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EFFECTS OF PLANTING DENSITY AND CROPPING PATTERN ON THE DRY MATTER ACCUMULATION AND YIELD OF MAIZE (*ZEA MAYS* L.) IN SOUTHWEST CHINA

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ABSTRACT

Maize (*Zea mays L.*) is one of the most important cereal crops worldwide. However, the grain yield of maize has lagged even as its demand has increased with human population growth. Ecological conditions have significant effects on maize yield. For example, fertile soils could increase the dry matter accumulation of maize, and abundant light and temperature are the basis for high maize yields. Plant density and cropping pattern also exert important effects on the grain yield of cereal crops. This study investigated the growth characteristics, dry matter accumulation (DMA) and distribution, yield, and yield components of maize planted at different densities and with different cropping patterns. Field experiments were conducted in Shehong (SH), Shuangliu (SL), and Yaan (YA) in Southwest China in 2012. Zhenghong 6 was planted at densities of 37,500; 48,750; or 60,000 plants ha^{-1} in equal or wide-narrow rows with single or double plants per hole. Results showed distinct differences in ecological conditions at the three planting sites. Thus, the plant height, leaf area index (LAI), DMA, and yield of maize were significantly higher in SL than in SH and YA, and the lowest values for these parameters were observed in YA. With increasing plant density, the DMA of each plant decreased, whereas plant height, LAI, and DMA at the population level and yield markedly increased. The highest values for these parameters were consistently correlated with the highest plant density in all experimental sites. In addition, grain yield significantly changed with cropping pattern under limiting conditions. Overall, the results suggested that increasing plant density within a certain range under single and wide-narrow row cultivation is a feasible strategy to increase the grain yield of maize in Southwest China.

Keywords: maize; plant density; cropping pattern; dry matter; yield.

INTRODUCTION

The increased grain yield of maize (*Zea mays* L.) in the world's primary maize-growing areas is mainly attributed to the increased tolerance of maize cultivars to environmental stress, thus resulting in markedly increased yield production and plant population per unit area over the past few years (Robles *et al.*, 2012, Shin *et al.*, 2014). The agronomic and economic responses of maize grain yield to plant densities in current cultivation practices have been extensively studied (Liu *et al.*, 2010, Zuo *et al.*, 2015, Yang *et al.*, 2010, Zhang *et al.*, 2015). These studies, along with concurrent university extension research, recommend that the economically optimal plant densities for maize in Southwest China are 30000−45000 plants ha^{-1} (Pan *et al.*, 2012). Given the heavy demand for maize and the decrease in arable land for maize production (Zhang *et al.*, 2014, Deng *et al.*, 2014), increasing plant density is a strategy that can improve maize yield. Densities in excess of 60,000 plants ha^{-1} may be required to achieve grain yields at or near the demand. However, maize breeders strictly recommend planting large-spike and high-stalk maize cultivars at 30,000 plants ha^{-1} in Southwest China because increased plant density increases the susceptibility of crops to lodging and diseases that will seriously affect yield (Yang *et al.*, 2010). Therefore, researchers should investigate maize cultivars that can tolerate increased inter-plant competition under different ecological conditions (Liu *et al.*, 2011, Haegele *et al.*, 2014), as well as the application of agronomic practices that allow density-tolerant cultivars to increase their yield in response to suitable ecological conditions. Row spacing and the number of plants per hole are important factors in these complementing agronomic practices.

A reasonable cropping pattern can improve the illumination, temperature, humidity, and CO_2 of the canopy microenvironment; these environmental factors all significantly affect dry matter accumulation (DMA) and crop yield (Yang *et al.*, 2010, Li *et al.*, 2015, Brodrick *et al.*, 2013). Equal row spacing (E), wide-narrow row (W), and single plant (S) and double plants (D) per hole are the most common cropping patterns in global maize production (Roekel *et al.*, 2012, Robles *et al.*, 2012, Wang *et al.*, 2015). Compared with E, W can increase light transmittance, leaf area index (LAI) and

DMA, ultimately increasing maize yield by improving group structure (Yang *et al.*, 2010). Plant height, LAI, panicle diameter, panicle length, and grain yield are significantly higher in S than in D cultivation (Wu *et al.*, 2015). In addition, the increase in planting distance markedly increases maize yield under D cultivation (Wang, 2009).

The grain yield of crops is determined by DMA and harvest index (Ning *et al.*, 2013, Deng *et al.*, 2012). Moreover, DMA and dry matter distribution in the leaf lamina, stem plus sheath, and panicle are crucial factors for yield formation (Deng *et al.*, 2014, Liu *et al.*, 2011). The effects of plant density on DMA are mainly observed after the jointing stage (JS); with the increase in plant density, the proportion of vegetative organ increases and that of panicles decreases (Han *et al.*, 2008). Numerous studies have investigated the effects of plant density and arrangement on DMA and dry matter distribution in maize (Ciampitti *et al.*, 2011, Wang *et al.*, 2015, Antonietta *et al.*, 2014, Karasahin, 2014). Plant density and cropping pattern have been studied separately, and these studies are mainly conducted in North China. Moreover, research on the effect of the combination of plant density and cropping pattern on dry matter production and yield in maize in Southwest China remain lacking. Southwest China is the second largest maize-producing region; it has a large land area and exhibits ecological conditions that are obviously different from those of other regions. The traditional manual method should be replaced because the agricultural labor force has dwindled in recent years. However, the special topography, complex and diverse cropping patterns, and differences in the plant types and growth cycles of maize cultivars severely limit the mechanization of maize production in Southwest China (Qu *et al.*, 2013).

This experiment, which consisted of 12 treatments, was conducted in Shenghong (SH), Shuangliu (SL), and Yaan (YA). This study aimed to (1) evaluate the effect of planting density and cropping pattern on maize yield and how dry matter accumulation and allocation, maize plant height, and LAI result in differences in grain yield; (2) investigate the differences in dry matter production and yield formation in SH, SL, and YA; and (3) determine the optimal combination of plant density and cropping pattern to increase maize yield and develop mechanized maize production in different ecological sites in Southwest China.

MATERIALS AND METHODS

Study sites and materials: In 2012, field experiments were conducted in SH, SL, and YA in Sichuan, China. The study sites have a subtropical humid monsoon climate. Figure 1 and Table 1 respectively show the meteorological data and the analytical results of the top soil layer (0–30 cm) of the study sites. In this experiment, we planted Zhenghong 6, a compact maize hybrid cultivar bred by Sichuan Agricultural University and Zhenghong Seed Co., Ltd.

