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YIELD AND YIELD ADJUSTMENTS OF NON-PROLIFIC MAIZE HYBRIDS IN RESPONSE TO PLANT POPULATION DENSITY

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ABSTRACT

Response of maize (*Zea mays* L.) grain yield to plant population density is depended on the sensitivity of each grain yield component to changes in plant population density. To determine the effect of plant population density on yield components and their role in yield adjustment in non-prolific maize hybrids, the present experiment was conducted at Koushkak Agricultural Research Station (30° 7′ N, 52° 36′ E) of Shiraz University, Shiraz, Iran. Three non-prolific maize single cross hybrids, 'SC108' (very early maturity hybrid), 'SC301' (early maturity hybrid) and 'SC604' (normal maturity hybrid) were sown at four plant population densities, 5.56, 6.67, 8.33 and 11.11 plants m^{-2} in a randomized complete block design, arranged as split-plot with four replicates, in 1995. The results showed that optimum plant population density (plant population density which resulted in maximum grain yield) was 11.11 plants m^{-2} for 'SC108' and 'SC301', and 8.33 plants m^{-2} for 'SC604'. Estimated optimum plant population density was 12.28, 9.98 and 9.31 plants m^{-2} for 'SC108', 'SC301' and 'SC604', respectively. Plant population density did not affect the duration of grain filling period in any hybrids. However, the rate of grain filling was significantly altered by change in plant population density. Increasing plant population density up to 11.11 plants m^{-2} in 'SC108' and up to 8.33 plants m^{-2} in two other hybrids significantly

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increased the rate of grain filling. Moreover, increasing plant population density up to 11.11 plants m^{-2} in 'SC108' increased leaf area index (LAI) throughout the growing season. However, in 'SC301' and 'SC604' increasing plant population density from 8.33 to 11.11 plants m^{-2} did not increase significantly LAI. Results of the present investigation showed that the response of grain yield to plant population density was similar to those of LAI and rate of grain filling. Kernel number per ear, and kernel number per ear row, were found to be the most important yield components in response to plant population density in these non-prolific hybrids. Weight per kernel and ear number per plant had a negligible effect on yield adjustment.

Key words: Maize, Plant density, Grain yield.

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عملکرد و تنظیم عملکرد هیبریدهای ذرت تک بلالی در واکنش بـــه تراکم بوته

منوچهر دستفال، یحیی امام و محمد تقی آساد

به ترتیب پژوهشگرمرکز تحقیقات کشـاورزی فـارس و دانشـیاران بخـش زراعـت و اصـلاح نباتات دانشکده کشاورزی دانشگاه شیراز ، شیراز ، جمهوری اسلامی ایران .

چکیده

پاسخ عملکرد دانهٔ ذرت به تراکم بوته، به حساسیت هر یک از اجزاء عملکرد نسبت بـه تغییر تراکم وابسته است. به منظور بررسی پاسخ عملکرد و اجزای عملکـرد دانـه در هیبریدهـای ذرت تـک بلالی نسبت به افزایش تراکـم بوتـه و تعییـن نقـش هـر یـک از ایـن اجـزا در تنظیـم عملکـرد دانـه در تراکم های مختلف بوته، پژوهش حاضر در ایستگاه تحقیقاتی دانشـکده کشـاورزی دانشـگاه شـیراز واقع در منطقه کوشکک ('۷ و °۳۰ شـمالی و '۳۶ و °۵۲ شـرقی) اجـرا گردیـد. در ایـن پژوهـش سـه هیبرید ذرت دانــه ای 'SC108' (خیلـی زود رس) ، 'SC301' (زود رس) و 'SC604' (متوسـط رس) در چهار تراکم ۵/۵۶ ، ۶/۶۷ ، ۸/۳۳ و ۱۱/۱۱ بوته در متر مربع در یک آزمایش کرتهـای خـرد شده در قالب طرح بلوک های کامل تصـادفی و در چهـار تکـرار در سـال ۱۳۷۴ مـورد مطالعـه قـرار گرفت. نتایج بدست آمده نشان داد که حداکثر عملکرد دانـه در هیبریدهـای 'SC108' و 'SC301' در تراکم ۱۱/۱۱ بوته در متر مربع و در هیبرید 'SC604' در تراکم ۸/۳۳ بوته در متر مزبع بدسـت آمـد. تراکم مطلوب تخمینی برای هیبریدهای 'SC108' ، 'SC301' و 'SC604' بـترتیب ۱۲/۲۸، ۹/۹۸، و ۹/۳۱ بوته در متر مربع بود. بنابراین، در تراکمهای زیادتر از ۱۱/۱۱ بوته در متر مربـع تنهـا عملکـرد دانهٔ هیبرید خیلی زودرس اندکی افزایش خواهد یافت. در کلیهٔ هیبریدها تراکم بوته تـأثیر چندانـی بـر

