Bangladesh J. Bot. **44**(5): 813-819, 2015 (December), Supplementary

EFFECTS OF MAJOR CULTURAL FACTORS IN IMPROVING YIELD OF AUTUMN SOYBEAN

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Key words: Autumn Soybean, Sowing date, Planting density, Mechanisms of increasing yield

Abstract

This study was conducted to explore mechanisms for increasing autumn soybean yield with a final goal of developing a high-yield and high-efficiency cultivation system. Two factors including seed sowing date and planting density were compared. Results showed that delayed seed sowing resulted in shorter period of each developmental stage and thus a shorter growth season. In the late-sowing treatment, plant height was significantly reduced and those plants had fewer nodes and branches on main stem compared to those planted earlier, but this trait was not affected by planting density. Sowing seeds early combined with high-density planting can significantly increase yield of autumn soybean. The dynamics of light intensity below the canopy and the dense-planting system produced bigger leaf area index, higher amounts of shade and a lower light transmission rate. With a greater utilization efficiency of solar energy, this is expected to produce high yield autumn soybean crops.

Introduction

A large number of researches have been carried out to develop strategies for increasing soybean yields, such as the adoption of appropriate agronomic system (Han *et al.* 2012, Li *et al*. 2013, Jossias and Monicah 2014) and cultivation methods (Li 2011, Xiao and Wang 2012, Xiao *et al*. 2013), sowing date and plant density (Mayers *et al.* 1991, Wiatrak and Chen 2011, Ibrahim 2012), the use of growth regulators (Leyla *et al*. 2006, Feng *et al.*2007), the management of soil moisture (Abayomi 2008, Liu 2014) and fertilizers (Wang 2008, Jiang *et al.* 2013, Mariangela *et al*. 2014), reducing the pods without seeds phenomenon (Zhang and Hou 2005), and production potential (Thomas *et al*. 2014). Compared to the well-studied spring and summer soybean crops, the autumn types are rarely examined. In this study, a popular autumn soybean variety Zheqiu No. 2 was chosen as the target crop, to investigate effects of sowing date and planting density on the yield (Fu 2006). Light intensity below the canopy and other parameters relevant to efficient utilization of sun light were analyzed to identify the mechanisms associated with the two cultural factors.

Materials and Methods

Two experimental factors were used including sowing date and planting density. Three levels of treatments for sowing dates were A1 (July 5), A2 (July 20) and A3 (August 4). The two treatment levels of planting density were B1 (180,000 plants/hm^2) and B2 (270,000 plants/ hm^2), with spacing between rows and individual plants at 33 × 33.67 and 33 × 22.45cm, respectively. The six treatments were A1B1, A1B2, A2B1, A2B2, A3B1 and A3B2. Each treatment had three

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replicates each on a plot of 10 m^2 in size. Two seeds were sown in one hole. Two factor randomized block design was applied in this experiment, and the data analysis was performed with statistical analysis system software (SAS Institute Inc. 1996).

Plants from the three sowing date treatments were harvested on Oct. 13, 16 and 21, respectively. Pods from each plot were harvested separately and they were dried to a constant weight to determine the yield from the respective treatment. Plots to be used for the determination of light intensity below the thickest canopy layer were seeded on July 5. Light intensity below the canopy was recorded at 08, 11, 14 and 17 hrs, daily during the period of August 12 - 31 and thereafter only once in every 5 days.

Results and Discussion

Plant characters were mostly affected by sowing date, and planting density had a very little influence on plant growth (Table 1). In treatments of delayed sowing, each growth period became shorter, and plant height was reduced. There were fewer nodes on the main stem and less effective branches.

Variance analysis indicates that among the three sowing date treatments, there was a significant difference in the duration of total growth period (D), plant height (H), the number of nodes on main stem (E) and the number of branches (F) per plant. Plants seeded earlier performed much better than those delayed in the sowing date. The variation ranges among the treatments from 79 - 98 days for the duration of total growth period (D), 59.75 - 81.45 cm for plant height (H), 16.44 - 20.86 for the number of nodes on main stem (E), and 3.2 - 4.9 for the number of branches (F) per plant. Between different planting density treatments, no significant level of difference in plant height was absent, the number of nodes on main-stem and the number of branches on each plant. Results of the regression analysis are: H = 1.0835, D-26.63(r = 0.9586**), E = 0.2254, D-1.42 (r = 0.9959**), F = 0.0787, D-2.96 (r = 0.9845**). It can be seen that delayed sowing resulted in shorter growth period. The reduced vegetative growth is the principal factor responsible for smaller plants bearing a fewer nodes and branches on short main stems.

Table 1. Influence of sowing date and planting density on duration of growth period and morphological characters of autumn soybeans.

Treatments	Total growth period (day)		Plant height (cm)		No of nodes on main stem		No of effective branching	
A1B1	98	A	80.82	A	20.86	A	4.9	A
A1B2	98	A	81.45	A	20.62	A	4.7	A
A2B1	89	B	64.64	B	18.69	B	4.0	B
A2B2	89	B	68.97	B	18.32	B	3.9	B
A3B1	79	C	59.75	C	16.46	C	3.4	C
A3B2	79	C	61.03	C	16.44	C	3.2	C

*Means within a column followed by the same letter are not significantly different at $p < 0.05$. Those followed by different capital letters are significantly different at $p < 0.01$ level.

