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COMPETITIVE INTERACTION BETWEEN MIXED-PLANTING MAIZE CULTIVARS ENHANCED YIELD AND WATER-USE EFFICIENCY IN A SEMI-ARID REGION

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ABSTRACT

Effects of competitive interaction between two mixed planting maize (*Zea mays* L.) cultivars on yield and water use efficiency are inevitable and the positive process needs more excavation. Two maize cultivars were mixed planting in two densities to explicit the potential of competitive interaction improving yield and water use efficiency in a semi-arid region over two growing seasons. During grain filling stage firstly, competitive interaction optimized stem to leaf ratio of two maize cultivars, and decreased root to shoot ratio at harvest under the same-high mixed planting density, great competitive intensity caused by high planting density suppressed vegetative growth of maize. Secondly, land equivalent ratio positively increased from 1.02 to 1.14, which signified the advantage of farming land use. Furthermore, positive values of total actual yield loss in the four mixed systems indicated a yield advantage. Over two years, mean yield and water use efficiency increased by 6.5 % and 11.7 % which resulted from the positive performance of two maize cultivars in the mixed systems. Thus, consequences of competitive interaction in the mixed planting systems performed as land use, maize yield and water use efficiency advantages in the dry land farming.

Keywords: Maize cultivars mixture, competitive parameter, yield and water use efficiency advantage

INTRODUCTION

In the world current cultivation practices, increasing the planting density has been considered as an efficient way to pursue higher grain yield (Rossini et al., 2011a; Dahmardeh 2011; Rossini et al., 2012; Williams and Boydston, 2013), especially for maize in semi-arid region of China (Yang et al., 2011). However, high planting density results in intensive intra-specific competition which involves maize plants to water or nutrient stress, further leads to soil resources imbalance (Yang et al., 2011; Ionenko et al., 2012). This imbalance generally performs as an obstacle to yield production. Furthermore, efficient strategies to utilize the favorable effects of cultivars competitive interaction on soil resources use were rare.

Mixed cropping has the potential of increase grain yield and water use efficiency (WUE) of maize (Fan et al., 2013), the responsible reasons are better intercept of solar energy by canopy structure (Awal et al., 2006), and greater soil microenvironment adaptation by spatial distribution and capacity of roots improved in a mixed system (Caballero et al., 2001; Rossini et al., 2011; Peng et al., 2012). Furthermore, competitive interaction among maize cultivars can help to reduce undesired impacts on biomass production and water use (Morris and Garrity, 1993; Weigelt and Jolliffe, 2003; Nassab et al., 2011), biomass allocation into vegetative parts and grains plays an important role in mixed planting system (Mushagalusa et al., 2008; Nassab et al., 2011; Lithourgidis et al., 2011). But, the relationship among cultivars competition, grains production and WUE are only partially understood in semi-arid farming region (Acciaresi and Guiamet, 2010). And, selection of suitable components with suitable plant density in a mixed cropping system needs more field testing (Lithourgidis et al., 2011).

The utility of competitive parameters for evaluating cultivars properties has been efficiently arranged in the intercropping system (Weigelt and Jolliffe, 2003), however, assessing the contribution of competitive interaction combined with biomass allocation investigation catches less attention (Jaggi et al., 2004; Acciaresi and Guiamet, 2010). Meanwhile, competition is a long-term process and influenced by planting density, resource levels and phonological condition of maize growing (Weigelt and Jolliffe, 2003). Competition for soil resource usually behaves as a constraining to crop production (Burton 1993). Furthermore, competition interaction can be separated by the stage of maize development at which the different competitive intensity occurs, and then the temporal distinction determines which resources can limit maize growth (Braconnier 1998; Adiku et al., 2001; Page et al., 2010). Increased availability of soil resource can mitigate the competition intensity among mix-cultivated species (Schenk, 2006). An early increase in crop growth variability and the further stable development probably attributes to the variability of competitive interaction in different resource and cultivation condition (Thorsted et al., 2006; Rossini et al., 2012). Thus, in a mixed system, any parameters applied alone fundamentally limits its accuracy to evaluate the complexity of crop competitive properties from temporal and spatial (Burton, 1993; Williams and Boydston, 2013). Previous studies have primarily focused on analyzing the competition when legumes and cereals intercropped (Zhang and Li, 2003; Li et al., 2011). But, few of them, to our knowledge, exist in maize cultivars mixed planting system.

The objectives of our research were to (1) investigate the improvement of biomass allocation into leaves, stem and roots and then (2) to compare several competitive parameters between two mixed planting maize cultivars, finally, aim to test the hypothesis that maize cultivars' competitive interaction could provide a yield and WUE advantage in a mixed system.