طول دورهٔ پر شدن دانه نداشت ولی آهنگ پرشدن دانه را تحت تاثیر قرار داد، به نحوی که در هیبرید ' SC108 افزایش تراکم تا ۱۱/۱۱ بوته در متر مربع و در هیبریدهای ' SC301 'و ' SC604 ' افزایش تراکم تا ۸/۳۳ بوته در متر مربع موجب افزایش معنی دار آهنگ پرشدن دانه شد. همچنین افزایش تراکم تا ۱۱/۱۱ بوته در متر مربع موجب افزایش شاخص سطح برگ (LAI) هیبرید بسیار زودرس در تمام طول فصل رشد شد. در هیبریدهای زودرس و متوسط رس، افزایش تراکم از ۸/۳۳ تا ۱۱/۱۱ بوته در متر مربع با افزایش معنی دار شاخص سطح برگ همراه نبود. بر اساس نتایج این آزمایش، پاسخ عملکرد دانه در واحد سطح نسبت به افزایش تراکم بوته مشابه واکنش شاخص سطح برگ و آهنگ پرشدن دانه نسبت به افزایش تراکم بوته بود. از بین اجزای عملکرد دانه، تعداد دانه در بلال و تعداد دانه در ردیف بلال با افزایش تراکم بوته بیشترین تغییرات را نشان دادند و در نتیجه، مهمترین نقش را در تنظیم عملکرد دانه برعهده داشتند. تغییرات وزن دانه و تعداد بلال در بوته نسبت به افزایش تراکم بوته ناچیز بود. نقش این اجزا در تنظیم عملکرد دانه در تراکم های مختلف قابل چشم پوشی بود.

INTRODUCTION

As plant population density increases, the grain yield of individual maize plant decreases due to decrease in some of the grain yield components. In contrast, yield per unit area rises with increasing plant population density to a maximum value at optimum plant population density. Therefore, there is a yield adjustment strategy controlled by the yield components. Tetio-Kagho and Gardner (14) reported that in prolific hybrids, kernel number per ear (KNE), kernel number per ear row (KNER), and ear number per plant (ENP), in the order given, were the most important yield adjustment components in response to plant population density. Mean kernel weight was relatively stable across plant population densities (14). According to Stringfield and Thatcher (13) kernel-row number per ear (KRNE) did not change when plant population density was increased from 1.3 to 4.6 plants m^{-2}. Prior and Russell (12) reported that ear proliferation differed among maize hybrid genotypes and ENP was a sensitive yield adjustment strategy in maize. Poneleit and Egli (11) showed that although weight per kernel (WK) of prolific hybrids was active in yield adjustment, it was less sensitive than other components. Krishnamurthy *et al.* (9) reported that the most sensitive yield components in maize were KNE and KNER. Hashemi-Dezfouli and Herbert (7) reported that with increasing plant population density, in non-prolific hybrids, weight per kernel decreased more than row number per ear but less than kernel number per ear row and ear number per plant. They found that number of kernel rows per ear showed the least response to increased population density.