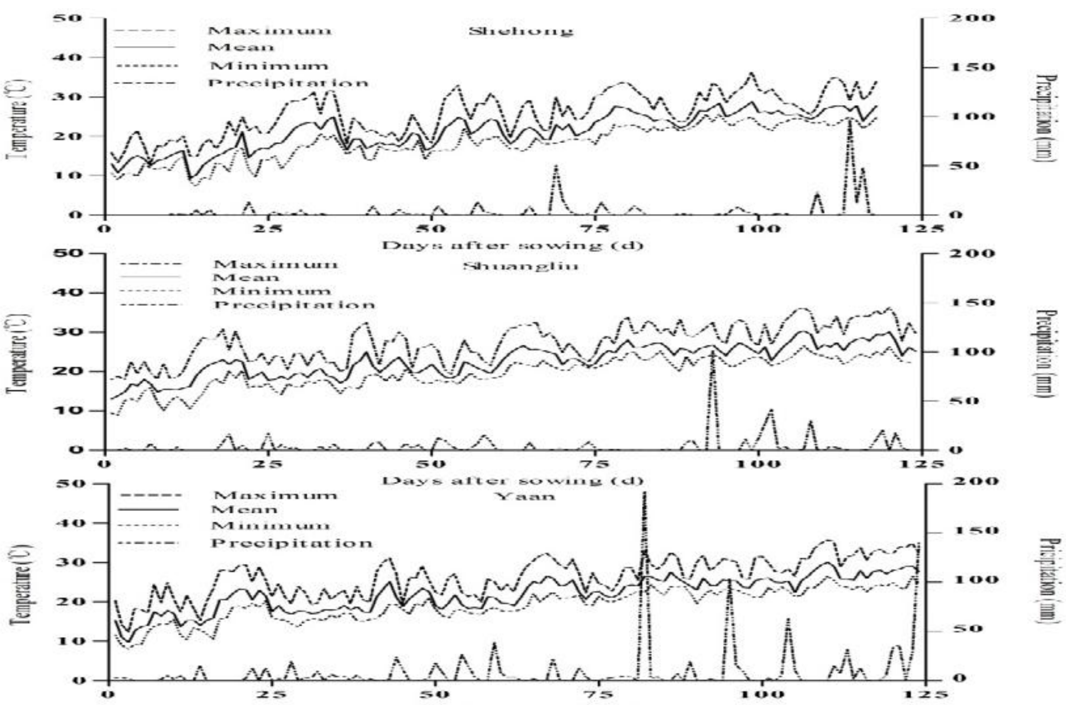

Fig.1 Meteorological data of experimental locations

Table 1. 0-30 cm soil conditions of experimental locations.

Location	Organic matter (g kg^{-1})	Total N (g kg^{-1})	Total P (g kg^{-1})	Total K (g kg^{-1})	Available N (mg kg^{-1})	Available P (mg kg^{-1})	Available K (mg kg^{-1})	pH
SH	13.78	1.21	0.42	8.21	87.52	30.37	132.75	7.47
SL	22.96	2.14	0.86	26.24	137.17	65.21	87.29	6.07
YA	20.74	1.75	0.54	27.60	121.47	47.92	127.65	6.98

Experimental design: The experimental design was a split–split plot with three replications. The treatments involved the combination of three plant densities [density 1 (D1) = 37,500 plant ha^{-1}; density 2 (D2) = 48,750 plant ha^{-1}; and density 3 (D3) = 60,000 plant ha^{-1}] as main plots; two row spacings [equal row (E): 1.0 m+1.0 m; wide-narrow row (W): 1.5 m+0.5 m] as subplots; and the number of plants per hole [single (S) and double plants (D) per hole] as subplots. Each plot measured 4 m × 5 m and consisted of four 5-m rows.

Field experiments were conducted after maize cultivation in SH and YA and after vegetable production in SL. Prior to sowing, the soil was ploughed after removing the residues of previous crops. The soil was then treated with fertilizers, irrigated, and film mulched. Nitrogen fertilizer (urea; 46.7–0–0) was divided equally and then applied at the sowing and pre-silking stages at a rate of 225 kg ha^{-1}. Prior to sowing, phosphorus (superphosphate; 0–12.0–0) and potassium (potassium chloride; 0–0–63.1) were applied at a rate of 72 and 90 kg ha^{-1}, respectively. In our study, the cultivation practices for maize, including pest, disease, and weed control, were all similar to those for high-yield cultivation in this region.

Sampling and measurements: The following parameters were measured: plant height and leaf area at the silking stage (SS) and total DMA in shoot at the JS, SS, and maturity stage (MS). Five representative plants were sampled from the middle of each plot and then separated as follows: leaf lamina and sheath plus stem at the JS and SS; leaf lamina, sheath plus stem, bracts plus cob, and grain at the MS. The samples were desiccated at 105 °C for 30 min and then oven dried at 80 °C to a constant weight. The height and leaf area at the SS were measured prior to separating the plants into different organs. Plant height was measured from the caudex up to the uppermost ligules. Leaf area was determined using the length-to-width coefficient method. The coefficient was determined as 0.75. The grain yield and 1000-kernel weight of all plants (except border plants) in each plot were determined and adjusted to a moisture content of 14.0%. Panicle characters (panicle length, panicle diameter, and barren panicle) and yield components (row number, grains per row, and grains per panicle) were determined from 20 consecutive plants per plot. The DMA and crop growth rate (CGR) of two adjacent sampling stages were calculated using the following formulas (Deng *et al.*, 2014):

DMA (t ha^{-1}) = DMA at t_2 − DMA at t_1 (1)

CGR (kg ha^{-1} d^{-1}) = DMA/($t_2 - t_1$) (2)

Harvest index (HI, %) = DMA of grain at MS/DMA at MS (3)

where t_1 and t_2 are the duration of the previous and present stages, respectively. HI is the ratio of dry matter in the grain to that in aerial plant parts at MS.

Data analysis: Data for each site were analyzed using SPSS 20.0 for Windows 2007. Variance analysis and means (n=3) were tested by least significant difference at p=0.05. Correlation analysis was conducted for the selected variables.

RESULTS

Plant height and LAI: Plant density and location significantly ($p \leqslant 0.01$) affected the height of plants in the three sites (Fig. 2). The mean plant height at the SS in SH was higher by 5.60% and 18.53% than that in SL and YA, respectively. As plant density increased, plant height at the SS significantly ($p \leqslant 0.01$) increased in the three locations. Compared with that of D1, the plant height of D2 and D3 increased by 1.99% and 3.73% in SH, 2.45% and 3.39% in SL, 4.08% and 6.95% in YA. Row spacing and the number of plants per hole negligibly affected plant height in SH and SL, whereas plant height under W and S cultivation was high in YA.

LAI was different among the three sites (Fig. 3). The mean LAI at the SS in SL was higher by 6.54% and 11.69% than that in SH and YA, respectively. In addition, plant density exerted significant ($p \leqslant 0.01$) effects on the LAI of maize in the three sites. The LAI of D2 and D3 was significantly higher than that of D1 by 25.18% and 49.24% in SH, 27.67% and 54.44% in SL, and 23.89% and 48.54% in YA. When averaged across row spacing, LAI in E cultivation was higher by 3.41% and 1.31% than that in W cultivation in SH and YA, respectively. The number of plants per hole also significantly ($p \leqslant 0.05$) affected the LAI of maize in SL and YA, in which LAI in S cultivation was higher than that of D by 2.63% and 3.55% in SL and YA.