MATERIALS AND METHODS

Location and environmental background

Field experiment was performed on spring maize during 2011 and 2012 at the Chang Wu Agro-ecological Experimental Station (35°12′30″ N, 107°40′30″ E, altitude 1200 m) of the Chinese Academy of Sciences located in the south-central area of the Loess Plateau, a typical semi-arid region. The soil is classified as Cumuli-Ustic Isohumosols, according to the Chinese Soil Taxonomy system (Gong et al., 2007). Zero - 20 cm soil profile had a pH 8.4 and soil bulk density of 1.3 g cm^{-3}, and organic matter, total nitrogen, available phosphorus and exchangeable potassium contents in 0 - 20 cm soil were 11.8 g kg^{-1}, 0.9 g kg^{-1}, 14.4 mg kg^{-1} and 144.6 mg kg^{-1}, respectively. The temperate semi-humid and semi-arid monsoon climate had a mean annual temperature of 19.0 ℃ and a 50-year mean precipitation of 421.9 mm during maize growing period (from May to Sep).

Characteristics of the two maize Cultivars

Two maize cultivars were selected: Zhengdan 958 (Z958, represented by Z) and Shendan 16 (S16, represented by S). Z958 is a density tolerant and resistant to drought, lodging and disease as a modern popular cultivar, due to its low plant height, tightly assembled leaves and short internodes, which support a high grain yield and WUE in semi-arid farming region.

S16 as an old cultivar is characterized by higher plant shoot, stocky stem, wide and thick leaves and larger root system. These characteristics require much more energy and resources to achieve normal development, which are limited in the dry climate and harsh environment of the Loess Plateau, S16 plants thus often suffer lodging due to higher height.

Experimental design and plot arrangement

Field experiment contained two maize cultivars (Z958 and S16), two planting methods (mixed crop and monoculture) and two planting densities (45000 / 75000 plants. ha^{-1}, represented as 1 / 2). Seeds were sown at April 20, 24 and harvested at September 15, 20 in 2011 and 2012, respectively. All of the plots were 5 x 5 m (25 m^2) and arranged in a split block design with three replicates. Each plot contained 10 rows (0.5 m row space and 5 m length), mixed systems of Z958 / S16 (Z / S) with row ratio of 6: 4 (Z: S = 6: 4) were established and made sure two adjacent rows with two different maize cultivars. Two maize cultivars in each plot were mixed-sown in pair rows alternate. Four mixed treatments are abbreviated as Z1S1, Z1S2, Z2S1 and Z2S2. Pure stand of the two cultivars at both planting densities were served as controls (i.e. CK- Z1, Z2, S1 and S2). Before seeds sowing, basal fertilizer arranged as 240 kg N ha^{-1} as urea (46% N), 120 kg P_2O_5 ha^{-1} as superphosphate (17%, P_2O_5) and 90 kg K_2O ha^{-1} as potassium sulfate (54%, K_2O), then scattered fertilizers uniformly in each plot then ploughed into 0-30 cm soil layer. All of the plots received 90 kg N ha^{-1} as urea at the jointing stage using a hole-seeding machine. No irrigation and weeds were controlled by hands.

Shoot and root samples collection

Three adjacent maize plants in the same row were selected randomly and cut to ground level from tasseling to waxy stages (Table 1), separated-leaves and stems were heated initially at 105ºC for 30 min and then dried to a constant weight at 80 ºC, weighted as the leaves and stem dry matter, shoot dry matter calculated by the sum of two parts.

Table 1. Sampling date of maize aboveground biomass

Experimental year	Tasseling stage	Grain filling stage	Milking stage	Waxy stage
2011	10th, Jul	25th, Jul	23th, Aug	11th, Sep
2012	15th, Jul	2nd, Aug	25th, Aug	9th, Sep

The soil cores position located between rows, between plants and at the plants (Fig.1), soil samples were sampled with a root auger (9 cm in diameter and 10 cm in height) at 10 cm interval to a maximum depth of 100 cm, then washed in baskets packed with spun yarn and dried to a constant weight at 80 ºC, the total root dry weight was then determined for calculating the root to shoot rate (Xia et al., 2013).

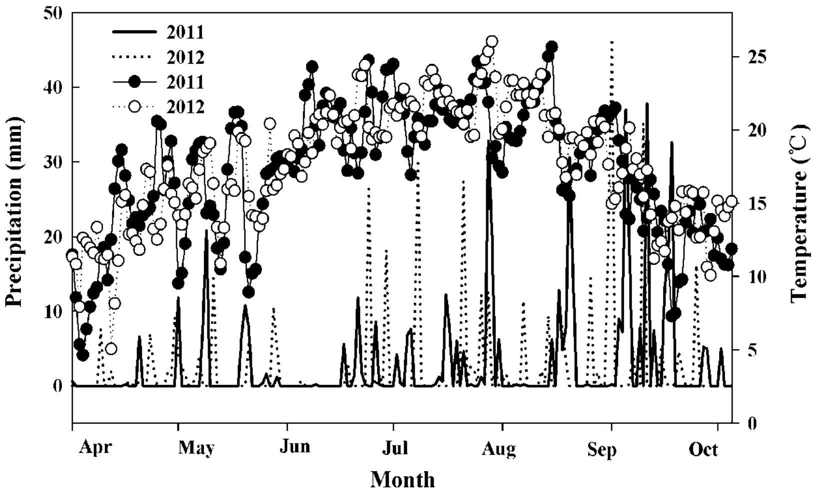

Figure 1. The daily precipitation and temperature during the two maize growing seasons, daily precipitation of 2011 (full line) and 2012 (dotted line); daily temperature of 2011 (close circle) and 2012 (open circle).

