher ($p<0.05$) in Awassa-95 variety than Belessa-95. Under current investigation, leaf area index of soybean varieties averaged over planting pattern and plant density was above the critical leaf area index (3.1 to 4.5) for interception of maximum radiation; however, the pod clearance for both varieties less than the minimum (50 to 60 cm required for mechanized harvesting (FAO,1994). When considering planting pattern, the number of branches/plant were significantly higher ($p<0.05$) in rectangular rows than either paired rows or equidistant rows, but first pod height was significantly higher ($p<0.05$) due to equidistant rows than either paired rows or rectangular rows. However, the effect of planting pattern was not significant upon leaf area, leaf area index and plant height at R7. The effect of plant density was significant ($p<0.05$) on number of branches/plant, leaf area index, first pod height and plant height at R7. Significantly greater ($p<0.05$) number of branches/plant was recorded due to 20 plants/m2 than other plant density levels. However, there was not significant ($p<0.05$) difference due to 20 and 30 plants/m2 density in number of branches/plant. Significantly larger leaf area index and taller first pod height were obtained due to 50 plants/m2 density than other plant densities. However, leaf area index and first pod height due to 40 and 50 plants/m2 were not significantly different ($p<0.05$)(Table 1). As plant densities were increased from 20 to 50 plants/m^2, there was subsequent increase in leaf area index, first pod height and plant height at R7. This result is in harmony with those of 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. Planting pattern x plant density interaction was significant ($p<0.05$) on first pod height and leaf area index. However, growth components did not respond significantly to other two way and three way interactions in the study. Thus strong main effects of variety x planting pattern and plant density were masked in the interaction. This might be due to induced rectangularity that moderated the adverse effect of higher plant densities in plant communities.

3.3 Grain yield components and grain yield

The effect of variety was significant ($p<0.01$) on seeds/pod, hundred seed weight, harvest index and grain yield/plant. The result indicated that variety Belessa-95 produced significantly higher number of seeds/pod, hundred seed weight and grain yield/plant than variety Awassa-95. On the contrary, Awassa-95 variety produced significantly higher harvest index than variety Belessa-95. Although the hundred seed weight of variety Belessa-95 (188 mg) was significantly greater than that of Awassa-95 (166 mg), both varieties produced seeds sized well above the range of seed size for tropical cultivars (Norman *et al*., 1995). This could be due to the fact that both varieties maintained adequate leaf area index at R2 stage of growth. Averaged over varieties and plant densities, paired rows gave significantly higher grain yield/plant than equidistant rows, but there was not statistical difference in grain yield/plant due to paired rows and rectangular rows. However, the harvest index was significantly ($p<0.01$) higher due to paired rows than either rectangular rows or equidistant rows. As plant densities were increased, there was a decreasing trend in number of seeds/pod, pods/plant, hundred seed weight, harvest index and grain yield/plant in both varieties. However, there was not significant difference between plant densities of 30, 40 and 50 plants/m^2 in number of pods/plant, hundred seed weight and harvest index (Table 2). As a result significantly lower number pods/plant, hundred seed weight, harvest index and grain yield/plant was obtained due to 50 plants/m^2 and significantly higher number pods/plant, hundred seed weight, harvest index and grain yield/plant was obtained due to 20 plants/m^2 density than other plant densities. Such reports are inconsistency with Hume *et al*. (1985) and Kayhan *et al.* (1999), who elaborated compensatory mechanism between or among yield attributes with yield/unit area in varying plant densities. Decline in seed weight at higher plant densities was also attributed to source limitation of photosynthesis due to which plants mobilize stored carbohydrates there by reducing seed weight as elaborated by Helm and Orf (1998). Moreover, Olfujo and Pal (1991) reported that higher pod production at lower densities is mostly attributed to delayed senescence, resulting from lesser competition, which ensures the presence of active photosynthetic tissue through out pod filling stage and better exposure of pods to light. Grain yield/unit area responded significantly ($p<0.01$) to main effects of varieties, planting pattern and plant densities. Results showed that Belessa-95 produced significantly higher ($p<0.01$) grain yield per unit area than variety Awassa-95 (Table 2).

