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Effects of row spacing on productivity and nodulation of two soybean varieties under hot sub-moist tropical conditions in south-western Ethiopia

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Abstract

The objective of this study was to determine the optimum row spacing to improve the productivity of two soybean (*Glycine max* L.) varieties under the tropical hot sub-moist agroecological conditions of Ethiopia. A two-year split-plot design experiment was conducted to determine the effect of variety (Awasa-95 [early-maturing], Afgat [medium-maturing]) and row spacing (RS: 20, 25, 30, 35, 40, 45, 50, 55, 60 cm) on the productivity, nodulation and weed infestation of soybean. Seed and total dry matter (TDM) yield per ha and per plant, and weed dry biomass per m^2 were significantly affected by RS. Soybean variety had a significant effect on plant density at harvest and some yield components (plant height, number of seeds/pod, and 1000 seed weight). Generally, seed and TDM yield per ha and per plant were high at 40 cm RS, and weed dry biomass per m^2 was higher for RS $\geq$ 40 cm than for narrower RS. However, the results did not demonstrate a consistent pattern along the RS gradient. The medium-maturing variety Afgat experienced higher mortality and ended up with lower final plant density at harvest, but higher plant height, number of seeds per pod and 1000 seed weight than the early-maturing variety Awasa-95. The results indicate that 40 cm RS with 5 cm plant spacing within a row can be used for high productivity and low weed infestation of both soybean varieties in the hot sub-moist tropical environment of south-western Ethiopia.

Keywords: soybean, plant density, weed infestation, early and medium maturing variety

1 Introduction

Soybean (*Glycine max* (L.) Merr.), a leading source of edible vegetable oil and protein for both humans and animals, has the potential to nourish humans worldwide in the near and distant future (Hartman *et al.*, 2011). However, soybean growers face different challenges including unpredictable weather, diseases, pests, weeds and variable soil quality, which can be offset by using varieties adapted to local conditions (Hartman *et al.*, 2011). Moreover, plant development, yield and oil content of soybean depend on both environmental and genetic factors (Edwards & Purcell, 2005; Edwards *et al.*, 2005; Lee *et al.*, 2008). Consequently, different agronomic settings are recommended for different genotypes growing in different locations. For example, a row spacing (RS) of 40 cm was recommended for early maturing soybean in mid-southern USA (Bowers *et al.*, 2000), and a RS of 60 cm for forage soybean in Mediterranean environments in Turkey (Acikgoz *et al.*, 2009). A 45 cm row by 5 cm plant spacing is commonly used in Kenya

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(Misiko *et al.*, 2008). In mid-western and southern Canada, a RS of less than 76 cm gave consistently higher yields than a RS of more than 76 cm (De Bruin & Pedersen, 2008), whereas in the semi-arid tropical environment of Sudan, a RS of 40 cm gave higher yields than wider RS (Yunusa & Ikawelle, 1990).

Soybean production in Ethiopia is steadily growing to meet the ever-increasing food and market demands of this crop in the country. Moreover, some soybean varieties that are categorised into three maturity groups: early-, medium- and late-maturing varieties, are recommended for different agro-ecological zones of Ethiopia. Growers traditionally use either 40 or 60 cm RS with 5 cm plant spacing, regardless of the maturity groups of the varieties and agronomic conditions of the location (Ali *et al.*, 2003). However, a recent study on the responses of early and late maturing varieties to planting density in south-western Ethiopia showed less weed growth and greater yield and yield components per m^2 as RS decreased from 70 to 50 cm and plant spacing from 10 to 2.5 cm or as plant density increased from 14 to 80 plants per m^2 (Worku & Astatkie, 2011). The optimum soybean planting density for this area may be higher than 80 plants per m^2, which can be achieved by narrower spaces between rows of plants. Similarly, several experiments conducted with soybean varieties assigned to different maturity groups under variable soil and climatic conditions in other countries report higher yields and yield components for higher planting densities (21–38 plants/m^2) and narrower RS (25–60 cm RS) than for lower planting densities and wider RS (Ethredge *et al.*, 1989; Kapustka & Wilson, 1990; Yunusa & Ikawelle, 1990; Chen *et al.*, 1992; Gan *et al.*, 2002; De Bruin & Pedersen, 2008; Acikgoz *et al.*, 2009; Sarkodie-Addo & Mahama, 2012).

