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Research Article

Maize Yields Performance in Strip Planting Patterns with Two Plant Densities

[1, 2, 3]Qian Zhang, [1, 2]Hongsheng Zhang, [1, 2]Xiyun Song, [1, 2]Shutang Liu and [1, 2]Wen Jiang
[1]College of Agronomy and Plant Protection, Qingdao Agricultural University,
[2]Shandong Key Laboratory of Dryland Farming Technology, Qingdao 266109, China
[3]Baolingbao Biology Co., Ltd., Dezhou, 251200, Shandong, China

Abstract: The Huang-Huai-Hai Plain is the most important maize production region in China. To further investigate the improvement of maize yield by changing the planting pattern combined with two plant densities in this region, field experiments involving four planting patterns (three-row strip, four-row strip, five-row strip and a conventional uniform row spacing pattern (the control) under two plant densities (67,500 and 82,500 plants/ha) were conducted in 2011 and 2012. Only the plant density, not the planting pattern, significantly influenced the leaf area index at R1 stage and the total leaf area duration. The radiation use efficiency and the above-ground biomass at R5 were both higher under the three strip planting patterns than under the control, but the differences were not statistically significant. The effects of the planting patterns on the grain yield were significant in both years and the yields were 16.7, 6.1 and 10.7%, respectively higher in 2011 and 17.2, 12.1 and 10.6%, respectively higher in 2012 under the three-, four- and five-row strip treatments, respectively, compared with the control. However, grain yield was affected by neither plant density nor the interaction between planting pattern and plant density. Therefore, optimal strip planting pattern could not be better estimated by considering plant density.

Keywords: Leaf area duration, radiation use efficiency, yield components, *Zea mays* L.

INTRODUCTION

Maize (*Zea mays* L.) is important as a staple food for human, as feed for livestock and as a raw material for many industrial products, especially in developing countries. However, in recent years, in addition to global warming, extreme weather has frequently occurred during the maize growing season. These extreme weather events increase the risk of reduced output under the traditional planting patterns for summer maize, especially with increased plant density. The Huang-Huai-Hai Plain is the most important winter wheat and maize production region in China and makes up 1/6 of the total cultivated land area in China. In this area, during the pollination period of summer maize, heat waves and overcast or rainy weather occur frequently (Li *et al*., 2005, 2008; Zhou *et al*., 2008), which negatively affects pollination and causes successfully pollinated kernels to abort, resulting in yield loss. Therefore, more research is required to find new technologies, including cultivation methods, to adapt to the impact of climatic variability on maize production.

Crop row spacing influences the canopy architecture, a distinguishing characteristic that affects the utilization of light, water and nutrients (Sharratt and McWilliams, 2005). Row spacing also affects the exploitation of the photosphere and rhizosphere by the plants, especially when the plants are too close to each other. A proper plant spacing is necessary for optimum yield (Obi, 1991). Optimal row spacing can improve group structure, reduce competition between strains and promote the development of individual growth, increasing the root number, leaf area and above-ground biomass (Wu *et al*., 2005). The above-ground biomass and yields were significantly affected by the planting patterns in maize hybrids (Yilmaz *et al*., 2008).

In our previous research, the above-ground biomass and grain yield were increased by using three new strip planting patterns (three-row strip, four-row strip, five-row strip) compared with the conventional uniform row spacing pattern (Zhang *et al*., 2012a, b). Under medium planting density (67,500 plants/ha), the grain yield increased by 10.58, 6.54 and 12.06%, respectively under the three-, four- and five-row strip treatments, respectively, compared with the control. Planting patterns response models might be further improved by considering the effects of plant density.