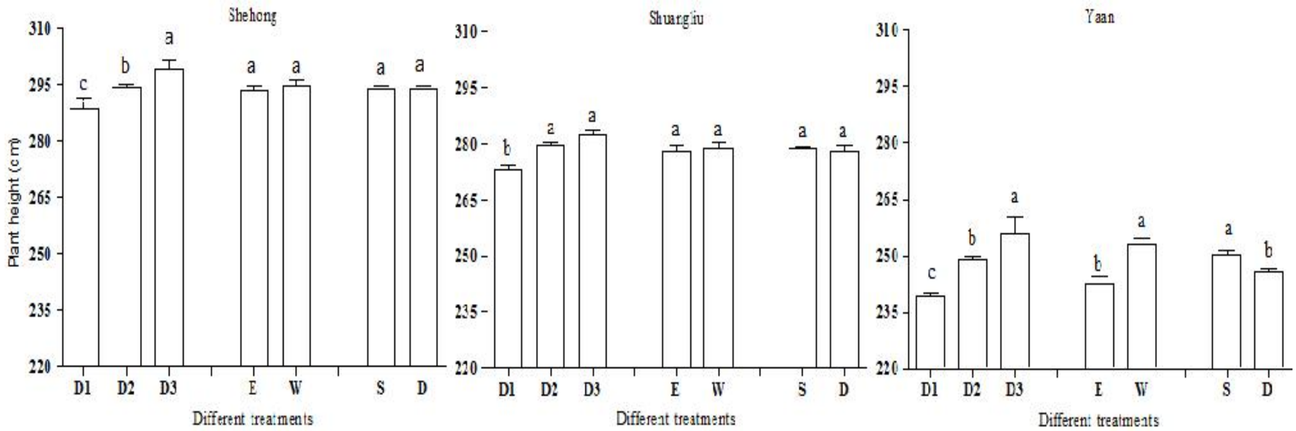

Fig. 2 Plant height of maize under different treatments

Data are presented as the means of different treatments. Different letters in the same treatment represent significant ($p \leqslant 0.05$) differences in different test sites.

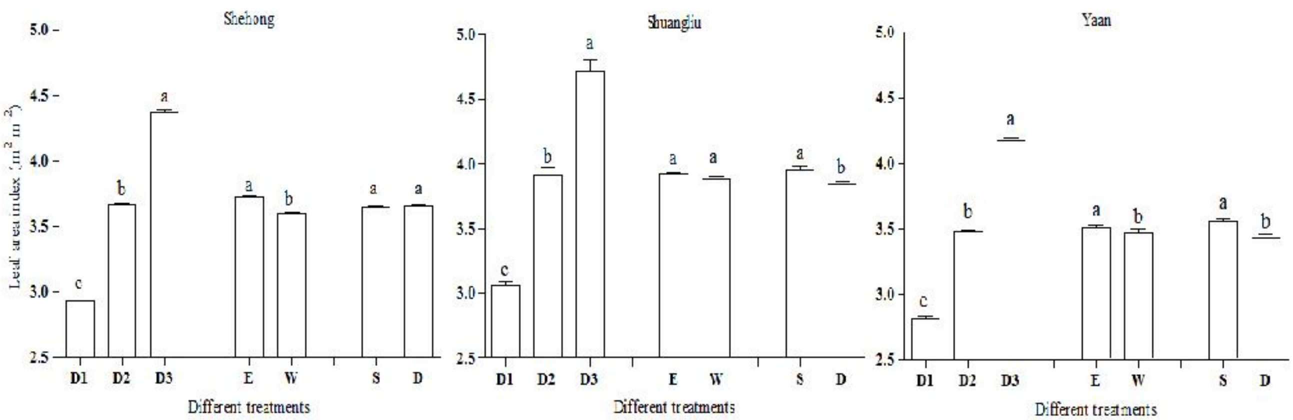

Fig. 3 Leaf area index (LAI) of maize under different treatments

Data are presented as the means of different treatments. Different letters in the same treatment represent significant ($p \leqslant 0.05$) differences in different test sites.

DMA: The DMA of each plant increased as maize growth progressed (Table 2). The mean DMA of each plant at the JS and SS was higher in SH, whereas DMA at the MS was high in SL. Plant density significantly ($p \leqslant 0.01$) affected the DMA of each plant in the three locations, that is, the increase in plant density significantly ($p \leqslant 0.01$) decreased the DMA of each plant in the three locations. Compared with D1, the fraction (an average of D2 and D3 treatments) of the DMA of each plant at the JS, SS, and MS decreased by 10.61%, 15.35%, and 18.79% in SL, 9.51%, 3.97%, and 9.94% in SH, and 9.93%, 8.83%, and 12.18% in YA, respectively. In addition, the DMA of each plant at the JS, SS, and MS (except in E cultivation in SL) under the E and S treatments was higher than that under the W and D treatments in the three sites. The interaction among plant density, row spacing, and the number of plants per hole significantly ($p \leqslant 0.05$) influenced the DMA of each plant at the JS, SS, and MS in SH, whereas the effects of this interaction at the SS were obvious only in SL and YA.

The DMA at the population level was remarkably higher in SH than in SL and YA before the SS, but was significantly higher in SL than in SH and YA at the MS (Table 3). Plant density, row spacing (except in SL at the SS), and the number of plants per hole (except in SH at the SS and in SL at the MS) significantly ($p \leqslant 0.01$) affected the populations' DMA in the three locations. In addition, increased plant density significantly ($p \leqslant 0.01$) increased the populations' DMA in the three locations. The DMA at the population level at the JS, SS, and MS under E treatment was markedly higher than that under W treatment by 5.51%, 9.29%, and 8.50% in SH and by 7.27%, 8.66%, and 5.68% in YA, respectively. In addition, the DMA at the population level significantly ($p \leqslant 0.01$) increased under S cultivation at the JS, SS, and MS in YA, at the JS and MS in SH, and at the JS and SS in SL. The interaction among plant density, row spacing, and the number of plants per hole exerted significant ($p \leqslant 0.01$) effects on DMA at the population level at the SS in the three sites, whereas the effects at the JS and MS were obvious only in SH.

Table 2. Dry matter accumulation of a single maize plant under different treatments.

Treatment	SH (g plant^{-1})			SL (g plant^{-1})			YA (g plant^{-1})		
	JS	SS	MT	JS	SS	MT	JS	SS	MT
D1	58.34^{a}	175.34^{a}	331.44^{a}	50.66^{a}	118.17^{a}	367.64^{a}	37.64^{a}	111.46^{a}	313.47^{a}
D2	54.59^{b}	155.55^{b}	278.13^{b}	47.54^{b}	116.40^{a}	341.76^{b}	34.75^{b}	105.91^{b}	288.15^{b}
D3	49.70^{c}	141.29^{c}	260.21^{c}	44.15^{c}	110.56^{b}	320.43^{c}	33.51^{c}	97.31^{c}	262.42^{c}
E	55.55^{a}	164.67^{a}	302.12^{a}	46.84^{b}	115.30^{a}	337.27^{b}	36.46^{a}	109.58^{a}	294.13^{a}
W	52.87^{b}	150.12^{b}	277.73^{b}	48.07^{a}	114.79^{a}	349.28^{a}	34.14^{b}	100.20^{b}	281.90^{b}
S	56.53^{a}	156.48^{a}	297.71^{a}	51.04^{a}	120.13^{a}	344.15^{a}	37.26^{a}	111.04^{a}	297.88^{a}
D	51.88^{b}	158.31^{a}	277.73^{b}	43.87^{b}	109.96^{b}	342.41^{a}	33.34^{b}	98.74^{b}	278.14^{b}
F-value									
Density (D)	133.97**	262.60**	257.41**	97.33**	42.65**	216.48**	27.53**	85.70**	255.72**
Row spacing (R)	38.64**	142.49**	83.60**	10.38**	0.54^{ns}	41.89**	24.68**	111.25**	44.08**
Plant number (P)	115.77**	2.24^{ns}	34.10**	353.87**	209.13	0.89^{ns}	70.32**	191.20**	114.71**
D×R	0.13^{ns}	11.77**	3.40*	4.06*	5.77**	8.30**	2.52^{ns}	10.86**	0.02^{ns}
D×P	3.04^{ns}	5.99**	0.67^{ns}	8.11**	5.26*	0.15^{ns}	0.36^{ns}	4.18*	2.34^{ns}
R×P	0.59^{ns}	11.03**	22.46**	11.96**	15.39**	1.65^{ns}	20.58**	1.74^{ns}	76.07**
D×R×P	4.23*	10.59**	13.08**	0.69^{ns}	7.32**	1.56^{ns}	2.42^{ns}	14.87**	1.95^{ns}