Planting density and RS also influence lodging, nodulation, N fixation, residual N, and weed resurgence (Herbert & Litchfield, 1984; Blumenthal *et al.*, 1988; Kapustka & Wilson, 1990; Jamro *et al.*, 1990; Yelverton & Coble, 1991; Chen *et al.*, 1992). Weed resurgence has been reported to increase as RS increases (Yelverton & Coble, 1991). Jamro *et al.* (1990) found that nodule weight per plant was higher at a RS of 60 cm compared to ones of the 30 and 45 cm, and in southern Quebec, Canada, high plant densities increased fresh nodule mass per unit area, but had little effect on individual plant nodulation (Chen *et al.*, 1992). A trend of increasing residual N and dry matter with increasing population density was reported by Blumenthal *et al.* (1988). However, in Fluvisols of southern Ethiopia, a decrease in the number and dry matter of nodules with increasing plant density was observed (Markos *et al.*, 2011, 2012). Other parameters, such as the dry matter of plant components, harvest index, grain yield per plant and per unit area, and protein content of soybean varieties also changed with variable plant density (Markos *et al.*, 2011, 2012). Furthermore, Ogoke *et al.* (2006) reported that in the moist Savanna of Nigeria, nodulation and nodule efficiency (g N fixed/nodule g weight) increased with days to maturity and P fertilization rate, but weight per nodule decreased significantly.

As indicated above, RS affects plant population, which ultimately affects grain yield, nodulation and weed growth. A previous study conducted in this study area but with different varieties (Worku & Astatkie, 2011) reported an increase in seed yield per unit area as RS decreased, but it did not identify optimum plant density for high yield, nodulation and weed control. Thus, we hypothesised that: (1) varieties with different maturity days will have distinct yield, nodulation and ground cover responses to RS (planting density), and (2) these varieties will have different RS for optimum yield, nodulation and weed control for our study site. To test these hypotheses, the study was conducted with the following specific objectives: (i) to investigate the effect of RS on grain and biomass productivity, nodulation and weed control of an early and a medium maturity soybean variety, and (ii) to determine the optimum RS for these two varieties in hot sub-moist tropical agroecological zone of south-western Ethiopia.

2 Materials and methods

2.1 The study site and treatments

The study was conducted in the 2011 and 2012 cropping seasons at Eladale Research Station of Jimma University College of Agriculture and Veterinary Medicine, southwest Ethiopia (N 7°40’ E 36°50’, 1753 m a.s.l.), with long-term average annual rainfall of 1529.5 mm, average monthly relative humidity of 67 %, average daily maximum and minimum temperatures of 25.5 and 11.9°C, respectively. The soil type of the study area is a Nitosol (44 % clay, 32 % silt and 24 % sand), and sorghum was grown on the field during the previous seasons. The experiment was designed as split-plot design with three blocks. The main plot treatments were the two soybean varieties (Awasa-95 – an early-maturing variety released in 2005, and Afgat – a medium-maturing variety released in 2007). The sub-plot treatments were the nine row spacings (RS: 20, 25, 30, 35, 40, 45, 50, 55, 60 cm) randomised within each of the main plots. Each subplot contained 5 rows of plants, each 4 m in length, but with 9 different RS, resulting in 9 different subplot sizes: 4, 5, 6, 7, 8, 9, 10, 11, 12 m^2, respectively. Each row contained one plant every 5 cm, resulting in 9 theoretical plant densities: 100, 80, 67, 57, 50, 44, 40, 36 and 33 plants per m^2, respectively. Soybean seeds were manually drilled in each row at the end of June (at the beginning of the main rainy season), and seedlings were thinned to one plant every 5 cm within the row two weeks after emergence to achieve the desired plant density in each row at establishment stage. Fertilizer was not applied on the experimental plots during the study periods. All data were taken from and calculated for the plants growing in the three central rows of each subplot, excluding border plants at the end of each row (harvested plants).