Sowing date, planting density and their interactive effect each had a significant influence on morphological character and yield of autumn soybeans (Table 2). The number of effective pods per plant varied greatly with the sowing date, planting density, and their interactive effect ($p < 0.05$).The treatments of early sowing dates combined with thin-planting produced more effective pods per plant than late sowing and dense-planting. Among all the treatments of the earliest sowing, thin-planting density produced a larger number of effective pods per plant than the dense-planting group. Such contrasting difference between planting density treatments was not found in the A2 or A3 sowing treatments. These results indicate that delayed sowing date diminished the effect of planting density on the number of effective pod per plant.

When compared with the same planting density level treatment of B1 or B2, the early sowing date group produced more effective pods per plant than the delayed sowing treatments ($p < 0.05$). Multiple comparison test found that the number of effective pods per plant from A1B1 was higher than A2B1 ($p < 0.01$), while they were the top two among all the treatments ($p < 0.01$). When compared between A1B2 and A2B2, no significant difference was found, however these two significantly out performed A3B1 and A3B2 ($p < 0.05$), with the latter treatment produced the least number of effective pods per plant. These results indicate that early sowing combined with thin-planting can greatly increase the number of effective pods per plant for autumn soybean crop.

Seed sowing date, planting density, and their interactive effect had no significant influence on the number of seeds per pod. For the 100-seed weight, sowing date and planting density both had significant effects on this trait ($p < 0.01$), but no significant interactive effect was identified between the two factors. Multiple comparison (LSD) test found that 100-seed weight from A1B1 significantly higher than rest of the five treatments ($p < 0.01$), but there was no significant difference between A1B2 and A2B1, nor between A2B2 and A3B1 although both were significantly higher than A3B2. These results indicate that early sowing and thin-planting can significantly improve the 100-seed weight.

The yield of autumn soybean was greatly influenced by the sowing date and planting density and their interactive effect ($p < 0.01$). Under the same planting density level, yields of early sowing plants were significantly higher than those sown at delayed dates ($p < 0.01$). The general trend is earlier the sowing date, is higher the soybean yield. When compared with the same sowing date, the yield of soybeans from the dense-planting group was found to be significantly higher than thin-planting treatments. In other words, increasing planting density increased soybean yield. Multiple comparison tests revealed that soybean yield differed significantly among A1B2, A1B1, A2B2, A2B1, A3B2 and A3B1. These results indicate that early sowing and dense-planting have the potential for producing a better yield of autumn soybean. Thus the crop should be seeded as early as possible, using appropriately higher planting density, to ensure a good harvest.

Table 2.The effect of different sowing time and planting density on yield attributes economy traits of autumn soybean.

Treatments	Effective pod number (pods/plant)			No. of seed (seed/pod)			100-seed weight (g)			Yield (Kg/hm^2)		
A1B1	44.00	a	A	1.679	ab	A	28.53	a	A	206.7	b	B
A1B2	36.46	b	B	1.704	ab	A	26.73	b	B	237.8	a	A
A2B1	30.28	c	C	1.772	ab	A	25.79	bc	BC	136.7	d	D
A2B2	29.72	c	C	1.795	ab	A	24.71	cd	CD	184.4	c	C
A3B1	20.81	d	D	1.815	a	A	24.49	d	CD	80.0	f	F
A3B2	17.94	e	D	1.836	a	A	23.72	d	D	111.1	e	E

*Means within a column followed by the same letter are not significantly different at $p < 0.05$. Those followed by different capital letters are significantly different at $p < 0.01$ level.

The light intensity under the canopy was affected by planting density (Table 3, Fig. 1). Under the high density planting conditions, the light intensity under the canopy was obviously weakened over the whole period from flowering till pod-setting stage compared to lower density planting conditions. Furthermore, differences in light intensity between the two planting density treatments

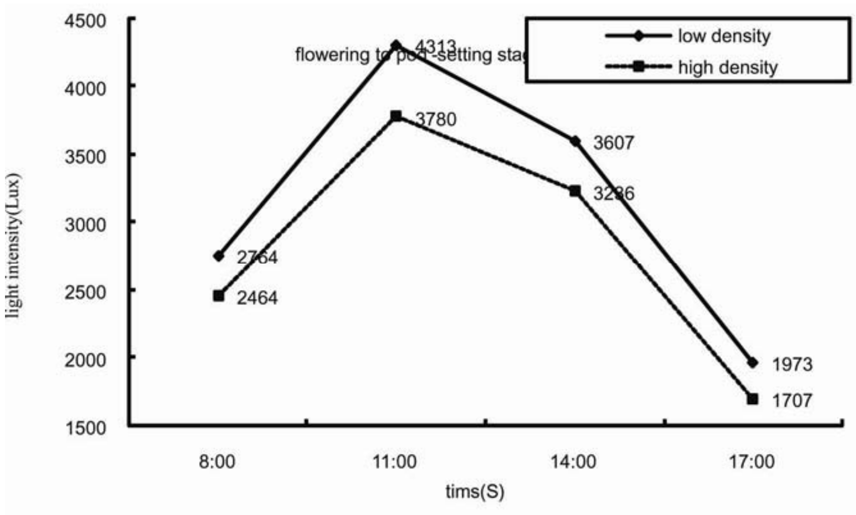

Fig. 1. Daily changes in light intensity and flowering to pod setting.