Rectangular rows gave significantly higher grain yield/m^2 than equidistant rows; however, there was not significant difference in grain yield/m2 due to rectangular rows and paired rows. When averaged over varieties and planting patterns, significantly higher ($p<0.01$) grain yield/m^2 was obtained due to 50plants/m2 than other plant densities. The effect of planting pattern x plant density interaction was significant on grain yield/plant, grain yield/unit area and harvest index only and variety x planting pattern x plant density interactions were significant on grain yield/plant, grain yield/unit area and harvest index only (Table 5 and 6). Moreover, year effect was significant on three way interactions of variety, planting pattern and density on grain yield/plant and grain yield/unit area basis. Finally variety, planting pattern and density interaction effects showed that rectangular rows produced significantly higher ($p<0.01$) grain yield due to $\geq$ 30 plants/m^2 in both Awassa-95 and Belessa-95 varieties when compared to plant density of 20 plants/m^2 (Table 3). Significantly higher grain yield was observed in paired rows due to higher plant densities ($\geq$ 40 plants/m2) in Awassa-95 variety and due to $\geq$ 30 plants/m^2 in Belessa-95 variety. Equidistant rows produced significantly lower grain yield/m2 in most plant densities ($\leq$ 40 plants/m^2) in both Awassa-95 and Belessa-95 varieties than plant density of 50 plants/m^2. Significantly lower yields were recorded due to 20 plants/m^2 density across all patterns in both varieties when compared to higher plant densities. It happened so due to lower podding, lesser branching and inadequacy of weed control which might have lead to inability to cover the ground fully at R2 stage of soybean growth which would intern resulted in low evapo transpiration control of the plant community. In addition, 33% increase in plant density from 30plants/m^2 to 40plants/m^2 in Awassa-95 variety produced only in 13.4 % yield increase and 3% yield increase in Belessa-95 variety (Table 3). The absence of significant difference in yield and yield components at plant densities of 30, 40 and 50 plants/m^2 was due to the fact that soybean tolerates wide variation in plant densities without significant change in yield, which agrees with previous work of many authors (IAR,1983; FAO,1994 and Herbek *et al*., 2004). They indicated that soybean plants have remarkable ability to compensate for variation in plant densities. Furthermore, the points of intersection for grain yield measured in individual plants and in unit area basis was due to 30 plants/m^2 density in both varieties (Fig 1 and 2). Physiologically speaking, this intersection marks the point of optimized productivity for each variety.

3.4 Association of characters

Positive significant association index occurred among grain yield and hundred seed weight ($r=0.73$, $p<0.001$), seeds/pod ($r=0.56$, $p<0.001$), pods/plant ($r=0.53$, $p<0.001$) and harvest index ($r=0.63$, $p<0.001$).

The result indicated that varieties that produce more yield would also produce more sized seeds, greater number of seeds/pod, pods/plant and harvest index. The correlation coefficient was negative and significant among dates to mid flowering and number of branches (Table 4).

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Table 1. Main effects variety, planting pattern and plant density on growth of soybean

	Branches/plant	Leaf area (cm2)	Leaf area index	First pod height (cm)	Plant height R2 (cm)	Plant height R7 (cm)	Date to R2	Date to R5	Dates to R7	Productive period
Variety										
Awassa-95	7.8	1721	6.04	7.8	51.3	68.80	61	86	113	52.4
Belessa-95	4.4	2011	7.29	16.4	51.0	76.17	79	90	155	75.6
SE(m)±	0.21	83.5	0.38	0.48	1.14	0.85	0.13	0.6	0.09	0.497
LSD	0.60*	237.7*	1.08*	1.36*	ns	2.45*	9.6**	6.9**	21**	1..19**
Planting pattern										
Rect. rows	6.98	1790	6.45	10.6	52.0	70.01	70	92	133	63.1
Paired rows	5.73	1781	6.66	11.4	48.7	69.80	70	93	133	63.3
Equidist. rows	5.62	2027	6.90	14.1	52.8	71.64	70	92	135	65.7
SE(m)±	0.25	102.4	0.47	0.58	1.4	1.04	0.16	0.8	0.59	0.61
LSD	0.72*	ns	ns	1.66*	ns	ns	ns	ns	1.68**	2.31**
Plant density										
20	6.9	2128	4.86	10.8	49.4	67.77	70.4	93	135	65.1
30	6.2	1758	6.12	11.3	52.2	68.61	70	91	133	63.4
40	5.5	1804	7.53	13.0	52.1	70.72	69	92	133	63.6
50	4.8	1774	8.18	13.2	51.0	71.81	70	92	134	63.9
SE(m)±	0.29	118.2	0.54	0.67	2.61	1.20	0.19	0.9	0.68	0.70
LSD	0.83*	ns	1.54**	1.91*	ns	3.42*	ns	ns	ns	ns
Cv(%)	20.2	3.54	15.59	3.54	13.38	10.27	1.14	4.1	2.15	4.7

Table 2. Main effects variety, planting pattern and plant density on yield and yield components

Traits	Seeds/pod	Pods/plant	100 seed weight (g)	Harvest index	Grain yield (g/plant)	Grain yield (g/m2)
Variety						
Awassa-95	2.2	59.0	16.6	0.43	16.23	473.6
Belessa-95	2.5	56.2	18.8	0.38	18.38	517.8
SE(m)±	0.045	2.07	0.21	0.009	0.27	10.43
LSD(%)	0.128**	ns	0.59**	0.026**	0.76**	29.69**
Planting pattern						
RR	2.41	59.7	17.6	0.39	17.89	519.8
PR	2.39	56.8	17.5	0.44	18.03	510.4
ER	2.37	56.3	18.1	0.39	15.99	457.0
SE(m)±	0.055	2.53	0.25	0.012	0.32	12.8
LSD(%)	ns	ns	ns	0.034**	0.81**	36.4**
Plant population density						
20	2.45	64.7	18.4	0.46	21.50	368.0
30	2.38	57.7	17.9	0.41	18.53	493.4

40	2.40	55.1	17.4	0.38	14.68	507.1
50	2.32	52.9	17.2	0.37	14.50	614.4
SE(m)±	0.064	2.93	0.29	0.014	0.38	14.7
LSD	ns	8.34**	0.83**	0.039**	1.08**	41.9**
Cv(%)	16.02	30.48	9.89	22.05	13.05	17.85

***,**-**stands for significance at 5 and 1% level of probability. ns-indicates absence of significant difference at 5% level of probability. R2, R5 and R7 refer to stages of soybean growth indicating 50% flowering, pod initiation and 90% physiological maturity.