Data are presented as the means of different treatments. Different letters in the same treatment represent significant ($p \leqslant 0.05$) differences in different test sites. Ns: $p > 0.05$, * $p \leqslant 0.05$, ** $p \leqslant 0.01$.

Table 3. Dry matter accumulation of maize population under different treatments.

Treatment	SH (t ha^{-1})			SL (t ha^{-1})			YA (t ha^{-1})		
	JS	SS	MT	JS	SS	MT	JS	SS	MT
D1	2.19^{c}	6.56^{c}	12.43^{c}	1.90^{c}	4.43^{c}	13.79^{c}	1.41^{c}	4.18^{c}	11.76^{c}
D2	2.66^{b}	7.58^{b}	13.56^{b}	2.32^{b}	5.67^{b}	16.66^{b}	1.69^{b}	5.16^{b}	14.05^{b}
D3	2.98^{a}	8.48^{a}	15.61^{a}	2.65^{a}	6.63^{a}	19.23^{a}	2.01^{a}	5.84^{a}	15.75^{a}
E	2.68^{a}	7.88^{a}	14.43^{a}	2.25^{b}	5.58^{a}	16.30^{b}	1.77^{a}	5.27^{a}	14.32^{a}
W	2.54^{b}	7.21^{b}	13.30^{b}	2.32^{a}	5.58^{a}	16.82^{a}	1.65^{b}	4.85^{b}	13.55^{b}
S	2.72^{a}	7.52^{a}	14.25^{a}	2.46^{a}	5.82^{a}	16.60^{a}	1.80^{a}	5.36^{a}	14.32^{a}
D	2.50^{b}	7.57^{a}	13.48^{b}	2.12^{b}	5.34^{b}	16.52^{a}	1.61^{b}	4.76^{b}	13.37^{b}
F-value									
Density (D)	536.99**	362.95**	207.44**	545.74**	1472.28**	1166.70**	220.26**	500.65**	752.34**
Row spacing (R)	44.55**	133.66**	76.73**	14.72**	0.00^{ns}	31.94**	26.65**	97.35**	49.64**
Plant number (P)	123.39**	0.86^{ns}	35.62**	325.61**	204.79**	0.76^{ns}	64.27**	190.94**	126.86**
D×R	1.57^{ns}	4.20*	0.62^{ns}	6.62**	6.51**	3.17^{ns}	4.28*	6.71**	0.66^{ns}
D×P	3.50*	4.25*	2.21^{ns}	0.18^{ns}	0.81^{ns}	0.14^{ns}	0.49^{ns}	6.66**	3.43*
R×P	2.09^{ns}	6.97*	14.74**	12.94**	12.56**	1.67^{ns}	23.32**	4.93*	81.88**
D×R×P	5.87**	6.68**	7.51**	1.59^{ns}	7.91**	1.48^{ns}	4.74**	20.18**	1.28^{ns}

Data are presented as the means of different treatments. Different letters in the same treatment represent significant ($p \leqslant 0.05$) differences in different test sites. Ns: $p > 0.05$, * $p \leqslant 0.05$, $^{**}p \leqslant 0.01$.

DMA and CGR: Maize growth after sowing is divided into three periods: vegetative (from sowing to the JS), symbiotic (from the JS to the SS), and reproductive (from the SS to the MS). Differences in plant density caused significant ($p \leqslant 0.01$) differences in DMA and CGR (Table 4). DMA and CGR were highest in SH at sowing–JS and JS–SS, whereas those in SL at SS–MS were the highest among the three sites. Among all sites, the highest DMA and CGR (except SH) values were observed at the SS–MS, in which 45.59% (SH), 65.17% (SL), and 63.46% (YA) of the biomass yields accumulated.

The plant density, row spacing (except in YA) and number of plants per hole significantly affected DMA and CGR in the three sites. DMA and CGR significantly ($p \leqslant 0.01$) increased with increased plant density in the three sites. Compared with D1, the average DMA of D2 and D3 at sowing–JS, JS–SS, and SS–MS increased by 28.98%, 18.71%, and 11.98% in SH, 30.71%, 45.01%, and 26.02% in SL, and 31.23%, 31.84%, and 24.02% in YA, respectively. DMA and CGR under E cultivation were markedly ($p \leqslant 0.05$) higher than those under W cultivation at JS–SS in the three sites, at sowing–JS in SH and YA, and at SS–MS in YA. DMA and CGR under S cultivation were significantly ($p \leqslant 0.05$) higher than those under D at all periods in the three experimental sites. The interaction among plant density, row spacing, and number of plants per hole significantly ($p \leqslant 0.05$) influenced DMA and CGR at all periods in SH, whereas the effects were significant soon after the JS in SL and prior to SS in YA.

Table 4. Dry matter accumulation and crop growth rate of maize population under different treatments.