were also affected by the daily change in intensity of sun light. The stronger of the sun light, the larger of the difference between the two treatments. Conversely, dim sun light resulted in less difference between the two planting density treatments. For example, at 17hrs when the sunlight gets weaker, light intensity below the canopy was very low, and there was a very small difference between the two planting density treatments. At 11hrs with strong sun light, light intensity below the canopy from the dense-planting group was significantly lower than the thin-planting canopy. The total differences in light intensity from flowering to pod-setting stages also changed following the same pattern.

Table 3. The differential values (thin minus dense) of below-canopy light intensity in thin- and dense-planting autumn soybeans.

Growth durations	Differential value	Time-points (hr)			
		8	11	14	17
Flowering to pod-setting stages	Daily average differential value (Lux)	300	533	371	267
	Maximum daily differential value (Lux)	700	1100	1000	500
	Differential value of total daily light intensity (Lux)	4200	8000	5200	4000

Based on the light intensity conditions, it can be concluded that in the dense-planting plots, plant population maintain a higher leaf area index. The canopy provides thick shade allowing very low light transmission below the canopy space, which is the basis for greatly increasing the photosynthetic production of autumn soybean.

For autumn soybean crops, the duration of growth and development period was significantly affected by sowing date ($p < 0.05$), but not by planting density. Delays in sowing seeds lead to shorter growth of vegetative and reproductive stages, and thus for the whole growth season. Late sowing is the principal factor causing smaller plants where the main stems had fewer nodes and branches. Planting density did not have such a significant effect on the character.

Within the scope of this experiment, under the same planting density, the earlier the sowing date the higher is the yield. Under the same sowing date, the higher the planting density the greater is soybean yield. These results suggest that early sowing and dense-planting together can greatly improve autumn soybean yield. The results was different with previous studies showing that late sowing with high sowing density was beneficial to improve the soybean yield (Xu *et al.* 2014).

Zhang *et al.* (2011) found that the leaf area index and the whole plant, stem, leaf, petiole and pod weight of unit area increased with the increase of planting density. In the present study, under dynamics of the light-intensity below-canopy, the dense-planting showed lower light intensity of the whole planting population. The canopy provided more shade and reduced the light transmission below the canopy layer. Such vertical population structure is beneficial for increasing solar energy utilization rate and photosynthetic production of autumn soybean crop. Further research is needed to verify it.

The present study showed that early sowing extended the whole growth season for both the vegetative and the reproductive stages, resulting in higher dry matter yields. Plants from the early sowing plots produced significantly higher number of main-stem nodes and branches. In contrast, the planting-density treatments showed very small effect on these characters. It was also found that the number of main-stem nodes and the effective branches per plant slightly declined in the high-density planting plots, but the total number of effective branches per unit ground surface area was increased.

Dense-planting had a significantly negative effect ($p < 0.01$) on the total and effective pod number per plant when given the same sowing date; thin-planting groups produced a larger number of pods per plant than the dense-planting treatment ($p < 0.01$); and early sowing significantly increased the number of effective pods and thus seeds per unit ground area. Even for the earliest sowing date treatment, the one hundred seeds weight from the thin-planting plots was greater than the dense-planting group ($p < 0.01$). Early sowing combined with dense-planting produced a higher bean yield per unit ground area than thin-planting at the same sowing date. Therefore early sowing and dense-planting should be used to achieve high yield of autumn soybean.

The leaf area index from dense-planting was significantly higher than the thin-planting treatment ($p<0.01$). The dense shade and less transmission loss of sun light through the canopy in the thin-planting plots are responsible for increasing light utilization efficient and photosynthetic production, and this eventually leads to higher yields for the autumn soybean crop.

When planted at appropriate density, the gaps between individual plants will be filled as plants grow. As the exposed ground area becomes smaller, it helps to control soil evaporation and dissipation of soil moisture, therefore the dense-planting style is effective in conserving soil moisture. Soybean plants at the middle developmental stage demand large amounts of water. When the ground is shaded by canopy it can hold moisture which helps the plants to alleviate the water-deficit stress during drought period (Zhao 2001).

Under the dense-planting condition, because of the population structure and canopy properties, the canopy is extremely dense in the upper layer where the biggest leaf area is formed. This canopy layer provides the strongest resistance to radiative heat exchange and turbulent flow of heat air. During hot days, canopy in the flat-dense planting field can protect soil from strong solar light. With lesser amount of light reaching the ground, plant evapotranspiration and soil evaporation will be reduced. By controlling the respiratory activity of tissues in the middle and lower canopy layers, the dense-planting style will increase net accumulation of dry matters of soybean plants (Zhao 2001).

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(Manuscript received on 14 August, 2015; revised on 27 August, 2015)