In prolific maize hybrids ENP is an active component in yield adjustment while in non-prolific hybrids, which almost always produce one ear per plant, other yield components could be more important. The objective of the present study was to determine the effect of plant population density on yield components and their role in yield adjustment in three non-prolific maize hybrids grown in southern Iran.

MATERIALS AND METHODS

The experiment was conducted at the Agricultural Research Station of Shiraz University, at Koushkak, 1650 m above sea level (longitude 52° 36′ E and latitude 30° 7′ N). Three non-prolific single cross maize hybrids, SC108, a very early maturity type, SC301, an early maturity type, and SC604, a normal maturity type, were sown at four plant densities, 5.56, 6.67, 8.33 and 11.11 plants m^{-2}, i.e., plants were 30, 25, 20, and 15 cm apart within the rows that were 60 cm apart, respectively. Seeds were double-planted by hand on June 1995, and thinned to desired densities at 2 leaf-stage. The experimental design was a randomized complete block arranged as split-plot, with four replicates. Maize hybrids were regarded main plots and plant population densities as subplots. Regular samples of plant material were taken weekly until physiological maturity i.e. the black layer stage (2). Daily maximum, minimum and average air temperature of the experimental site is shown in Fig.1. Each sample consisted of five adjacent well-bordered plants from each subplot. A temperature index, $\dot{M}$, rather than calendar time (days) was used for fitting growth curves such as leaf area index, and the rate of grain filling; M was calculated by:

$$M = mi = \Sigma[(Tmax + Tmin)/2] - Tb$$

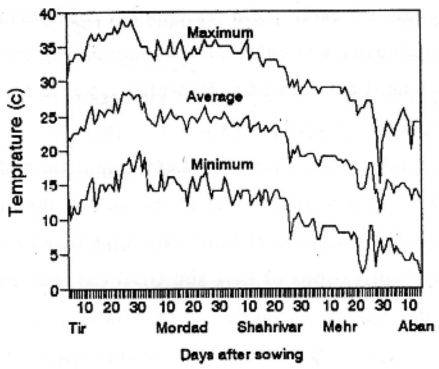

Fig. 1. Daily maximum, minimum and average air temperatures during the growing season (1995).

where mi was the growing degree days (GDD) value for the ith day, Tmax was the maximum daily air temperature (with an upper limit of 30° C), Tmin was the minimum daily air temperature (with a lower limit of 10° C), and Tb, base temperature, was taken to be 10°C. Ear measurement samples (10 plants) were taken after midsilking. Whole ears were dried at 70° C for 4 days. Linear regressions were obtained using all the grain dry weight values between 5% and 95% of the final yield on accumulated growing degree days (GDD), and the regression coefficient of the equation was considered as the rate of grain filling (8). Effective grain filling period duration, was obtained by dividing maximum grain dry weight by the respective rate of growth (1). To determine the optimum plant population density for each hybrid, a quadratic polynomial regression was fitted over mean values of grain yields (as the dependent variable) and respective plant population densities (as the independent variable). Then maximum value of the dependent variable derived from the quadratic regression equation was assumed as estimated optimum plant population density. Nearest plant population density to the estimated optimum plant population density was considered as actual optimum plant population density. Final harvest measurements of grain yield components included ear number per plant (ENP), kernel row number per ear (KRNE), kernel number per ear (KNE), kernel number per ear row (KNER), and weight per kernel (WK).

Percentage change of each yield component of hybrids due to increasing plant population density was calculated by comparing the lowest and highest real number value. Leaf area of a five-plant sample from each subplot was calculated using the formula (4, 10):

Leaf area (LA) = Leaf length × Leaf maximum width × 0.75

The mean total LA plant^{-1} was multiplied by the number of plants m^{-2} to obtain LAI. Cubic polynomial functions were fitted to the observed mean values of four replications of LAI and GDD (5). For each of the measured variables an analysis of variance was performed and differences between mean values for variables were tested using Duncan's new multiple range test.