Location	Treatment	Sowing–jointing stage		Jointing–silking stage		Silking–maturity stage	
		DMA ($t\ ha^{-1}$)	CGR ($kg\ ha^{-1}\ d^{-1}$)	DMA ($t\ ha^{-1}$)	CGR ($kg\ ha^{-1}\ d^{-1}$)	DMA ($t\ ha^{-1}$)	CGR ($kg\ ha^{-1}\ d^{-1}$)
SH	D1	2.19^{c}	37.72^{c}	4.39^{c}	182.82^{c}	5.86^{b}	167.26^{b}
	D2	2.66^{b}	45.88^{b}	4.92^{b}	205.08^{b}	5.98^{b}	170.73^{b}
	D3	2.98^{a}	51.41^{a}	5.35^{a}	222.72^{a}	7.29^{a}	208.15^{a}
	E	2.68^{a}	46.15^{a}	5.20^{a}	216.75^{a}	6.56^{a}	187.29^{a}
	W	2.54^{b}	43.86^{b}	4.57^{b}	190.33^{b}	6.19^{b}	176.80^{b}
	S	2.72^{a}	46.92^{a}	4.80^{b}	199.85^{b}	6.74^{a}	192.43^{a}
	D	2.50^{b}	43.08^{b}	4.97^{a}	207.23^{a}	6.01^{b}	171.66^{b}
F-value							
Density (D)		536.39^{**}	530.65^{**}	81.65^{**}	81.05^{**}	30.76^{**}	30.72^{**}
Row spacing (R)		44.55^{**}	44.05^{**}	106.52^{**}	106.08^{**}	4.95^{*}	4.93^{*}
Plant number (P)		123.74^{**}	123.47^{**}	8.33^{**}	8.28^{**}	19.46^{**}	19.34^{**}
D×R		1.57^{ns}	1.53^{ns}	6.59^{**}	6.62^{**}	0.32^{ns}	0.32^{ns}
D×P		3.50^{*}	3.45^{*}	9.32^{**}	9.24^{**}	0.41^{ns}	0.41^{ns}
R×P		2.09^{ns}	1.89^{ns}	13.42^{**}	13.49^{**}	20.73^{**}	20.67^{**}
D×R×P		5.87^{**}	5.71^{**}	5.45^{*}	5.41^{*}	7.10^{**}	7.12^{**}
SL							
	D1	1.90^{c}	33.33^{c}	2.53^{c}	110.06^{c}	9.36^{c}	217.57^{c}
	D2	2.32^{b}	40.66^{b}	3.36^{b}	145.96^{b}	10.99^{b}	255.49^{b}
	D3	2.65^{a}	46.48^{a}	3.98^{a}	173.25^{a}	12.59^{a}	292.84^{a}
	E	2.25^{b}	39.54^{b}	3.33^{a}	144.71^{a}	10.72^{b}	249.20^{b}
	W	2.32^{a}	40.77^{a}	3.25^{b}	141.47^{b}	11.24^{a}	261.40^{a}
	S	2.46^{a}	43.10^{a}	3.36^{a}	146.12^{a}	10.78^{b}	250.70^{b}
	D	2.12^{b}	37.21^{b}	3.22^{b}	140.06^{b}	11.18^{a}	259.90^{a}
F-value							
Density (D)		545.74^{**}	550.33^{**}	589.03^{**}	599.90^{**}	423.38^{**}	426.75^{**}
Row spacing (R)		14.72^{**}	14.56^{**}	4.33^{*}	4.70^{*}	33.49^{**}	33.65^{**}
Plant number (P)		325.61^{**}	330.63^{**}	16.28^{**}	$1.6.48^{**}$	18.86^{**}	19.11^{**}
D×R		6.62^{**}	6.99^{**}	1.24^{ns}	1.20^{ns}	6.61^{**}	6.68^{**}
D×P		0.18^{ns}	0.18^{ns}	1.17^{ns}	1.08^{ns}	0.00^{ns}	0.00^{ns}
R×P		12.94^{**}	13.26^{**}	2.27^{ns}	2.27^{ns}	6.98^{*}	6.93^{*}
D×R×P		1.59^{ns}	1.74^{ns}	11.09^{**}	11.47^{**}	4.56^{*}	4.61^{*}
YA							
	D1	1.41^{c}	24.76^{c}	2.77^{c}	131.81^{c}	7.58^{c}	172.17^{c}
	D2	1.69^{b}	29.72^{b}	3.47^{b}	165.21^{b}	8.88^{b}	201.91^{b}
	D3	2.01^{a}	35.27^{a}	3.83^{a}	182.28^{a}	9.91^{a}	225.15^{a}
	E	1.77^{a}	30.99^{a}	3.51^{a}	166.95^{a}	8.87^{a}	201.68^{a}
	W	1.64^{b}	28.85^{b}	3.20^{b}	152.59^{b}	8.70^{a}	197.81^{a}
	S	1.80^{a}	31.57^{a}	3.56^{a}	169.46^{a}	8.97^{a}	203.77^{a}
	D	1.61^{b}	28.27^{b}	3.15^{b}	150.07^{b}	8.61^{b}	195.72^{b}

F-value						
Density (D)	220.26**	219.23**	190.69**	187.73**	216.43**	217.01**
Row spacing (R)	26.65**	27.10**	44.69**	44.09**	3.46^{ns}	3.46^{ns}
Plant number (P)	64.27**	64.55**	81.52**	80.36**	14.87**	14.95**
D×R	4.28*	4.07*	9.74**	9.59**	3.22^{ns}	3.25^{ns}
D×P	0.49^{ns}	0.52^{ns}	6.21**	6.17**	0.21^{ns}	0.21^{ns}
R×P	23.32**	23.14**	0.14^{ns}	0.13^{ns}	52.69**	52.96**
D×R×P	4.74*	5.54*	10.94**	10.78**	1.94^{ns}	1.92^{ns}

Data are presented as the means of different treatments. Different letters in the same treatment represent significant ($p \leqslant 0.05$) differences in different test sites. Ns: $p>0.05$, $^{*}p \leqslant 0.05$, $^{**}p \leqslant 0.01$.

Dry matter distribution: The ratio of leaf lamina decreased with as maize growth progressed, the highest ratio of stem plus sheath was achieved at the SS (Table 5). The highest mean ratio of the leaf lamina was achieved at JS, whereas the highest ratio for the panicle was observed at the MS in the three experimental sites. Plant density significantly ($p \leqslant 0.05$) affected dry matter distribution in different plant organs in SL. By contrast, plant density obviously influenced the ratio of leaf lamina at the SS and MS, the ratio of stem plus sheath at the SS, and the ratio of the panicle at the SS and MS in SH, as well as the ratio of stem plus sheath at the SS in YA. The increase in plant density increased the ratio of the leaf lamina (except at MS in SL and YA) and decreased the ratio of stem plus sheath at the JS but increased that at the MS. The effects of row spacing and the number of plants per hole on the ratio of leaf lamina were noticeable ($p \leqslant 0.01$) at the SS in the three sites. In addition, the ratio of the leaf lamina at the SS was significantly higher under W and D (except in SH) than under E and S cultivation. The ratio of stem plus sheath was significantly ($p \leqslant 0.05$) affected by the number of plants per hole at the SS, and the ratio of stem plus sheath under S were higher than that under D in SH and SL.

Table 5. Distribution ratios of maize organs under different treatments.