2.2 Response measurements

The response variables measured and then calculated from the harvested plants for both years were: 1) weed infestation (dry biomass per m^2 and visual scoring); 2) final plant density (number of plants at harvest per m^2), reduction in plant density calculated as the theoretical plant density minus the actual plant density, and percent reduction in plant density; 3) yield (seed weight and total dry matter (TDM) per plant and per ha); 4) yield components (plant height; number of primary branches, pods and seeds per plant; number of seeds per pod; number of primary branches, pods and seeds per m^2; 1000 seed weight; and harvest index); and 5) number of nodules per plant and per m^2. Visual scoring of weed infestation (0 = no, 1 = little, 2 = medium, 3 = high and 4 = very high weed infestation) was performed when soybeans flowered, just before weeding. Immediately after visual scoring, weeds per subplot were collected and dry biomass was measured. Yield and yield component measurements were taken at harvest, and yields per plant and per unit area under the harvested plants were calculated.

Yield data per unit area (m^2 and ha) were calculated for all subplots taking into account only the harvested plants and the area under those plants, which was different for each subplot. The 1000 seed weight was determined for each subplot from the seed samples randomly taken from the total grain harvested from the harvested plants. Per plant values (average plant height; number of primary branches, pods and nodules per plant; and TDM and seed yield per plant) were measured from five plants randomly selected from the three central rows of each subplot, and the number of seeds per pod was taken from five randomly picked pods from the total pods of the five sampled plants. The number of seeds per plant was calculated for each subplot as the product of pods per sampled plant (n=5) and seeds per sampled pod (n=5). The number of nodules, branches, pods and seeds per m^2 were calculated by multiplying the number of nodules, branches, pods and seeds per sampled plant (n=5) with plant density (number of plants at harvest per m^2). Final plant density (number of plants at harvest per m^2) and weed dry biomass per m^2 were calculated based on the total number of plants at harvest and total dry weight of weeds at soybean flowering per area under the harvested plants (i.e. the three central rows minus border plants), respectively. Soybean plant TDM and seed yield per ha were calculated based on their yields per land area from which these products were harvested (parts of the subplots in m^2). The harvest index was defined as the total seed yield (kg/ha) divided by TDM yield (kg/ha).

2.3 Statistical methods

The experimental field had 3 blocks, and each block was partitioned into two main plots, each of which was randomly assigned to one of the two varieties. Within each main plot, the 9 row spacings (subplots) were completely randomised. This layout resulted in a split-plot design with variety (V) as the main plot factor and row spacing (RS) as the subplot factor. Both V and RS were considered as fixed factors, and block, which is a combination of the three blocks in the field and the two years giving a total of 6 blocks, was considered as a random factor. ANOVA was completed for all response variables using the Mixed Procedure in SAS (SAS Institute Inc., 2010). Further multiple means comparisons were completed for significant (p-value < 0.05) and marginally significant (p-value between 0.05 and 0.1) effects by comparing the least squares means of the corresponding treatment combinations or levels. Letter groupings were generated using a 1 % level of significance to compare the means of the 18 combinations of V and RS arising from the interaction effect. Letter groupings for the 9 RSs were also generated using a 1 % level of significance. A 1 % level of significance was used to protect the experimentwise error rate from over-inflation due to the relatively large number of means (18 and 9) being compared. However, the letter groupings for comparing the means of the two varieties were generated using a 5 % level of significance. For each response variable, the validity of model assumptions (normal distribution and constant variance) on the error terms was verified by examining the residuals as described in Montgomery (2013).

3 Results

The two factors, V and RS, had significant effects on some of the response variables, but not on all (Table 1). V had significant effect on plant height, number of seeds/pod, final plant density, reduction in plant density (both number and percent), and 1000 seed weight, while the significance of the main effect of RS was restricted to reductions in plant density, seed yield (kg/ha and g/plant), TDM (kg/ha and g/plant), and weed dry biomass (g/m^2) (Table 1).