This study was conducted to test the hypothesis for corn production in the Huang-Huai-Hai Plain, Eastern China: yield increases with the strip planting patterns are greater with high plant density beyond 67,500 plants/ha. This paper reports our study on the above-ground biomass and grain yield in summer maize in the

Corresponding Author: Wen Jiang, College of Agronomy and Plant Protection, Qingdao Agricultural University, Changcheng Road, Chengyang District, Qingdao 266109, China, Fax: +86 (532) 86080447

Table 1: Some climatological data of experimental site during maize growing seasons in 2011 and 2012 (meteorology station of Qingdao)

		2011			2012			Avg. of 30 year*		
Months	Date	Mean temp. (°C)	Rainfall (mm)	Sun-shine (h)	Mean temp. (°C)	Rainfall (mm)	Sun-shine (h)	Mean temp. (°C)	Rainfall (mm)	Sun-shine (h)
June	20-30	22.3	59.3	38.0	23.5	20.6	48.9	22.9	81.4	74.0
July	1-10	24.5	124.9	54.4	25.0	88.4	43.4	24.2	46.5	65.8
	10-20	24.1	13.1	47.4	25.7	33.9	72.0	25.0	54.1	61.0
	20-31	26.2	66.1	49.3	27.7	33.5	67.4	26.1	53.1	79.0
	Whole month	24.9	204.1	151.1	26.1	155.8	182.8	25.1	153.7	205.8
Aug.	1-10	26.1	32.9	37.6	26.9	91.0	71.9	26.1	45.5	76.3
	10-20	25.0	87.7	32.0	25.4	80.7	45.9	25.4	23.7	68.9
	20-31	24.6	69.0	78.6	24.7	13.3	74.6	24.2	43.3	74.4
	Whole month	25.2	189.6	148.2	25.7	185.0	192.4	25.2	112.5	219.6
Sept.	1-10	23.0	2.5	69.4	22.8	21.3	75.3	22.7	37.8	70.8
	10-20	20.1	59.3	30.6	20.9	2.5	70.6	20.7	11.5	77.3
	20-30	19.1	47.0	84.3	20.2	67.3	63.9	19.1	14.0	73.0
	Whole month	20.7	108.8	184.3	21.3	91.1	209.8	20.8	63.3	221.1
Oct.	1-10	16.4	0.3	61.9	18.7	0.9	78.4	17.4	13.5	65.9
Maize growing season (July-Oct.)		21.9	562.1	583.5	23.1	453.4	712.3	22.3	424.4	786.4

*: From 1980 to 2010

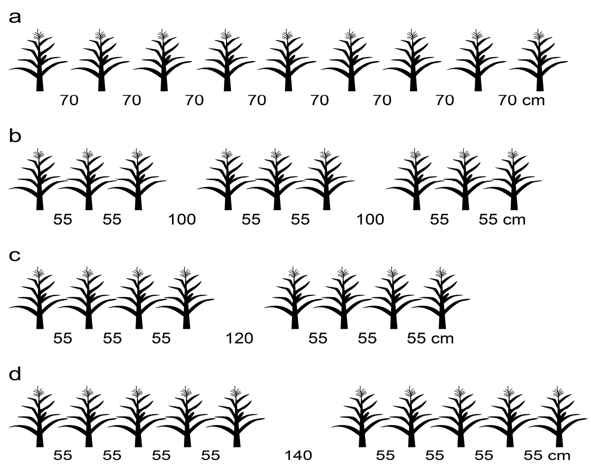

Fig. 1: Graphical representation of the planting patterns (row and broadband spacing) (a) conventional uniform row spacing planting pattern (control): equal row spacing (70 cm), the plant spacing was 21.2 and 17.3 cm under 67,500 and 82,500 plants/ha, respectively, (b) three-row strip planting pattern: two equal row spacing (55 cm) and a broadband (100 cm), the plant spacing was 21.2 and 17.3 cm under 67,500 and 82,500 plants/ha, respectively, (c) four-row strip planting pattern: three equal row spacing (55 cm) and a broadband (120 cm), the plant spacing was 20.8 and 17.0 cm under 67,500 and 82,500 plants/ha, respectively, (d) five-row strip planting pattern: four equal row spacing (55 cm) and a broadband (140 cm), the plant spacing was 20.6 and 16.8 cm under 67,500 and 82,500 plants/ha, respectively

Huang-Huai-Hai Plain of China as a further step towards understanding the effect of planting patterns combined with plant density on plant growth, as measured by the leaf area index, leaf area duration, above-ground biomass, radiation use efficiency, yield and yield components of the maize.