Location	Treatment	Ratio of leaf lamina (%)			Ratio of stem plus sheath (%)			Ratio of panicle (%)	
		JS	SS	MS	JS	SS	MS	SS	MS
SH	D1	62.09 ^{b}	33.62 ^{c}	14.21 ^{b}	37.91 ^{a}	50.71 ^{c}	25.29 ^{a}	15.67 ^{a}	60.50 ^{a}
	D2	62.80^{ab}	35.38 ^{b}	15.06 ^{a}	37.20^{ab}	53.94 ^{b}	25.36 ^{a}	10.68 ^{b}	59.58 ^{b}
	D3	63.45 ^{a}	36.51 ^{a}	15.23 ^{a}	36.55 ^{b}	55.72 ^{a}	25.39 ^{a}	9.77 ^{b}	59.37 ^{b}
	E	63.57 ^{a}	34.36 ^{b}	14.73 ^{a}	36.43 ^{b}	53.32 ^{a}	25.37 ^{a}	12.32 ^{a}	59.91 ^{a}
	W	61.99 ^{b}	35.99 ^{a}	14.94 ^{a}	38.01 ^{a}	53.59 ^{a}	25.33 ^{a}	11.76 ^{a}	59.73 ^{a}
	S	62.21 ^{b}	35.76 ^{a}	14.78 ^{a}	37.80 ^{a}	52.06 ^{b}	25.32 ^{a}	12.18 ^{a}	59.90 ^{a}
	D	63.36 ^{a}	34.58 ^{b}	14.89 ^{a}	36.64 ^{b}	54.86 ^{a}	25.38 ^{a}	11.90 ^{a}	59.73 ^{a}
F-value									
Density (D)		2.89^{ns}	21.81**	17.35**	2.89^{ns}	67.03**	0.28^{ns}	50.61**	16.33**
Row spacing (R)		11.65**	20.58**	1.96^{ns}	11.65**	0.57^{ns}	0.09^{ns}	1.20^{ns}	1.08^{ns}
Plant number (P)		6.21*	10.72**	0.51^{ns}	6.21*	61.00**	0.24^{ns}	0.30^{ns}	0.91^{ns}
D×R		1.21^{ns}	1.30^{ns}	1.24^{ns}	1.21^{ns}	4.99*	0.01^{ns}	13.55**	0.93^{ns}
D×P		1.00^{ns}	15.08**	2.11^{ns}	1.00^{ns}	18.20**	0.51^{ns}	9.56**	1.28^{ns}
R×P		5.42*	14.08**	0.17^{ns}	5.42*	45.74**	0.22^{ns}	0.27^{ns}	0.00^{ns}
D×R×P		0.32^{ns}	7.62**	0.85^{ns}	0.32^{ns}	1.32^{ns}	0.07^{ns}	22.49**	0.34^{ns}
SL									
	D1	59.94 ^{b}	33.43 ^{b}	12.38 ^{a}	40.06 ^{a}	55.70 ^{a}	22.04 ^{a}	10.87 ^{c}	65.58 ^{b}
	D2	60.78^{ab}	33.41 ^{b}	11.77 ^{b}	39.22^{ab}	54.32 ^{b}	22.12 ^{a}	12.27 ^{b}	66.10 ^{b}
	D3	61.61 ^{a}	34.09 ^{a}	11.49 ^{b}	38.39 ^{b}	52.90 ^{c}	21.35 ^{b}	13.01 ^{a}	67.16 ^{a}
	E	60.46 ^{a}	33.27 ^{b}	12.24 ^{a}	39.55 ^{a}	54.98 ^{a}	21.48 ^{b}	11.75 ^{b}	66.27 ^{a}
	W	61.10 ^{a}	34.02 ^{a}	11.52 ^{b}	38.90 ^{a}	53.64 ^{b}	22.19 ^{a}	12.35 ^{a}	66.29 ^{a}
	S	59.92 ^{b}	32.98 ^{b}	11.74 ^{a}	40.08 ^{a}	54.06 ^{b}	21.72 ^{a}	12.96 ^{a}	66.54 ^{a}
	D	61.63 ^{a}	34.31 ^{a}	12.02 ^{b}	38.37 ^{b}	54.55 ^{a}	21.95 ^{a}	11.14 ^{b}	66.02 ^{b}
F-value									
Density (D)		4.29*	6.66**	19.43**	4.29*	81.43**	5.81**	34.73**	17.35**
Row spacing (R)		1.91^{ns}	18.43**	37.27**	1.91^{ns}	56.77**	11.96**	8.00**	0.01^{ns}

Plant number (P)		13.42^{**}	57.83^{**}	5.51^{*}	13.42^{**}	7.62^{*}	1.33^{ns}	73.29^{**}	5.31^{*}
D×R		0.73^{ns}	1.83^{ns}	2.73^{ns}	0.73^{ns}	23.60^{**}	1.89^{ns}	9.14^{**}	2.26^{ns}
D×P		11.74^{**}	13.83^{**}	0.19^{ns}	11.74^{**}	48.19^{**}	1.89^{ns}	15.93^{**}	1.93^{ns}
R×P		1.91^{ns}	3.31^{ns}	16.50^{**}	1.91^{ns}	3.30^{ns}	1.03^{ns}	0.00^{ns}	1.53^{ns}
D×R×P		0.76^{ns}	5.98^{**}	1.93^{ns}	0.76^{ns}	9.76^{**}	1.85^{ns}	1.19^{ns}	3.95^{*}
YA									
	D1	61.63 a	34.52 a	11.60 a	38.37 a	50.69 a	20.92 a	14.78 b	67.48 a
	D2	62.40 a	34.16 a	11.74 a	37.60 a	49.81ab	21.15 a	16.03 a	67.10 a
	D3	62.37 a	35.09 a	11.55 a	37.63 a	49.55 b	21.51 a	15.36ab	66.95 a
	E	61.46 b	33.95 b	11.38 b	38.54 a	48.72 b	21.07 a	17.33 a	67.55 a
	W	62.81 a	35.23 a	11.89 a	37.19 b	51.32 a	21.31 a	13.46 b	66.80 b
	S	61.82 a	33.88 b	11.89 a	38.18 a	50.72 a	21.28 a	15.40 a	66.84 b
	D	62.45 a	35.30 a	11.37 b	37.55 a	49.31 b	21.11 a	15.39 a	67.52 a
F-value									
Density (D)		1.11^{ns}	1.42^{ns}	0.69^{ns}	1.11^{ns}	3.40^{*}	1.49^{ns}	3.27^{ns}	1.32^{ns}
Row spacing (R)		8.02^{**}	7.81^{**}	12.76^{**}	8.02^{**}	47.69^{**}	0.72^{ns}	93.60^{**}	7.35^{*}
Plant number (P)		1.74^{ns}	9.69^{**}	12.87^{**}	1.74^{ns}	14.16^{**}	0.34^{ns}	0.00^{ns}	5.95^{*}
D×R		1.28^{ns}	3.01^{ns}	0.75^{ns}	1.28^{ns}	2.58^{ns}	0.52^{ns}	8.85^{**}	0.52^{ns}
D×P		0.35^{ns}	0.72^{ns}	0.92^{ns}	0.35^{ns}	1.63^{ns}	1.12^{ns}	2.71^{ns}	2.24^{ns}
R×P		0.60^{ns}	1.28^{ns}	2.70^{ns}	0.60^{ns}	0.05^{ns}	0.08^{ns}	1.20^{ns}	0.32^{ns}
D×R×P		1.38^{ns}	1.44^{ns}	0.72^{ns}	1.38^{ns}	2.01^{ns}	0.44^{ns}	4.93^{*}	1.19^{ns}

Data are presented as the means of different treatments. Different letters in the same treatment represent significant ($p \leqslant 0.05$) differences in different test sites. Ns: $p>0.05$, * $p \leqslant 0.05$, ** $p \leqslant 0.01$.

Final plant density, HI, yield, and yield components: The mean values of the final plant density, panicle rows, 1000-kernel weight, and yield were highest in SH. The highest values for kernels per row, grains per panicle, and HI were in SL and YA (Table 6). The yield in SL was significantly higher by 9.21% and 18.51% than that in SH and YA, respectively. In addition, the grains per panicle in SL were higher by 13.00% and 6.39% than that in SH and YA, respectively. The HI in YA was higher by 14.71% and 10.61% than that in SH and SL, respectively.

The final plant densities were generally close to the target plant densities, and the three plant density treatments were distinct from each other. As plant density increased, the maize yields in the three locations significantly ($p \leqslant 0.01$) increased. Compared with D1, the mean values for yield in D2 and D3 increased by 37.61% in SH, 33.69% in SL and 20.42% in YA. The 1000-kernel weight of maize was significantly ($p \leqslant 0.05$) affected by plant density, row spacing, number of plants per hole (except in SL), and the interaction among the three treatments. The effects of plant density on HI were obvious only in SL, although the increase in HI with the increase in plant density was congruent in the three sites. Row spacing treatments did not significantly ($p \leqslant 0.05$) affect panicle rows, kernels per row, and grains per panicle in SH and SL, but significantly ($p \leqslant 0.05$) affected those in YA.