Table 1: *ANOVA P-values that show the significance of the main and interaction effects of variety (V) and row spacing (RS) on the 21 response measurements examined.*

Response variables	*V*	*RS*	*V*RS*
Plant height (cm)	**0.013**	0.107	0.644
Number of seeds/pod	**0.019**	0.470	0.384
Final plant density (# of plants/m^2) at harvest	**0.008**	0.316	0.748
Reduction in plant density (# of plants/m^2)	**0.008**	**0.001**	0.748
Percent reduction in plant density (%)	**0.006**	**0.001**	0.164
Seed yield (kg/ha)	0.474	**0.021**	0.177
Seed yield (g/plant)	0.308	**0.009**	0.107
Total dry matter, TDM (kg/ha)	0.251	**0.067**	0.278
Total dry matter, TDM (g/plant)	0.138	**0.053**	0.133
1000 seed weight (g)	**0.021**	0.562	0.612
Weed dry biomass (g/m^2)	0.893	**0.013**	0.520
Weed infestation (0–4 rating)	0.578	0.799	**0.044**
Number of branches/m^2	0.762	0.165	0.929
Number of branches/plant	0.243	0.493	0.849
Number of pods/m^2	0.342	0.666	0.847
Number of pods/plant	0.792	0.707	0.821
Number of seeds/m^2	0.883	0.568	0.954
Number of seeds/plant	0.457	0.308	0.849
Number of nodules/m^2	0.703	0.801	0.925
Number of nodules/plant	0.901	0.796	0.825
Harvest index	0.336	0.104	0.560

Significant effects that require multiple means comparison are shown in bold

The interaction effect of V and RS was significant only on weed infestation (Table 1). Neither variety, row spacing nor their interaction significantly affected the number of branches (per m^2 and per plant), number of pods (per m^2 and per plant), number of seeds (per m^2 and per plant), number of nodules (per m^2 and per plant), or the harvest index (Table 1). These results suggest that, for the agronomic conditions of the experimental area, there is no preference between the two varieties and the 9 row spacings in terms of these parameters (response variables).

Regardless of RS, the medium maturing variety Afgat had significantly taller plants, a higher number of seeds per pod as well as a higher 1000 seed weight than the early maturing variety Awasa-95 (Table 2). However, Awass-95 showed a significantly higher plant density at harvest and lower plant density reduction than Afgat (Table 2).

Multiple means comparison of the means from the 18 combinations of V and RS on weed infestation (Table 3) reveals that RS did not have much of an effect on weed infestation in plots where the medium maturing variety of soybean (Afgat) was planted, but it does affect weed infestation of plots where the early maturing variety (Awasa-95) grew. Greater weed infestation was observed when Awasa-95 was planted in rows with spaces greater or equal to 40 cm.

The highest reduction in plant density was observed in subplots with a 20 cm RS, and each subsequent RS having a significantly lower reduction (Table 3). The non-significant effect of RS on plant density at harvest (Table 1) confirms that although there was a big difference in the initial (theoretical) plant density ranging from 33 to 100 plants/m^2, there was no difference at harvest, and the plant densities at harvest obtained from the individual subplots ranged from 10.3 to 17.3 plants/m^2. Regardless of the variety, the highest soybean seed yield (446 kg/ha and 3.57 g/plant) was obtained from a row spacing of 40 cm (Table 3). The highest soybean plant TDM values were obtained from subplots with a RS of 40 cm (1210 kg/ha, 9.59 g/plant) and 50 cm (1236 kg/ha, 9.03 g/plant) (Table 3).

On the other hand, the lowest soybean plant TDM (815 kg/ha and 6.32 g/plant) and weed dry biomass (37 g/m^2) was obtained from 20 cm row spacing (Table 3). In general, the results did not show a consistent pattern along the row spacing gradient albeit relatively greater yields from both individual plants and per unit area were obtained from subplots with a row spacing of 40 cm than from subplots with smaller or larger spaces between rows.