Grain yield and water consumption calculation

Grain yield (GY) was estimated from all consecutive plants within a 5.0 m^2 of the middle two rows in each plot. All ears were manually collected and grains adjusted to 15% moisture as GY. Soil water storage (SWS), evapotranspiration (ET) and water use efficiency (WUE) in the intercropped treatments was calculated using the following formulas (Fang et al., 2014):

$$SWS = SWC \times SD \times SBD$$

(1)

$$ET = SWS_S - SWS_H + Pi$$

(2)

$$WUE = \frac{GY}{ET}$$

(3)

SWC means soil water content. SD and SBD mean soil depth and soil bulk density, respectively. SWS_S and SWS_H mean the initial and final soil water storage, P_i is the precipitation during the maize growing period.

SWC was measured gravimetrically and soil samples collected between the two middle rows (planted two different maize cultivars) in each plot using a soil auger at 10 cm interval to a depth of 100 cm and at 20 cm interval to a depth of 100-200 cm, and instantly packed into aluminum specimen boxes which were weighed before and after dried at 105 ºC for 24 h to determine the SWC. Daily precipitation and temperature during the two growing seasons recorded using the local automatic weather station and showed in Fig. 1.

Calculation of growing and competitive parameters

Growing parameters as stem to leaf rate (SLR) and root to shoot rate (RSR) were calculated using the following formulas (Prince et al., 2001):

$$SLR = \frac{B_S}{B_L} \qquad RSR = \frac{B_R}{B_H}$$

(4)

B_S, B_L, B_R and B_H mean the biomass of stems, leaves, roots and shoots, respectively.

Land equivalent ratio (LER) represents the advantage of a mixed stand and indicates the environmental resource use efficiency in mixed cropping system compared with sole cropping. When $LER_{Z\ or\ S} > 0.5$ or $LER_{ZS} > 1$, mixed cropping system will have the growth and yield advantage. When $LER_{Z\ or\ S} < 0.5$ or $LER_{ZS} < 1$ means the opposite results, LER is calculated by the formulas (Ren et al., 2016):

$$LER_{ZS} = LER_Z + LER_S \qquad LER_Z = \frac{Y_{zi}}{Y_z}$$

$$LER_S = \frac{Y_{si}}{Y_s} \qquad (5)$$

Y_Z and Y_S mean the yields of Z958 and S16 in sole crops; Y_{Zi} and Y_{Si} are the yields of Z958 and S16 in mixed crop.

Competitive ratio (CR) represents the ratio of the individual LER of the two component crop and reflects the proportion of each crop within the population in which it is initially sown. CR is calculated using the following formulae (Mead and Willey, 1980):

$$CR_Z = \left(\frac{LER_Z}{LER_S}\right)\left(\frac{Z_{si}}{Z_{zi}}\right) \qquad CR_S = \left(\frac{LER_S}{LER_Z}\right)\left(\frac{Z_{zi}}{Z_{si}}\right) \qquad (6)$$

Where Z_{Zi} is the sown proportion of Z958 in the mixture, and Z_{Si} is the sown proportion of S16 in the mixture.

Aggressivity (A) is used to indicate degree of the relative yield increase in crop Z958 compared with that of crop S16 in mixed cultivation. A is derived from the following equations (Agegnehu et al., 2006):

$$A_Z = \left(\frac{Y_{zi}}{Y_z Z_{zi}}\right) - \left(\frac{Y_{si}}{Y_s Z_{si}}\right) \qquad A_S = \left(\frac{Y_{si}}{Y_s Z_{si}}\right) - \left(\frac{Y_{zi}}{Y_z Z_{zi}}\right) \qquad (7)$$

Actual yield loss (AYL) is the proportionate loss or gain in yield of mixture compared with that in respective monoculture. In addition, partial actual yield loss (AYL_Z or AYL_S) represents the proportionate loss or gain in yield of each cultivar when it is grown as a mixed pattern compared with its yield in a pure stand. The AYL is calculated by (Mead and Willey, 1980; Lithourgidis et al., 2011b):

$$AYL_{ZS} = AYL_Z + AYL_S \qquad AYL_Z = \left[\left(\frac{Y_{zi} / Z_{zi}}{Y_z / Z_z}\right)\right] - 1$$

$$AYL_S = \left[\left(\frac{Y_{si} / Z_{si}}{Y_s / Z_s}\right)\right] - 1 \qquad (8)$$

Statistical analysis

Treatment means exhibiting significant differences among cultivars, mixed planting and monoculture were separated using one-way ANOVA in SPSS 17 at $P \le 0.05$ or the least significant difference (LSD) test at $P \le 0.05$.

RESULTS

Dynamic change of daily mean temperature and precipitation for the study period are presented in Figure 2.