Table 6. Final plant density, harvest index, yield, and yield components of maize under different treatments.

Location	Treatment	Final plant density achieved	Panicle rows	Kernels per row	Grains per panicle	1000-kernel weight (g)	Yield (t ha^{-1})	Harvest index (%)
SH	D1	37221 c	16.58 a	36.33 a	602.12 a	257.25 a	6.33 c	51.87 a
	D2	48524 b	16.68 a	35.17 b	586.41 b	252.90 b	8.21 b	51.93 a
	D3	59659 a	16.19 b	33.44 c	541.32 c	247.92 c	9.09 a	52.10 a
	E	48486 a	16.46 a	34.99 a	575.93 a	253.82 a	7.97 a	51.97 a
	W	48450 a	16.51 a	34.97 a	577.30 a	251.56 b	7.78 b	51.97 a
	S	48374 a	16.47 a	35.57 a	585.94 a	253.64 a	7.94 a	51.98 a
	D	48562 a	16.49 a	34.40 b	567.29 b	251.74 b	7.81 a	51.96 a
F-value								
Density (D)		5451.54^{**}	8.96^{**}	75.49^{**}	227.07^{**}	3549.86^{**}	539.30^{**}	0.29^{ns}
Row spacing (R)		0.04^{ns}	0.26^{ns}	0.01^{ns}	0.32^{ns}	624.74^{**}	7.59^{*}	0.00^{ns}
Plant number (P)		1.30^{ns}	0.03^{ns}	36.45^{**}	59.47^{**}	440.65^{**}	3.78^{ns}	0.00^{ns}
D×R		0.88^{ns}	0.04^{ns}	0.54^{ns}	0.52^{ns}	13.48^{**}	2.33^{ns}	0.14^{ns}

D×P		0.63^{ns}	0.61^{ns}	1.36^{ns}	0.19^{ns}	105.57^{**}	0.03^{ns}	0.13^{ns}
R×P		1.03^{ns}	1.15^{ns}	3.26^{ns}	0.75^{ns}	277.87^{**}	0.07^{ns}	0.16^{ns}
D×R×P		0.56^{ns}	0.24^{ns}	1.18^{ns}	2.79^{ns}	355.51^{**}	3.88^{*}	0.24^{ns}
SL								
	D1	37012 c	16.13 a	41.92 a	676.27 a	254.28 a	7.02 c	50.94 b
	D2	47965 b	15.98 a	40.80 b	651.98 b	247.06 b	8.60 b	51.60 b
	D3	59327 a	15.78 b	39.72 c	626.52 c	242.43 c	10.17 a	52.93 a
	E	48048 a	16.00 a	40.82 a	650.08 a	246.21 b	8.49 b	52.02 a
	W	48154 a	15.93 a	40.81 a	653.11 a	249.64 a	8.70 a	51.62 a
	S	48215 a	15.98 a	41.08 a	656.64 a	247.93 a	8.65 a	52.07 a
	D	47987 a	15.94 a	40.55 b	646.55 b	247.92 a	8.54 a	51.58 a
F-value								
Density (D)		1432.27^{**}	10.60^{**}	75.02^{**}	190.21^{**}	2060.32^{**}	712.89^{**}	16.96^{**}
Row spacing (R)		0.12^{ns}	1.28^{ns}	0.00^{ns}	2.03^{ns}	507.81^{**}	9.34^{**}	1.97^{ns}
Plant number (P)		0.45^{ns}	0.37^{ns}	13.21^{**}	23.49^{**}	0.00^{ns}	2.63^{ns}	2.95^{ns}
D×R		1.50^{ns}	0.05^{ns}	0.23^{ns}	0.08^{ns}	181.06^{**}	0.88^{ns}	0.34^{ns}
D×P		0.21^{ns}	0.28^{ns}	6.52^{**}	4.69^{*}	3.49^{*}	1.29^{ns}	1.98^{ns}
R×P		0.41^{ns}	4.01^{ns}	14.28^{**}	3.11^{ns}	64.22^{**}	1.04^{ns}	0.00^{ns}
D×R×P		0.07^{ns}	1.28^{ns}	0.28^{ns}	1.25^{ns}	7.86^{**}	0.98^{ns}	1.20^{ns}
YA								
	D1	37109 c	16.08 a	39.56 a	635.92 a	252.72 a	6.39 c	53.11 a
	D2	48355 b	15.92ab	38.26 b	608.80 b	248.08 b	7.39 b	53.31 a
	D3	59204 a	15.81 b	37.50 c	592.66 c	241.73 c	7.99 a	53.54 a
	E	47997 a	15.78 b	38.99 a	615.58 a	248.96 a	7.35 a	53.57 a
	W	48449 a	16.08 a	37.88 b	609.34 b	246.06 b	7.16 b	53.07 a
	S	48298 a	15.99 a	38.58 a	616.85 a	248.02 a	7.43 a	52.99 b
	D	48148 a	15.88 a	38.30 a	608.07 b	247.00 b	7.08 b	53.65 a
F-value								
Density (D)		3622.87^{**}	3.07^{ns}	43.76^{**}	102.37^{**}	1222.07^{**}	232.57^{**}	0.74^{ns}
Row spacing (R)		1.18^{ns}	11.53^{**}	36.83^{**}	6.24^{*}	252.75^{**}	10.43^{**}	2.98^{ns}
Plant number (P)		0.47^{ns}	1.58^{ns}	2.47^{ns}	12.36^{**}	31.55^{**}	32.24^{**}	5.22^{*}
D×R		0.74^{ns}	0.87^{ns}	3.90^{*}	9.94^{**}	11.88^{**}	1.25^{ns}	0.29^{ns}
D×P		0.25^{ns}	2.38^{ns}	0.12^{ns}	4.50^{*}	25.21^{**}	2.37^{ns}	1.70^{ns}
R×P		0.00^{ns}	5.71^{*}	6.61^{*}	39.45^{**}	34.70^{**}	1.07^{ns}	0.08^{ns}
D×R×P		0.71^{ns}	1.74^{ns}	2.74^{ns}	13.43^{*}	7.98^{**}	2.44^{ns}	0.75^{ns}

Data are presented as the means of different treatments. Different letters in the same treatment represent significant ($p \leq 0.05$) differences in different test sites. Ns: $p>0.05$, * $p \leq 0.05$, ** $p \leq 0.01$.

DISCUSSION

Increasing plant density is one of the most effective way to close the yield gap between maize production and demand; nevertheless, high plant densities exert an important effect on maize lodging, panicle uniformity, and mechanical harvesting (Wang *et al*., 2012, Liu *et al*., 2011). Therefore, the optimal plant density and cropping pattern should be determined to increase maize yield and to develop mechanized maize production. This experiment used the compact maize hybrid Zhenghong 6 to investigate the effects of different plant densities and cropping patterns. This experiment provides some important findings that are useful in optimizing cropping patterns and developing the mechanization of maize production in Southwest China.