Table 2: *Mean plant height, number of seeds/pod, plant density at harvest, reduction in plant density (theoretical minus actual number of plants at harvest per m^2), percent reduction in plant density, and 1000 seed weight obtained from the two soybean varieties.*

Variety	*Plant height (cm)*	*Number of seeds/pod*	*Plant density at harvest (plants/m^2)*	*Reduction in plant density (plants/m^2)*	*Percent reduction in plant density*	*1000 seed weight (g)*
Awasa-95	32.9 ^{b}	1.99 ^{b}	14.5 ^{a}	41.9 ^{b}	70.7 ^{b}	73 ^{b}
Afgat	58.0 ^{a}	2.38 ^{a}	12.6 ^{b}	43.8 ^{a}	74.7 ^{a}	135 ^{a}

For each response, means sharing the same letter are not significantly different at the 5 % level.

Table 3: *Mean reduction in plant density (theoretical minus final number of plants at harvest per m^2), percent reduction in plant density, seed yield, plant TDM, and weed dry biomass obtained from the 9 row spacings; and mean weed infestation (visual rating of 0 to 4) obtained from the 18 combinations of the two soybean varieties and the 9 row spacings.*

Row Spacing (cm)	*Mean reduction in plant density (plants/m^2)*	*Reduction in plant density (%)*	*Seed yield*		*TDM*		*Weed dry biomass (g/m^2)*	*Weed infestation rating (0-4 ranking)*	
			(kg/ha)	*(g/plant)*	*(kg/ha)*	*(g/plant)*		*Awasa-95*	*Afgat*
20	87^a	87^a	246^b	1.87^b	815^b	6.32^b	37^b	1.33^b	2.00^{ab}
25	66^b	83^b	325^{ab}	2.37^{ab}	1005^{ab}	7.40^{ab}	51^{ab}	1.67^{ab}	1.67^{ab}
30	53^c	80^c	382^{ab}	2.92^{ab}	1084^{ab}	8.23^b	51^{ab}	1.33^b	2.00^{ab}
35	44^d	77^d	247^b	1.89^b	817^b	6.41^{ab}	81^{ab}	1.33^b	2.33^a
40	37^e	73^d	446^a	3.57^a	1210^a	9.59^a	129^{ab}	1.67^{ab}	2.33^a
45	30^f	68^e	299^{ab}	2.16^b	863^{ab}	6.26^b	121^{ab}	2.00^{ab}	2.00^{ab}
50	26^g	65^e	400^{ab}	2.91^{ab}	1236^a	9.03^{ab}	154^a	2.33^a	1.67^{ab}
55	23^h	63^f	357^{ab}	2.67^{ab}	1045^{ab}	7.85^{ab}	133^{ab}	2.33^a	1.67^{ab}
60	19^i	59^g	401^{ab}	3.02^{ab}	1128^{ab}	8.55^{ab}	151^a	2.00^{ab}	1.67^{ab}

For each response, means sharing the same letter are not significantly different at the 5 % level.

4 Discussion

The results show that the medium maturing variety Afgat regardless of RS, produced taller plants, with a greater number of seeds per pod and heavier seeds, though its plant density at harvest was lower than that of the early maturing variety Awasa-95 under the study site conditions. However, unlike the findings of other studies (Ball *et al.*, 2001; Kahlon *et al.*, 2011), these differences in plant density, number of seeds and seed weight did not lead to a significant difference in seed yield or TDM per plant nor per unit area of land between the two maturity groups. On the other hand, the average plant density at harvest for both varieties (14.5 plants/m^2 for Awasa-95, 12.6 plants/m^2 for Afgat) was lower than the lowest initial planting density (33 plants/m^2), and RS had no influence on the final plant density of either variety. As all subplots had high plant mortality rates, which reduced the plant density at harvest to about 14 plants/m^2, irrespective of RS or variety, it may be concluded that the initial planting density can be greatly reduced, as few plants survive to maturity. The reason for this reduction could be competition among individual plants mostly for light and nutrients, but may not be for moisture as it is abundant in the study site. However, a study in Iowa, USA, reported that row spacing and seeding rates do influence final plant population density (De Bruin & Pedersen, 2008). Nonetheless, the impact of mechanical versus hand weeding, drilling of seeds and thinning of seedlings on final plant density and seedling survival was not taken into account either in the previous (De Bruin & Pedersen, 2008) or in this study.