For the Chang Wu Agro-ecological Experimental Station site of Chinese Academy of Science, the 50-year annual average precipitation is 578 mm and almost 73% occurs from May to Sep (the entire growth period). Growing seasons were wetter in 2011 and dryer in 2012, with 11.6% (2011) more and 14% (2012) less in precipitation than the long-term mean.

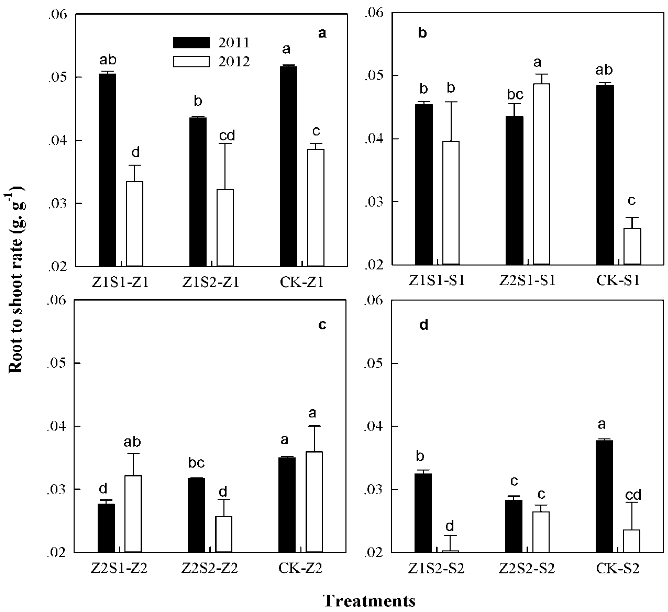

Figure 2. Root to shoot ratio between the mixed and mono-cropping treatments at harvest over two years, the data represents as 2011 (black bar) and 2012 (white bar), respectively, calculated on the basis of total dry matter of shoot and root at harvest. Different lowercase letters above the histogram bars indicated the significant differences ($P < 0.05$) of maize cultivar under mixed and pure planting with the same density over two years.

Stem to leaf ratio (SLR) and root to shoot ratio (RSR)

Mixed planting arrangement resulted in SLR of two maize cultivars increase in Z1S1 and Z1S2 then reached a maximum at grain filling stage and subsequently decreased (Table 2). Compared with sole cropping, SLR of maize cultivar in mixed cropping system increased when the planting density of mixed partner increased. While the two maize cultivar mixed planting with different densities (i.e. Z1S2 and Z2S1), SLR increased by 34% before milking stage, and then decreased by 12% averagely after grain filling stage compared with sole crops. However, SLR of two mixed maize in Z1S1 was enhanced by 24% averagely before milking stage, and that in Z2S2 decreased by 22% averagely during grains filling. Furthermore, SLR of Z958 exceeded S16 in Z1S1, and became lower than S16 in Z2S2.

Mixed planting gave lower RSR of two maize cultivars compared with sole cropping, and associated with mixed planting density. Especially at higher plant density, RSR of two maize cultivars in Z2S2 decreased significantly compared with controls (Fig. 2). RSR of Z958 decreased significantly when it mixed with high planting density of S16. But, RSR of S16 showed lightly variation when mixed planting density of Z958 increase. And, in 2012, RSR of S16 increased significantly at 45000 plants ha^{-1} and that of Z958 decreased when they were mixed planting (Fig. 2 b).

Changes of competitive parameters between two mixed maize cultivars

Land equivalent ratio (LER_{ZS}) was greater or equal to unity in mixed planting systems Z2S1 (1.05) and Z2S2 (1.07) averaged over two years, indicated a slight land use advantage in Z958/S16 mixed planting. Partial LERs in Z2S1 and Z2S2 was 0.54 and 0.57 in 2011, Partial LER z was 0.68 and 0.58 in 2012, which were greater contribution to mixed systems' LER (Fig. 4). Compared LERz with LERs over two years, we demonstrated that increase mixed planting density of one maize cultivar limited partial LER of its partner.

The results of competitive ratio (CR) conformed to those of aggressivity (A) (Fig. 4 & 5). S16 was the dominant cultivar (CR_S and A_S, positive) in four mixed planting systems of Z958 / S16. Over two years, in the mixtures CRs and As were higher than the corresponding values of CR_Z and A_Z.