MATERIALS AND METHODS

Site description and soil properties: Field experiments were conducted in 2011 and 2012 at the Research Farm of Qingdao Agricultural University, Jiaozhou Experiment Station (36°15’52’’N, 120°01’41’’E), Qingdao, China. The total rainfall during the maize growing season was 554 mm in 2011 and 394 mm in 2012. During the same period, the total sunshine was 527.8 h in 2011 and 679.7 h in 2012. The previous crop was winter wheat; maize was shown on June 29, 2011 and June 26, 2012 and harvested on October 12, 2011 and October 9, 2012, (total 105 days in both years). The maize cultivar was 'Zhengdan' 958, which is popular in the local area. During the growing seasons of summer maize, a light irrigation was given on June 30 in 2011 and June 28, 2012 after planting and no additional irrigation was given for either year. The soil at the experimental site was fluvo-acqui soil with a pH of 6.88; the organic matter concentration was 6.75 g/kg, the available nitrogen (alkali hydrolysable N) was 84.00 mg/kg, the available Phosphorus (P) was 69.25 mg/kg and the available potassium (K) was 86.82 mg/kg (Table 1).

Experimental details: The experiment was conducted as a two-factor split-plot design with three replications. The main factor was the planting pattern, with four planting patterns (three-row strip, four-row strip, five-row strip and a conventional uniform row spacing pattern) and the split factor was plant density (67,500 and 82,500 plants/ha). The plot size was 6.5×11.0 m (71.5 m^2). Slow-release fertilizer (Kingenta Company, China, N-P_2O_5-K_2O: 22-8-12) was applied with 750 kg/ha as the basal application and no top-dressing during the growing season. The planting patterns and the space between two adjacent maize were shown in Fig. 1.

The above-ground biomass and leaf area were measured at 53 (R1 stage) and 105 (R5 stage) Days after Sowing (DAS) in 2011 and at 57 (R1 stage) and 105 (R5 stage) DAS in 2012. Three, four, five and three plants, respectively, (corresponding to the number of rows) were sampled from each subplot of the three-, four- and five-row strip arrangement and the conventional uniform row spacing planting pattern. The samples were dried at 105° for 30 min and then at 80° to dry till constant dry mass.

The total solar radiation was calculated from the weather data (from local weather forecast station) as:

$$(Q) = Q_0 (a + b\, S/S_0) \quad (1)$$

where,
Q_0 = The daily solar radiation
S = The real sunshine hours
S_0 = The theoretical sunshine hours
S/S_0 = The percentage of sunshine
a and b = Coefficients (Zuo *et al*., 1963)

The calorific value of maize is 18.07 kJ/kg (Lin *et al*., 2000; Xu *et al*., 2002) and the intercepted Photosynthetically Active Radiation (PAR) is computed as 0.45 of the incoming solar radiation (Kiniry *et al*., 1998). Thus, the Radiation Use Efficiency (RUE) (%) was calculated as:

$$\text{Unit area of biomass above ground (kg/m}^2) \times 18.07\ \text{(kJ/kg)} / (Q\ \text{(kJ/m}^2) \times 0.45) \times 100 \quad (2)$$

The leaf area (m^2) was calculated as:

$$\text{Leaf area} = L \times W \times K \quad (3)$$

where,
L = Maximum length of leaf
W = Maximum width of leaf
K = Adjustment factor (0.75)

The leaf area index was calculated as suggested by Sestak *et al*. (1971):

$$\text{Leaf Area Index (LAI)} = (\text{Leaf area m}^{-2}) / (\text{Land area m}^{-2}) \quad (4)$$

The Leaf Area Duration (LAD) was calculated by adopting the formula of Power *et al*. (1967) and expressed in terms of days as:

$$LAD = (L_1+L_2)/2 \times (t_2-t_1) \quad (5)$$

where,
L_1 = The leaf area index at time t_1
L_2 = The leaf area index at time t_2
t_2-t_1 = The time interval in days between the two stages

The percentage of barren stalks was calculated as:

$$\text{Percentage of barren stalks (\%)} = \text{Number of barren stalks} \times 100/\text{Total number of plants} \quad (6)$$

The Harvest Index (HI) was calculated as:

$$HI = \text{Grain yield (kg/ha)} / \text{Total biomass yield (kg/ha)} \quad (7)$$

At R5 stage (105 days after sowing) in 2011 and 2012, the plants in the middle two zones of each plot were sampled to measure the total biomass and grain yield. In the harvest area, the number of plants and barren stalks (no ear or no grain-bearing ears) were both counted and recorded for the calculation of percentage of barren stalks. Twenty ears were selected to determine the components of yield, such as number of kernel rows per ear, number of kernels per row and 100-kernel weight.