In agreement with previous studies conducted in various environments (Ethredge *et al.*, 1989; Boquet, 1990; Yunusa & Ikawelle, 1990; Kapustka & Wilson, 1990; Yelverton & Coble, 1991; Bowers *et al.*, 2000; Gan *et al.*, 2002; Acikgoz *et al.*, 2009; Worku & Astatkie, 2011; Markos *et al.*, 2012), row spacing had significant effects on seed yield and TDM of individual plants and per unit area, as well as on weed dry biomass. In contrast to previous studies, row spacing did not have a significant effect on nodulation in the study environment. Furthermore, contrary to previous studies in the same area (Worku & Astatkie, 2011) and in other areas (Herbert & Litchfield, 1984; Ethredge *et al.*, 1989; Kapustka & Wilson, 1990), which all reported significantly higher seed yield and masses and numbers of nodules on soybean plants grown in narrow row spacings (25, 30, 50 and 51 cm) than in row spacings greater than 51 cm, the patterns of grain yield and TDM we found along the row spacing gradient were inconsistent and the differences among many of the row spacings considered in this study were not significant. This indicates that different soybean varieties may be flexible in their productivity response to row spacings under different agronomic and environmental conditions, as postulated by Bowers *et al.* (2000).

The lower plant density at harvest, but taller plants with higher number of seeds per pod and 1000 seed weight observed for the medium maturing variety Afgat than that for the early maturing variety Awassa-95 despite the same planting density in each RS may be evidence of a different strategy followed by these two maturity group varieties to increase productivity. For example, high self-thinning, but growing into taller plants with high number of seeds per pod and individual seed weight can be a strategy to increase yield per plant and per unit area for the former variety, whereas a reverse for the latter one. However, the inconsistency of this result (except 1000 seed weight) with the results of previous studies in this study area (Worku & Astatkie, 2011) and other areas (Chen *et al.*, 1992; Gan *et al.*, 2002; Edwards & Purcell, 2005) may indicate that a similar strategy is not shared by all varieties within a maturing group. For example, in a study by (Worku & Astatkie, 2011), the early maturing variety Clark had higher mean number of branches per plant and numbers of seeds per pod than the late maturing variety CSC-1, but both had statistically similar plant heights, while (Gan *et al.*, 2002) reported that the lower seed yield per unit area of land at low density was mainly associated with a decrease in the number of pods or seeds per unit area of land. Soybeans grown at high densities are taller, more sparsely branched, lodge more, and set fewer pods and seeds than those planted at lower densities (Weber *et al.*, 1966; Boquet, 1990; Acikgoz *et al.*, 2009). Conversely, provided that lodging does not increase, taller plants can lead to less grain loss during harvest (Chen *et al.*, 1992) and greater grain yields (Markos *et al.*, 2012).

The lack of interaction effect of variety and row spacing on yield and yield components confirms our previous conclusion (Worku & Astatkie, 2011) that the early and late maturity group soybean varieties can be grown at the same row and plant spacing (plant density) for high grain yield in the study site. Increased days to maturity did not require greater row spacing for grain production and nodulation under our experimental site conditions. This implies that row spacing recommendations for optimising soybean production in the hot submoist agroecological zone of southwest Ethiopia need not be as variety specific as plant spacing recommendations made previously (Worku & Astatkie, 2011). Genotypes with different growth habits also responded with different total biomass and seed yield to increased plant density (Gan *et al.*, 2002). Studies that have examined the effect of population density of soybean on nodulation and N fixation have also reported contradictory results. As population increased, some showed an increase in these parameters (Weber *et al.*, 1966; Blumenthal *et al.*, 1988; Kapustka & Wilson, 1990; Gan *et al.*, 2002), others showed a decrease (Jamro *et al.*, 1990; Markos *et al.*, 2011), while others showed no response (Sarkodie-Addo & Mahama, 2012). However, comparison of varieties with contrasting nodulating lines showed that the supernodulating character of a supernodulating variety did not translate to higher soybean productivity (Nakamura *et al.*, 2010).