Table 2. Stem to leaf ratio at four growing stages over two years

Treatments	**Stem to leaf ratio (g g^{-1})**			
	Tasseling stage	**Grain filling stage**	**Milking stage**	**Waxy stage**
Z1S1-Z1	1.84 ± 0.17 b	2.39 ± 0.13 a	2.10 ± 0.22 a	2.04 ± 0.13 a
Z1S2-Z1	2.24 ± 0.33 a	2.44 ± 0.22 a	1.95 ± 0.26 a	1.82 ± 0.11 a
CK-Z1	1.56 ± 0.13 b	1.97 ± 0.23 b	2.17 ± 0.10 a	1.85 ± 0.08 a
LSD ($p \leq 0.05$)	0.64	0.37	0.32	0.27
Z1S1-S1	1.98 ± 0.12 a	2.34 ± 0.13 a	2.42 ± 0.17 a	1.88 ± 0.15 a
Z2S1-S1	1.94 ± 0.03 a	2.24 ± 0.05 a	2.24 ± 0.14 a	1.79 ± 0.06 a
CK-S1	1.68 ± 0.13 b	2.19 ± 0.13 a	2.19 ± 0.25 b	1.78 ± 0.07 a
LSD ($p \leq 0.05$)	0.29	0.36	0.20	0.24
Z2S1-Z2	1.73 ± 0.06 a	1.86 ± 0.09 b	2.00 ± 0.10 a	1.67 ± 0.11ab
Z2S2-Z2	1.87 ± 0.14 a	2.05 ± 0.18 a	1.82 ± 0.17 a	1.59 ± 0.08 b
CK-Z2	1.72 ± 0.14 a	1.88 ± 0.13 b	2.07 ± 0.25 a	1.86 ± 0.12 a
LSD ($p \leq 0.05$)	0.38	0.24	0.36	0.23
Z1S2-S2	1.76 ± 0.08 b	2.03 ± 0.30 b	1.68 ± 0.22 b	1.67 ± 0.16 b
Z2S2-S2	2.04 ± 0.23a	2.05 ± 0.15 ab	1.86 ± 0.14 ab	1.84 ± 0.16 b
CK-S2	1.92 ± 0.12 ab	2.24 ± 0.22 a	2.12 ± 0.11 a	2.40 ± 0.16 a
LSD($p \leq 0.05$)	0.33	0.21	0.29	0.43
Cultivars	NS	NS	*	NS
Densities	*	*	*	*
Cultivar × density	*	*	*	*

*significant and ^{NS} non-significant difference among the four growing stages, values (mean ± SE) followed different letters in a column indicated significant difference among mixed and monoculture with the same cultivar and planting density ($p < 0.05$).

A similar trend to that of CR and A was also observed for actual yield loss (AYL). AYL_S was positive and increased with own mixed planting density increase, decreased with planting density increase of mixed partner. Over two years, AYLs slightly decreased but AYLz increased significantly (Fig. 6 a). Firstly, higher grain yield was noted at greater AYL (0.17 and 0.39, averaged of two years), increased by the range of 14 - 71% in Z1S2 and Z2S2 (Figure 6 b). Lower AYL (-0.02 and -0.03) had a negative effect to mixed system grain production in Z1S1 and Z1S2.

Grain yield (GY) and water use efficiency (WUE)

Mixed planting density showed positive effect on the GY and WUE of mixed systems. Compared with pure stands, yields of Z2 in Z2S1 and S2 in Z1S2 had greater values than sole crops, but S1 and Z1 showed negative effects on the GY of mixed system, which generally limited the mixed planting advantage, a similar trend conformed to WUE of two maize cultivars when mixed planting (Table 3). High mixed planting density of Z958 / S16 had an advantage of GY and WUE due to the positive increase rate of both mixed maize cultivars. GY of Z958 / S16 in Z2S2 increased concurrently and caused a 6.5% increase in GY of Z2S2 system compared with that in sole crops. WUE of Z958 / S 16 in Z2S2, average of two years, increased apparently by 6.9% and 16.6% respectively compared with sole crops, resulted in an 11.7% increase in WUE of Z2S2. However, in Z1S2 and Z2S1, WUE of S2 and Z2 obtained positive increase companied with that negative increase in Z1 and S1, this phenomenon reduced the competitive advantage. Finally, Z958 showed more stable WUE and S16 with more stable GY over four mixed systems.

DISCUSSION

Grain production and WUE response to mixed cropping practices

Maize cultivars mixture increased GY and WUE by 6.5 % and 11.7 % averagely over two years at high mixed planting density due to the positive effect of competitive interaction (Table 3). Even though under the situation as Li et al. (2015) reported: high density planting resulted in a shortage of resources and then restricted normal growth of crop plants, as an alternative, mixed crops could be an economical and environmental promise for sustainable and stable crop production under adverse growing condition (Lithourgidis et al., 2011; Dahmardeh 2013; Fang et al., 2014). Mixed planting significantly improved shoot and roots growth (Li et al., 2015), better for exploit the available soil resources (Yang et al., 2013), attributed to positive mixed interaction (Rossini et al., 2011). However, GY and WUE decreased occasionally when two wheat cultivars mixed in the same low or different densities that could be attributed to unbalanced competitive interaction between component lines (Fang et al. 2014), furthermore, for higher yield and WUE in mixed cultivation, climate risk, cultivation habits and farmers' preference should also be taken into consideration (Temesgen et al., 2015).