Statistical analysis: The data were analyzed using standard Analysis of Variance (ANOVA) and General Linear Model (GLM) procedures and the means were separated according to Fisher's protected Least Significant Difference (LSD) at $p \le 0.05$ (SAS, 1996).

RESULTS

Leaf area index: During the maize growing season, the LAI was greater at R1 stage (silking) than at R5 stage (maturity) (Table 2) and the LAI at R1 stage was lower in 2012 than in 2011, which might be due to less rainfall during V3-V6 stage in July, 2012 than that in 2011 (Table 1). No large differences in LAI ($p<0.05$) were found among the planting patterns at either R1 or R5 stage in either year. No significant difference was found between the densities in LAI at R5 stage, while at R1 stage, the LAI was generally significantly greater for the high plant density (82,500 plants/ha) than for the

Table 2: Leaf Area Index (LAI) at R1 and R5 stages in maize affected by planting patterns and plant densities in years 2011 and 2012

		Leaf area index (m^2/m^2)			
		R1 stage		R5 stage	
Planting patterns	Density plants/ha	2011	2012	2011	2012
CK	67,500	4.90	3.43	2.84	2.31
	82,500	5.97	4.36	2.27	3.14
Three-row	67,500	4.58	3.80	2.21	2.54
	82,500	5.88	4.69	2.72	2.77
Four-row	67,500	4.41	3.87	3.08	2.34
	82,500	5.54	4.35	2.59	2.45
Five-row	67,500	4.61	3.79	2.77	2.73
	82,500	5.76	4.59	2.81	2.66
Planting patterns average	CK	5.43	3.89	2.56	2.72
	Three-row	5.23	4.25	2.47	2.65
	Four-row	4.98	4.11	2.83	2.40
	Five-row	5.18	4.19	2.79	2.70
LSD		ns	ns	ns	ns
Density average	67,500	4.63	3.73	2.72	2.48
	82,500	5.79	4.50	2.60	2.75
LSD		0.35*	0.46*	ns	ns
Pattern×density		ns	ns	ns	ns

*: Significant at 0.05 probability level; ns: Not significant

Table 3: Leaf Area Duration (LAD) of summer maize with different planting patterns and densities in years 2011 and 2012

		Leaf area duration (m^2 day/m^2)					
		2011			2012		
Planting patterns	Density (plants/ha)	0-53 (day)	53-105 (day)	Total LAD	0-57 (day)	57-105 (day)	Total LAD
CK	67,500	123.9	198.7	322.6	91.0	137.9	228.9
	82,500	186.2	229.8	416.0	115.4	179.8	295.2
Three-row	67,500	141.8	200.3	342.1	100.8	152.2	252.9
	82,500	166.2	237.2	403.4	124.2	179.0	303.2
Four-row	67,500	127.6	197.0	324.5	102.6	149.1	251.8
	82,500	217.1	235.0	452.1	115.4	163.3	278.7
Five-row	67,500	132.7	201.3	334.0	100.5	156.6	257.1
	82,500	150.3	231.0	381.3	121.5	173.9	295.4
Planting patterns average	CK	155.0	214.3	369.3	103.2	158.8	262.1
	Three-row	154.0	218.7	372.8	112.5	165.6	278.1
	Four-row	172.3	216.0	388.3	109.0	156.2	265.2
	Five-row	141.5	216.2	357.6	111.0	165.2	276.3
LSD		13.3*	ns	ns	ns	ns	ns
Density average	67,500	131.5	199.3	330.8	98.7	148.9	247.7
	82,500	179.9	233.3	413.2	119.1	174.0	293.1
LSD		20.1*	5.1*	22.0*	12.2*	17.6*	28.0*
Pattern×density		ns	ns	ns	ns	ns	ns