Lower weed visual rating and weed dry biomass for soybeans planted in narrower rows ($\leq$ 35 cm) than in wider ones ($\geq$ 40 cm) indicate greater ground-covering canopy of the soybean plants, which did not allow additional weed growth. It supports the hypothesis that a thin plant stand allows more weed growth as a result of less ground-covering canopy. In agreement with results of this study, Yelverton & Coble (1991) reported the highest weed resurgence in wide row spacings. However, our previous study in the same location, but with different varieties, did not reveal that row spacing affected weed infestation; instead, plant spacing within rows affected weed infestation (Worku & Astatkie, 2011).

5 Conclusions

The results indicate that a row spacing of 40 cm with 5 cm plant spacing within a row can be used for high productivity and less weed infestation of both early and medium maturing soybean varieties under rain-fed agriculture in the tropical, hot sub-moist agroecological zone of southwest Ethiopia. A row spacing of between 40 cm and 60 cm with 5 cm plant spacing within a row is also possible if weeds are not a problem. However, further research may be needed to determine the best combination of row and plant spacings for optimising seed yield and other responses such as nutrient management (N fixation and accumulation) to maximize yields and weed control. Further research can also be necessary to check whether the final plant density obtained for different RSs in this study (≈14 plants per m^2) will be observed or not if the initial plant density is thinned into 14 plants per m^2.

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References

Acikgoz, E., Sincik, M., Karasu, A., Tongel, O., Wietgrefe, G., Bilgili, U., Oz, M., Albayrak, S., Turan, Z. M. & Goksoy, A. (2009). Forage soybean production for seed in mediterranean environments. *Field Crops Research*, 110, 213–218.

Ali, K., Kenneni, G., Ahmed, S., Malhotra, R., Beniwal, S., Makkouk, K. & Halila, M. H. (Eds.) (2003). *Food and forage legumes of Ethiopia: Progress and prospects. Proceedings of the workshop of food and forage legumes, Addis Ababa, Ethiopia*. ICARDA, Aleppo.

Ball, R. A., McNew, R. W., Vories, E. D., Keisling, T. C. & Purcell, L. C. (2001). Path Analyses of Population Density Effects on Short-Season Soybean Yield. *Agronomy Journal*, 93, 187–195.

Blumenthal, M. J., Quach, V. P. & Searle, P. G. E. (1988). Effect of soybean population density on soybean yield, nitrogen accumulation and residual nitrogen. *Australian Journal of Experimental Agriculture*, 28, 99–106.

Boquet, D. J. (1990). Plant population density and row spacing effects on soybean at post-optimal planting dates. *Agronomy Journal*, 82, 59–64.

Bowers, G. R., Rabb, J. L., Ashlock, L. O. & Santini, J. B. (2000). Row Spacing in the Early Soybean Production System. *Agronomy Journal*, 92, 524–531.

Chen, Z., MacKenzie, A. F. & Fanous, M. A. (1992). Soybean nodulation and grain yield as influenced by N-fertilizer rate, plant population density and cultivar in southern Quebec. *Canadian Journal of Plant Science*, 72, 1049–1056.

De Bruin, J. L. & Pedersen, P. (2008). Effect of Row Spacing and Seeding Rate on Soybean Yield. *Agronomy Journal*, 100, 704–710.

Edwards, J. T. & Purcell, L. C. (2005). Soybean yield and biomass responses to increasing plant population among diverse maturity groups: I. Agronomic characteristics. *Crop Science*, 45, 1770–1777.

Edwards, J. T., Purcell, L. C. & Karcher, D. E. (2005). Soybean Yield and Biomass Responses to Increasing Plant Population among Diverse Maturity Groups: II. Light Interception and Utilization. *Crop Science*, 45, 1778–1785.

Ethredge, W. J., Ashley, D. A. & Woodruff, J. M. (1989). Row Spacing and Plant Population Effects on Yield Components of Soybean. *Agronomy Journal*, 81, 947–951.

Gan, Y., Stolen, I., van Keulen, H. & Kuiper, P. J. C. (2002). Physiological responses of soybean varieties to plant density. *Field Crops Research*, 74, 231–241.