Biomass allocation response to mixed cropping

The observed increase of stem to leaf ratio (SLR) under low mixed planting density could be attributed to competition for growing space between two maize cultivars, and SLR decreased under high mixed planting density was attributed to the limited growing space compared with sole cropping, grain filling stage was the demarcation point for SLR variation (Table 2), just like previous research reported (Zhang et al., 2011). Planting density plays an important role to dry matter allocation in maize / soybean when they were intercropped (Ren et al., 2016). In contrast, Van et al. (2002) demonstrated that dry matter allocation between leaf blade and stem fraction in pearl millet was not affected by plant density and most of that was allocated into leaves before filling stage. SLR increased before grain filling and decreased after that in our mixed cropping system, just for supporting much more dry matter production and transferring into grains which consistent with (Seran and Brintha, 2010; Zhang et al., 2011). Seran and Brintha (2010) consfirmed that two species mixture could cause positive interaction which improved the biomass allocated into leaf and root, but being ignored for many years. Biomass allocation associated with final grain yield, and important for understanding plant strategies for resources use in mixed planting system (Zhang et al., 2012).

In many cases, it had been reported that dynamic of crop roots growth and spatial distribution, a fundamental process to uptake and transfer solutes, connected with the dynamic of shoot biomass accumulation (Dubrovsky and Forde, 2012; Xia et al., 2013). This connection was regarded as a crucial role in crops mixed planting and productive potential construction (Hauggaard-Nielsen et al., 2006; Dubrovsky and Forde, 2012). Mixed competition for resource uptake firstly remained the proportions of leaves and then ensured shoot and roots growing in a relative equilibrium (Wilson, 1988b), through adjusting root-shoot biomass allocation (Zhang et al., 2012). In the present study, RSR decreased in mixed system, especially with high planting density (Fig.3), i.e. limiting root redundant growth while improved canopy structure, better for reducing root consumption and useless leaf transpiration (Li et al., 2015). Furthermore, Wilson (1988a) confirmed that competitive interaction in roots had a greater influence on crop yield compared with that in shoots (Li et al., 2006; Li et al., 2011), root development under a competitive environment was vital for diverse resources uptake (Blackman and Davies, 1985; Westgate and Boyer, 1985; Zhang et al., 2012), such as water uptake from root zones (Adiku et al., 2001; Neykova et al., 2011). Increasing planting density strengthened intra-specific competition then decreased biomass allocation to the roots, but increased allocation to the panicles (Li et al., 2015), and showed no negative effects on shoots growing on our results.

Table 3. The grain yield and *WUE* under different cropping patterns

Treatments		Yield ($\times 10^3$ kg ha^{-1}) 2011	2012	Mean	System	WUE (kg ha^{-1} mm^{-1}) 2011	2012	Mean	System
Z1S1	Z1S1-Z1	9.11±0.19 b	13.87±1.62 a	11.49 (-6.35%)	11.49	25.81±0.54 b	40.16±7.58 a	32.99 (-4.10%)	32.97
	Z1S1-S1	9.15±0.74 b	13.83±1.57 a	11.49 (-10.51%)		25.91±2.08 b	40.04±4.55 a	32.98 (-5.28%)	
Z1S2	Z1S2-Z1	8.78±0.22 b	14.31±1.09 a	11.55 (-5.86%)	12.99	23.76±0.59 b	40.44±3.14 a	32.10 (-6.69%)	35.15
	Z1S2-S2	13.17±0.49 a	14.43±0.32 a	13.80 (1.85%)		35.61±1.33 b	40.77±7.42 a	38.19 (2.52%)	
Z2S1	Z2S1-Z2	14.07±0.23 a	13.71±1.98 a	15.39 (16.24%)	12.49	40.1±0.65 b	45.28±5.38 a	42.69 (20.97%)	35.90
	Z2S1-S1	8.41±0.20 b	13.63±1.37 a	10.52 (-18.07%)		23.97±0.56 b	34.24±3.71 a	29.11 (-16.40%)	
Z2S2	Z2S2-Z2	12.49±0.55 a	14.06±1.32 a	13.28 (0.30%)	14.28	35.41±1.56 b	40.05±4.90 a	37.73 (6.91%)	40.58
	Z2S2-S2	13.78±0.60 b	16.78±1.22 a	15.28 (12.77%)		39.04±1.70 b	47.80±3.47 a	43.42 (16.56%)	
LSD ($p \leq 0.05$)		0.78	3.22	1.61	2.64	2.19	5.12	4.56	6.84
Cultivars		*	NS	*		*	NS	NS	
Densities		*	*	*		*	*	*	
Cultivars × Densities		*	*	*		*	*	*	

The values (mean ± SE) followed by different letters in a row means significant difference between two years. Relative increase rate (%) calculated by the means across two years under mixed planting comparing to controls, the difference of yield and *WUE* among four combinations / controls were evaluated at by LSD ($p < 0.05$).
*, significant at $P < 0.05$; NS, non-significant