0, 53, 57, 105: Days after sowing; *: Significant at 0.05 probability level

Table 4: Above-ground biomass of maize with different planting patterns and densities at R1 and R5 stage

		Above-ground biomass (kg/ha)			
		R1 stage		R5 stage	
Planting patterns	Density (plants/ha)	2011	2012	2011	2012
CK	67,500	7782	6597	19651	18956
	82,500	8229	7977	19695	22383
Three-row	67,500	8479	7642	22120	20648
	82,500	9520	8194	22458	22193
Four-row	67,500	7556	6762	19472	18777
	82,500	8816	7805	21101	22251
Five-row	67,500	7989	6948	20073	20325
	82,500	8997	7742	20790	19648
Planting patterns average	CK	8006	7287	19673	20669
	Three-row	8999	7918	22289	21420
	Four-row	8186	7283	20286	20514
	Five-row	8493	7345	20432	19986
LSD		657*	ns	ns	ns
Density average	67,500	7952	6987	20329	19676
	82,500	8890	7930	21011	21619
LSD		465*	748*	ns	1592*
Pattern×density		ns	ns	ns	ns

*: Significant at 0.05 probability level; ns: Not significant

medium density (67,500 plants/ha) in both years. The pattern×density interactions were insignificant for the LAI at both R1 and R5 stage in both years.

Leaf area duration: The planting patterns had no significant effect on the Leaf Area Duration (LAD) of the maize in either year, except at 0-53 day (before R1 stage) in 2011, while the LAD was significantly greater for the high plant density than for the medium plant density during the whole development period in both years (Table 3). The pattern×density interactions were insignificant for both the LAD and the total LAD in both years. Among all treatments, the highest total LAD was recorded in the treatment of the four-row strip planting pattern with high plant density in 2011 and in the treatment of the three-row strip planting pattern with high plant density in 2012, while the lowest total LAD was recorded in the control planting pattern with medium plant density for both years.

Above-ground biomass: The above-ground biomasses at R1 and R5 stage were less in 2012 than in 2011; however, the responses of above-ground biomass to the planting patterns and plant density were similar in 2011 and 2012 (Table 4). Among all the planting patterns, the average above-ground biomass of the three-row strip planting pattern was highest at both R1 and R5 stage in both years, while a significant difference existed only in the above-ground biomass at R1 stage in 2011 ($p<0.05$). The plant density significantly influenced the above-ground biomass at R1 stage in both years and at R5 stage only in 2012 and the above-ground biomass at both stages was generally greater for the higher plant density than for the medium density in both years. The planting pattern×plant density interactions were not significant for the plant above-ground biomass at either R1 or R5 stage in either year (Table 4).

Radiation use efficiency and grain yield: In both years, the treatment effects of the planting pattern on the Harvest Index (HI) and Radiation Use Efficiency (RUE) at R5 stage were insignificant ($p<0.05$), but significantly for the grain yield (Table 5). Among the four planting patterns, the three-row strip planting pattern and the control planting pattern produced the highest and lowest grain yield, respectively. Compared with the control, the average grain yield increased by 16.7, 6.1 and 10.7%, respectively in 2011 and by 17.2,

Table 5: Yield, harvest index and radiation use efficiency of summer maize with different planting patterns and densities at R5 stage

Planting patterns	Density (plants/ha)	Grain yield (kg/ha) 2011	Grain yield (kg/ha) 2012	Harvest index 2011	Harvest index 2012	RUE (%) 2011	RUE (%) 2012
CK	67,500	6926	6395	0.35	0.34	1.92	1.81
	82,500	7166	6745	0.36	0.31	1.93	2.14
Three-row	67,500	7792	7394	0.35	0.36	2.16	1.97
	82,500	8655	8003	0.39	0.36	2.20	2.12
Four-row	67,500	7116	7352	0.37	0.39	1.90	1.80
	82,500	7831	7373	0.37	0.33	2.06	2.13
Five-row	67,500	7749	7494	0.39	0.37	1.96	1.94
	82,500	7854	7036	0.38	0.36	2.03	1.88
Planting patterns average	CK	7046	6570	0.36	0.32	1.92	1.98
	Three-row	8223	7699	0.37	0.36	2.18	2.05
	Four-row	7474	7363	0.37	0.36	1.98	1.96
	Five-row	7801	7265	0.38	0.36	2.00	1.91
LSD		745*	622*	ns	ns	ns	ns
Density average	67,500	7396	7159	0.36	0.37	1.99	1.88
	82,500	7876	7289	0.38	0.34	2.05	2.07
LSD		ns	ns	ns	0.02*	ns	1.15*
Pattern×density		ns	ns	ns	ns	ns	ns