Effect of plant density and cropping pattern on growth characteristics: Increased plant density affects maize growth (Robles *et al*., 2012, Mao *et al*., 2014). In this study, plant density significantly increased plant height (Fig. 2). Maize growth is influenced by numerous synergistic factors, including temperature, photoperiod, and soil conditions (Karasahin, 2014). Cropping pattern negligibly influenced maize plant height in SH and SL and significantly influenced maize plant height in YA (Fig. 2). W and S cultivation are beneficial in improving plant height to attenuate interplant competition. This result indicated that the variation in plant height is mainly caused by plant density, and that a reasonable cropping pattern can improve plant height by decreasing interplant competition under high plant density. Although plant height increased with plant density, no lodging and diseases were found in all experimental sites. Therefore, the compact maize hybrid Zhenghong 6 is suitable for high-density cropping in Southwest China.

LAI is a main physiological determinant of crop yield because green leaves are the major site of photosynthesis (Wang *et al.*, 2015). The average LAI at the SS were 3.7, 3.9 and 3.5 m^{-2} in SH, SL, and YA, respectively (Fig. 3). Although ecological conditions in SH allow for optimal vegetative development (Table 2 and 3), the unusually low precipitation over a prolonged period after the SS affected dry matter production and kernel setting, shortened the grain-filling period, and negatively influenced the final yields. Plant density is the major factor that drove LAI variations in this study, and the highest LAI values were consistently observed at the highest plant density level in all experimental sites (Fig. 3).

Numerous studies have already investigated the effects of plant density on LAI (Dai *et al.*, 2013, Peng *et al.*, 2015); however, the effects of row spacing and number of plants per hole on LAI have not been extensively documented in Southwest China. In the present study, although the overall cropping pattern significantly affected LAI ($p \leqslant 0.05$) only in YA, E and S cultivation consistently produced higher yield than W and D cultivation. Nevertheless, plant density remains an important factor in any row spacing research (Robles *et al.*, 2012). In SL, the higher LAI values achieved under E cultivation than those achieved under W cultivations did not translate into high grain yields, whereas the higher LAI values achieved under S cultivation than those under D cultivation in all experimental sites in this study resulted in high grain yields (Fig. 3 and Table 6). This result indicated that E cultivation effectively increases maize LAI, whereas high LAI does not benefit final grain yield in areas where LAI is high under high plant density (SL). Moreover, S can improve maize LAI, thereby increasing grain yield.

Effects of plant density and cropping pattern on DMA and dry matter distribution: DMA and dry matter distribution in different plant organs are affected by cultivar type, ecological conditions, and cultivation management practices. DMA is affected by low plant density, that is, DMA is low at the population level. This phenomenon affects the production of photoassimilates and the distribution of assimilates in reproductive organs (Antonietta *et al.*, 2014, Mao *et al.*, 2014). The overall maize DMA was higher at the JS and SS in SH, and the highest DMA was observed at the MS in SL. These results indicated that adequate light and temperature in SH are beneficial for DMA in the earlier stages of growth. In addition, abundant nutrients can delay the senescence of maize in SL, consequently increasing DMA in the latter stages of growth.

High yield is associated with DMA before and after the SS (Ma *et al.*, 2014). With the increase in plant density, the DMA in each plant significantly decreased, whereas the DMA at the population level markedly increased in all experimental sites. The populations with high yield exhibited a high DMA at the MS. Therefore, high plant densities likely promote the development of vegetative organs before the SS, especially the transfer of nutrients to reproductive organs after the SS, significantly increasing grain yield. The effects of plant density on dry matter distribution in vegetative organs were significant only in SL, indicating that plant density is the limiting factor for maize growth in SL. Moreover, increased plant height and LAI promoted the inter competition of the maize population in SL. The application of W cultivation favors leaf expansion and distribution under high plant density; thus, the DMA was markedly higher in W than in E at MS in SL.

Effect of plant density and cropping pattern on grain yield: Similar to the trends in DMA, grain yield was noticeably higher in SL (~8.6 $t{\cdot}ha^{-1}$) than in SH and YA (~7.9 and~7.3 $t{\cdot}ha^{-1}$, respectively; Table 6). These substantial differences in grain yields among experimental sites are related to differences in ecological conditions (Fig. 1 and Table 1). The effect of plant density on maize grain yield follows a characteristic curvilinear pattern with an optimum value that is strongly dependent on ecological conditions (climatic conditions, soil conditions, and cultivation management practices) (Robles *et al.*, 2012, Yang *et al.*, 2010, Li *et al.*, 2012). The currently recommend plant densities for modern hybrids in Southwest China range from 45,000 plant ha^{-1} to 55,000 plant ha^{-1} (Dai *et al.*, 2013, Peng *et al.*, 2015). In the present study, plant density significantly affected grain yield, and the highest grain yields were observed at 60,000 plant ha^{-1} in the three experimental sites (Table 6). Moreover, the highest grain yields were associated with the highest plant density.

Although the overall effect of cropping pattern on maize grain yields was significant ($p \leqslant 0.05$) only in YA, S cultivation consistently produced a higher yield than D cultivation (Table 6). The grain yield in SH was influenced by the interaction among row spacing, number of plants per hole, and plant density ($p \leqslant 0.05$). Consistent with our findings, the report of Thelen (Thelen *et al.*, 2006) indicated that grain yield is more likely to change with cropping pattern when crop development is restricted. In the current study, the excessive amounts of precipitation during the early stage of growth restricted the development of the vegetative organs of plants in YA compared with those in SH and SL (Table 6). Therefore, DMA and grain yield were obviously higher under E than under W cultivation in YA under low LAI condition. By contrast, plant height and LAI were the highest in SL, and DMA and grain yield were markedly higher under W than under E cultivation in SL under high LAI condition. These results indicated that grain yield increases with increasing plant density, and that S and W cultivation practices are beneficial for the improvement of maize grain yield under high plant densities in Southwest China.

The sparse planting of maize cultivars with large panicles and tall stalks has been the most common maize planting method in Southwest China for the past 30 years (Yang *et al*., 2010, Qu *et al*., 2013). However, increased plant density and uniform planting patterns have become necessary with the increasing demand for maize and mechanized production. The compact type maize hybrid Zhenghong 6 endures crowding and is resistant to lodging and diseases; planting this cultivar in high density under S and W cultivations not only can increase maize yield but can also promote the development of mechanized maize production by allowing for a uniform planting pattern and maturation.

Conclusion: The plant height, LAI, DMA and dry matter distribution, yield, and yield components of Zhenghong 6, a hybrid maize cultivar, were investigated under field conditions in SH, SL, and YA in Southwest China to explore the effects of plant density and cropping pattern on DMA and yield. The results showed significantly different maize growth characteristics and yield in the three locations. Plant height, LAI, DMA, and grain yield were highest in SL and were lowest in YA. Moreover, plant density had significant effects on maize growth, DMA, and yield. With the increase in plant density, the DMA of each plant obviously decreased, whereas plant height, LAI, DMA, and yield markedly increased. The highest values for these parameters were consistently associated with the highest plant density in all three experimental sites. Furthermore, the DMA and grain yield of S were consistently higher than those of D, and those of W were higher than those of E under high plant densities. Therefore, the grain yield of maize and mechanized maize production in Southwest China could be enhanced by applying S and W cultivation in managing high plant density.

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