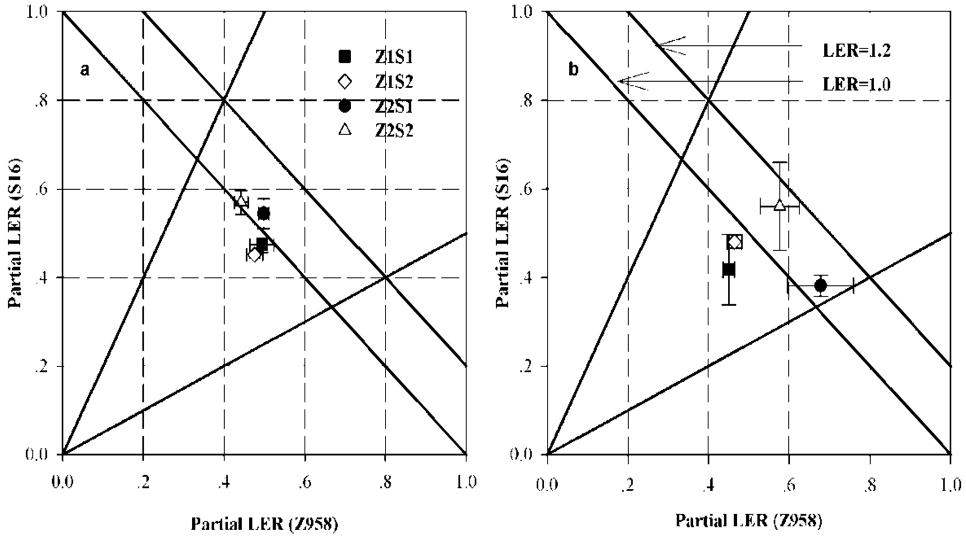

Figure 3. Partial land equivalent ratio (partial LER) of the two maize cultivars mixed planting in 2011(a) and 2012 (b). The diagonal lines show the land equivalent ratio (LER), the above area of diagonal lines of LER=1(1.2) represent there is mixing advantage according to grain yield. The two lines (the left and bottom line indicate partial LER of S16 and Z958) crossing the *x-y* coordinate 0-0.5 indicates a 50% to 50% balanced use of environmental sources for grains growth by S16 and Z958, values are the mean±SE (n=3).

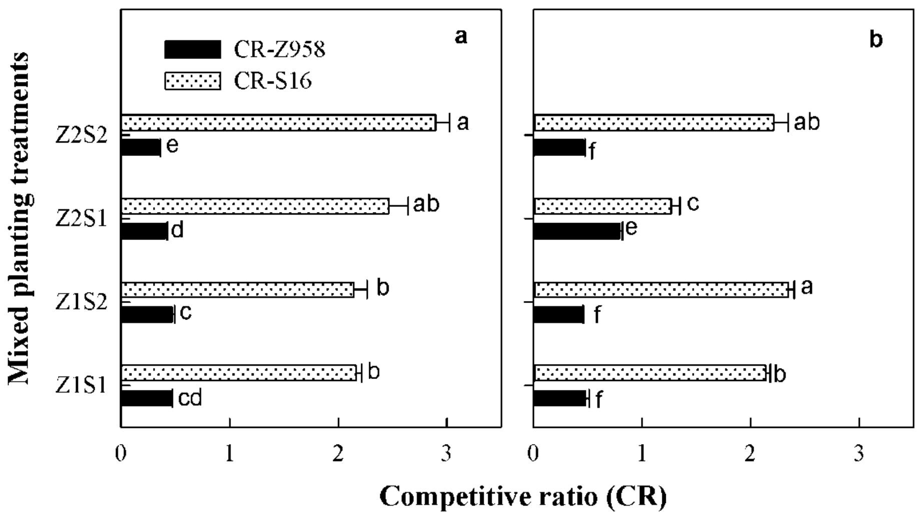

Figure 4. Competitive ratio (CR) of two maize cultivars in four mixed combinations over two years (2011, a; 2012, b), CR-Z958 showed in black bars and CR-S16 in dotted bars, the different lowercase letters in the bars means significant differences between CR z and CRs in two growing seasons, respectively.

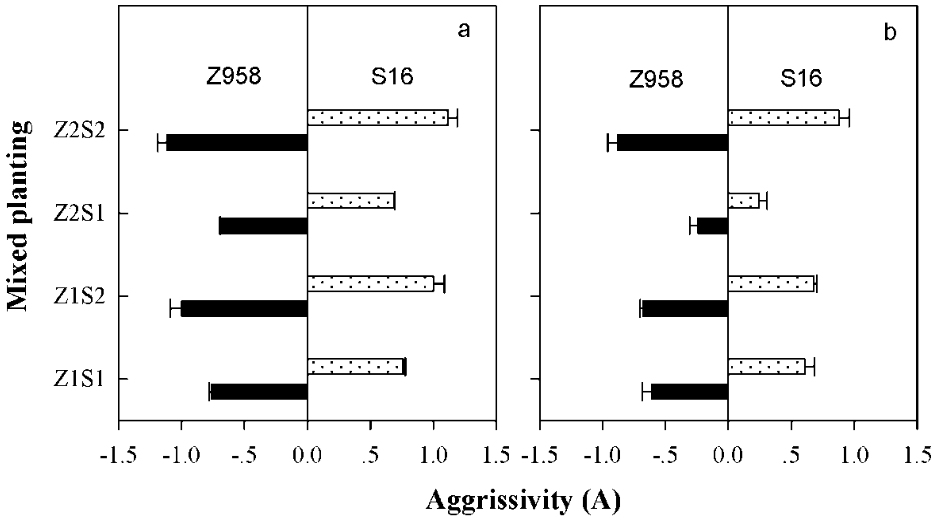

Figure 5. Aggressivity (A) between Z958 and S16 in four mixed planting patterns over two years (2011, a; 2012, b), Z958 represents as left part (black bar), S16 represents as right part (dotted bar).