*: Significant at 0.05 probability level; ns: Not significant

Table 6: Yield components of summer maize with different planting patterns and densities at R5 stage (2011)

Planting patterns	Density (plants/ha)	Barren stalks (%)	Number of kernel rows	Number of kernels/row	100-kernel weight (g)	Kernel weight/ear (g)
CK	67,500	12.97	14.51	32.80	29.89	142.26
	82,500	19.15	14.33	30.62	29.00	127.35
Three-row	67,500	6.17	15.02	33.80	28.91	146.83
	82,500	12.61	15.11	32.78	28.08	139.12
Four-row	67,500	5.52	15.33	32.24	28.14	139.13
	82,500	15.18	14.67	32.78	27.96	134.68
Five-row	67,500	6.13	14.71	33.40	28.55	140.83
	82,500	13.99	15.32	31.47	28.18	135.71
Planting patterns average	CK	16.06	14.42	31.71	29.45	134.80
	Three-row	9.39	15.07	33.29	28.50	142.98
	Four-row	10.35	15.00	32.51	28.05	136.90
	Five-row	10.06	15.02	32.43	28.37	138.27
LSD		ns	ns	ns	ns	ns
Density average	67,500	7.69	14.89	33.06	28.87	142.26
	82,500	15.23	14.86	31.91	28.30	134.22
LSD		5.01*	ns	ns	ns	ns
Pattern×density		ns	ns	ns	ns	ns

*: Significant at 0.05 probability level; ns: Not significant

Table 7: Yield components of summer maize with different planting patterns and densities at R5 stage (2012)

Planting patterns	Density (plants/ha)	Barren stalks (%)	Number of kernel rows	Number of kernels per row	100-kernel weight (g)	Kernel weight/ear (g)
CK	67,500	3.76	14.11	30.28	28.03	114.91
	82,500	3.08	14.33	32.61	27.21	118.17
Three-row	67,500	1.18	13.93	35.75	31.49	158.98
	82,500	1.92	14.11	33.97	30.33	148.71
Four-row	67,500	1.73	13.67	34.28	30.96	147.73
	82,500	1.56	13.33	33.48	30.87	135.83
Five-row	67,500	0.96	14.24	33.65	30.63	150.50
	82,500	1.01	14.02	32.15	29.01	130.83
Planting patterns average	CK	3.42	14.22	31.44	27.62	116.54
	Three-row	1.55	14.02	34.86	30.91	153.85
	Four-row	1.65	13.50	33.88	30.92	141.78
	Five-row	0.99	14.13	32.90	29.82	140.67
LSD		1.24*	ns	1.19*	1.81*	14.34*
Density average	67,500	1.91	13.99	33.49	30.28	143.03
	82,500	1.89	13.95	33.05	29.35	133.39
LSD		ns	ns	ns	ns	ns
Pattern×density		ns	ns	*	ns	ns

*: Significant at 0.05 probability level; ns: Not significant

12.1 and 10.6%, respectively in 2012 under the three-row strip, four-row strip and five-row strip treatments, respectively. Although the grain yield and RUE were greater for the higher plant density than for the medium plant density, the differences were not significant except for the RUE in 2012 (Table 5). The difference between the densities in the harvest index was significant only in 2012. The results showed no significant pattern×density interaction for the grain yield, HI or RUE in either year (Table 5).