Table 3. Means of grain yield (g/m^2) of soybean as affected by interaction effects of variety x planting pattern x plant density for two consecutive years (2005- 2006) at Awassa

Planting	Awassa-95				Iessa-95			
Patterns	20	30	40	50	20	30	40	50
Rectangular rows	390.4	534.9	534.3	578.8	359.5	675.9	538.8	545.5
Paired rows	355.9	436.8	518.2	558.9	412.4	564.5	535.5	700.7
Equidistant rows	250.3	426.2	473.4	625.0	439.3	321.9	442.5	677.4

	Planting pattern x variety	Planting pattern x density	Variety x planting pattern x density
SE(m)±	18.06	25.54	36.11
LSD(%)	NS	72.7**	102.8**
CV(%)		17.85	

Table 4. Coefficient of correlation (r) among growth and yield components of soybean (n=144)

Traits	Date to R2	Number of branches	Leaf area	Grain yield	Hundred seed weight (HSW)	Seed/pod	Pods/ plant	Harvest Index	Plant height
Dates to R2	1	-0.70***	0.11ns	-0.19ns	-0.189ns	0.046ns	0.58***	0.22ns	0.23ns
Branch/plant		1	-0.06ns	0.322*	0.050ns	0.11ns	0.045ns	0.2ns	0.40ns
Leaf area			1	0.23ns	0.20ns	0.03ns	0.315*	0.23ns	0.12ns
Grain yield				1	0.73***	0.56***	0.53**	0.63***	0.73***
HSW					1	0.59***	0.36***	0.40***	0.76***
Seed/pod						1	0.37***	0.38***	0.64***
Pods/plant							1	0.45***	0.53***
Harvest index								1	0.51***
Plant height									1

*,**,***- indicates significant difference at 0.05, 0.01 and 0.001 level of probability. ns-indicates absence of significant difference at 5% level of probability.

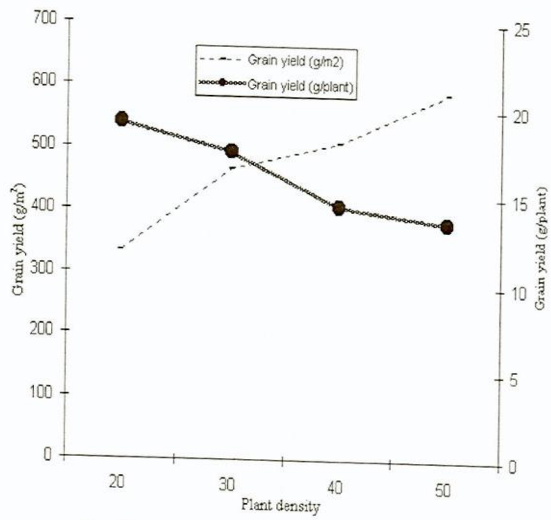

Fig 1. Effects of plant density on grain yield of Awassa-95 variety

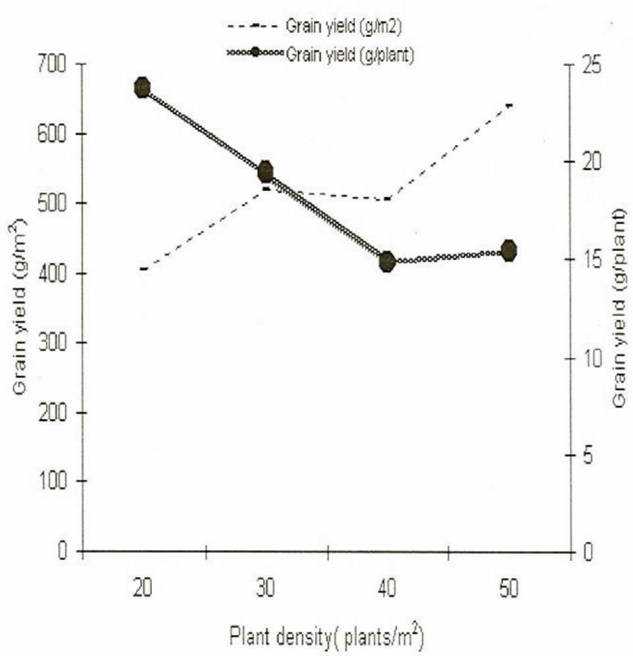

Fig 2. Effects of plant density on grain yield of Belessa-95 variety