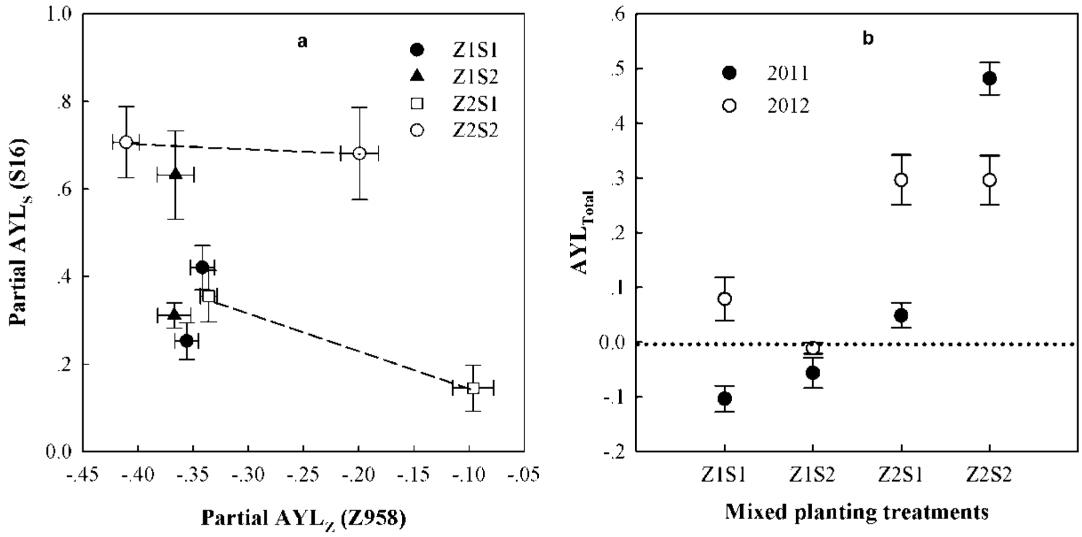

Figure 6. Partial actual yield loss (partial AYL) of two maize cultivars in four mixed combinations (a), and total AYL (AYL $_{total}$, b) of that over two years, close circle, 2011; open circle, 2012. The two dash lines (a) indicated the changes of partial AYL of two maize cultivars from 2011 to 2012, the dotted line (b) means AYL $_{total}$ = 0, values above- and below the line mean having- or non-mixed advantage.

Mixed competition based on grain yield production

Competitive parameters, i.e. LER, A, CR and AYL calculated basis on grain production can provide detailed information on mixed competition (Ren et al., 2016), the competitive dynamics were significantly affected by plant density and sowing proportions (Nassab et al., 2011). In the cases of Z2S1 and Z2S2, total LER were higher than 1.00 over two years, which showed a yield advantage of mixed planting over sole crops (Fig. 4), due to better land utilization and better use of environmental resources for plants growth (Jaggi et al., 2004; Lithourgidis et al., 2011). Partial LER generally associated with the mixed density of synergic cultivar increasing, these findings are in agreement with that of Polthanee and Kotchasatit (1999), Weigelt and Jolliffe (2003) and Nassab et al. (2011), total LER values of high density mixed systems were 1.02-1.14, which means 2-14% land using advantage in mixed planting systems (Z2S1 and Z2S2).

Planting densities influence the competitive intensity (Li et al., 2015; Ren et al., 2016), the comparison of partial CR, A and AYL values clearly indicated that S16 as dominant cultivar when mixed planting with Z958, attributed more positive effects to systematic GY and WUE. In all mixed treatments, partial CRs and As values were greater than CRz and Az which indicated a greater competitive capacity of S16 to exploit resources (Fig. 5 & 6). Furthermore, planting density showed positive effects on the two indices increase, i.e. competitive intensity had the potential to realize mixed planting advantage (Lithourgidis et al., 2011a and 2011b). Similarly, over two years, positive values of AYLs generated a great contribution to the GY and WUE of mixed systems compared with AYLz (Fig.6), total AYL of Z2S1and Z2S2 were 0.18 and 0.39, i.e. a 18% and 39% increase in GY compared with that of sole cropping. Overall, integrated considering LER, CR, A and AYL indices, greater GY and WUE advantages of 6.5% and 11.7% were proved positively in Z2S2 due to better utilization of growth resources and optimization of biomass allocation in leaves, stems and roots. Competitive interaction adjusted the below- and aboveground relationship, weaken the negative interaction between the two maize cultivars (Awal et al., 2007; Nassab et al., 2011; Li et al., 2015), eventually increased the grains production and WUE.

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