Yield components: No difference in the percentage of barren stalks was observed among the planting patterns in 2011, but a significant difference was observed in 2012 and the conventional uniform row spacing pattern (control) had the highest percentage of barren stalks in both years (Table 6 and 7). The pattern did not significantly influence the kernel number per row in either year or the 100-kernel weight or kernel weight per year in 2011. However, a significant difference in kernel number per row, 100-kernel weight and kernel weight per year was observed between the patterns in 2012. The lowest values for these parameters were recorded for the control planting pattern. The percentage of barren stalks was significantly influenced by the plant density only in 2011 and the percentage of barren stalks was greater for the high density treatment than for the medium density treatment. No significant difference in kernel number per row, 100-kernel weight, or kernel weight per year was observed between the densities for either year (Table 6 and 7). There was no significant pattern×density interaction for any of the yield component indices in either year except for the kernel number per row in 2012 (Table 6 and 7).

DISCUSSION

Leaf Area Index (LAI) is a key structural attribute for agricultural crops and is closely related to light interception, which determines biomass production (Monteith, 1977). Canopy photosynthesis increases with LAI (Rochette *et al*., 1995; Campbell *et al*., 2001). Leaf area is influenced by genotype, plant population, climate and soil fertility (Valadabadi and Farahani, 2010), however, leaf area is not significantly affected by the plant spacing (Ibeawuchi *et al*., 2008). On the other hand, the LAI varies depending on a number of factors, including seasonal climate, water and nitrogen availability (Ewert, 2004). We found no significant difference in the LAI between the planting patterns (Table 2). The LAI was significantly influenced by the plant density but only at R1 stage and generally increased with increasing plant density. These findings are consistent with Ferreira and Abreu (2001) and Saberali *et al*. (2007). The Leaf Area Duration (LAD) shows an integrated lasting time of assimilation surface (Beadle, 1993); a higher leaf area index leads to increased leaf area duration (Shivamurthy, 2005). The LAD also determines the extent of the above-ground biomass production (Krishnamurthy *et al*., 1973); the LAD during the period of generative organ formation has a great impact on productivity (Gawrońska, 1980). In this research, the LAD was also significantly influenced by the plant density, not the planting patterns or the interaction between plant density and planting patterns (Table 3).

Radiation Use Efficiency (RUE) is the key factor determining crop yield and is related to crop biomass (Huang *et al*., 2007; Miranzadeh *et al*., 2011). The planting patterns did affect the RUE (Tollenaar and Aguilera, 1992) and the high density may also improve it (Sangoi *et al*., 2002). Although the RUE was not significantly influenced by the planting patterns in either year, the RUE increased under those three strip planting patterns (i.e., three-row strip, four-row strip, five-row strip) compared with that under the control (uniform row spacing pattern) and the average values of the biomass were also higher for the three strip planting patterns than for the control, although the difference did not reach the significant level (Table 4 and 5).

Grain yield and HI can be increased by enhanced plant spacing precision or density (Doerge *et al*., 2002; Andrade *et al*., 2002; Gozubenli *et al*., 2004; Sharratt and McWilliams, 2005; Yilmaz *et al*., 2008). The HI was not significantly influenced by either the planting pattern or the density, while the planting patterns significantly affected the grain yield (Table 5) and the three-row strip pattern showed the highest yield in both years (Table 5), which is consistent with our former report (Zhang *et al*., 2012a). The percentage of barren stalks of the three strip planting patterns (Table 6 and 7) are consistent with our previous report and it might be because that leaf angles above the ear became more upright allowing greater light penetration into the canopy in strip planting patterns, especially in three-row strip pattern (Zhang *et al*., 2012b). Among all treatments, the highest grain yield was obtained from the three-row strip planting pattern with high plant density (82,500 plants/ha) in both 2011 and 2012. It was found that the photosynthesis of the two leaves above the ear was highest in three-row strip planting pattern, which contribute greatly to grain filling and the kernel weight per year (Zhang *et al*., 2012b). However, the interaction between planting pattern and plant density was insignificant. In addition, the yields and harvest index were not high for either years, which was mainly due to late planting in both years and unfavorable weather, such as low temperature and less sunshine during grain filling period in 2011 and over raining at the early grain filling in 2012 (Table 1).

This research tested the hypothesis and the result was that strip plant patterns, especially three-row strip planting pattern indeed could increase grain yield, however, the effect of the interaction between planting pattern and plant density on yield was not statistically significant, in other words, yield response to strip planting patterns was not greater with increased plant density, therefore, plant density need not be considered in the estimation of optimum strip planting pattern.

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