Hartman, G. L., West, E. D. & Herman, T. K. (2011). Crops that feed the World 2. Soybean - worldwide production, use, and constraints caused by pathogens and pests. *Food Security*, 3, 5–17.

Herbert, S. J. & Litchfield, G. V. (1984). Growth response of short-season soybean to variations in row spacing and density. *Field Crops Research*, 9, 163–171.

Jamro, G. H., Memon, G. H. & Ibupota, K. A. (1990). Effect of combined nitrogen and row spacing on nodulation and grain yield of soybean. *Sarhad Journal of Agriculture*, 6, 107–112.

Kahlon, C. S., Board, J. E. & Kang, M. S. (2011). An Analysis of Yield Component Changes for New vs. Old Soybean Cultivars. *Agronomy Journal*, 103, 13–22.

Kapustka, L. G. & Wilson, K. G. (1990). The influence of soybean planting density on dinitrogen fixation and yield. *Plant and Soil*, 129, 145–156.

Lee, C. D., Egli, D. B. & Tekrony, D. M. (2008). Soybean Response to Plant Population at Early and Late Planting Dates in the Mid-South. *Agronomy Journal*, 100, 971–976.

Markos, D., Pal, U. R. & Uragie, E. (2011). Selection of Planting Pattern and Plant Population Density (PPD) for Medium and Late Maturing Soybean Varieties (*Glycine max* (L.) Merrill) in the Tropics. *Innovative Systems Design and Engineering*, 2, 242–249.

Markos, D., Pal, U. R. & Uragie, E. (2012). Dry Matter Partitioning, Nodulation and Seed Traits of Medium and Late Maturing Soybean Varieties as Affected by Planting Pattern and Plant Density. *Journal of Agricultural Science and Technology B*, 2, 142–150.

Misiko, M., Tittonell, P., Ramisch, J. J., Richards, P. & Giller, K. E. (2008). Integrating new soybean varieties for soil fertility management in smallholder systems through participatory research: Lessons from western Kenya. *Agricultural Systems*, 97, 1–12.

Montgomery, D. C. (2013). *Design and analysis of experiments. 8th Edition*. Wiley, New York.

Nakamura, T., Nakayama, N., Yamamoto, R., Shimamura, S., Kim, Y., Hiraga, S., Takuji, O., Setsuko, K. & Shinji, S. (2010). Nitrogen Utilization in the Supernodulating Soybean Variety "Sakukei 4" and Its Parental Varieties, "Enrei" and "Tamahomare". *Plant Production Science*, 13, 123–131.

Ogoke, I. J., Togun, A. O., Carsky, R. J. & Dashiell, K. E. (2006). N_2 Fixation by Soybean in the Nigerian Moist Savanna: Effects of Maturity Class and Phosphorus Fertilizer. *Tropicultura*, 24, 193–199.

Sarkodie-Addo, J. & Mahama, O. (2012). Growth and Yield Response of Early and Medium Maturity Soybean (*Glycine max* (L.) Merrill) Varieties to Row Spacing. *International Journal of Science and Advanced Technology*, 2, 115–122.

SAS Institute Inc. (2010). *SAS/STAT® 9.3 User's Guide*. SAS Institute Inc., Cary, North Carolina.

Weber, C. R., Shibles, R. M. & Byth, D. E. (1966). Effect of Plant Population and Row Spacing on Soybean Development and Production. *Agronomy Journal*, 58, 99–102.

Worku, M. & Astatkie, T. (2011). Row and Plant Spacing Effects on Yield and Yield Components of Soya Bean Varieties under Hot Humid Tropical Environment of Ethiopia. *Journal of Agronomy and Crop Science*, 197, 67–74.

Yelverton, F. H. & Coble, H. D. (1991). Narrow Row Spacing and Canopy Formation Reduces Weed Resurgence in Soybeans (*Glycine max*). *Weed Technology*, 5, 169–174.

Yunusa, I. A. M. & Ikawelle, M. C. (1990). Yield Response of Soybean (*Glycine max* [L.] Merr.) to Planting Density and Row Spacing in a Semi-arid Tropical Environment. *Journal of Agronomy and Crop Science*, 164, 282–288.