RESULTS

Grain Yield

Results of the present experiment showed that in all three hybrids increasing plant population density up to 8.33 plants m^{-2} resulted in an increase in grain yield. Increasing plant population density from 8.33 to 11.11 plants m^{-2} did not change the grain yield significantly (Table 1).

On the basis of regression analysis optimum plant population density in this experiment for 'SC108' and 'SC301' was 11.11 plants m^{-2} (i.e., the highest plant population density) and for 'SC604' was 8.33 plants m^{-2} (Table 2). Estimated values for optimum plant population density for 'SC108', 'SC301' and 'SC604' were 12.28, 9.98 and 9.31 plants m^{-2}, respectively (Table 2).

Grain Yield Components

Plant population density only slightly affected the ear number per plant (ENP) in all hybrids. At highest plant population density all three non-prolific hybrids had slightly less than one ear per plant and at lower plant population densities, hybrids had slightly more than one ear per plant (Table 1).

Kernel number per ear (KNE) was not significantly affected by plant population density up to 6.67 and 8.33 plants m^{-2} in 'SC301' and 'SC108', respectively. In 'SC604' there was a reduction in KNE as plant population density increased (Table 1).

Table 1. Influence of plant density on grain yield (GY), ear number per plant (ENP), kernel number per ear (KNE), kernel number per ear row (KNER), kernel row number per ear (KRNE) and weight per kernel (WK) in three maize hybrids.

Hybrid	Plant density (plants m^{-2})	GY (kg ha^{-1})	ENP	KNE	KNER	KRNE	WK (mg)
	5.56	6113 i†	1.01 ab	464 d	28.1 d	16.6 c	232 c
	6.67	7331 h	1.00 ab	456 d	27.4 d	16.6 c	230 cd
SC108	8.33	8305 g	1.00 ab	440 d	26.6 d	16.5 c	227 de
	11.11	8934 fg	0.97 bc	367 e	23.2 e	15.9 d	225 e
	% Chang §	+46.1	-4.0	-20.9	-17.4	-4.2	-3.0
	5.56	9771 ef	1.02 a	708 b	44.6 a	15.9 d	243 a
	6.67	10663 de	1.00 ab	663 b	42.0 a	15.8 d	241 ab
SC301	8.33	11734 bc	1.00 ab	591 c	37.6 b	15.7 d	238 b
	11.11	11908 bc	0.95 c	488 d	32.6 c	15.0 e	231 c
	% Change	+21.9	-6.9	-31.1	-26.9	-5.7	-4.9
	5.56	10922 cd	1.02 a	785 a	41.8 a	18.8 a	245 a
	6.67	11786 bc	1.01 ab	717 b	38.4 b	18.7 a	244 a
SC604	8.33	13385 a	1.00 ab	665 b	36.0 b	18.5 a	241 ab
	11.11	12508 ab	0.97 bc	485 d	27.1 d	17.9 b	237 b
	% Change	+22.6	-4.9	-38.2	-35.2	-4.8	-3.3
SE (d.f.=17)		310.1	0.014	20.28	1.04	0.36	1.24

† Means followed by the same letter in each column are not significantly different (P>0.05).

§ The lowest real number value compared to the highest, e.g., GY of SC604 was increased 22.6% at 8.33 plants m^{-2} and KRNE of SC108 was reduced 4.2% at 11.11 plants m^{-2}.

Response of kernel number per ear row (KNER) to plant population density differed among hybrids. In 'SC108', KNER was not reduced in plant population density up to 8.33 plants m^{-2}. In 'SC301' and 'SC604', KNER decreased as plant population density increased from 6.67 plants m^{-2} in 'SC301' and 5.56 plants m^{-2} in 'SC604' (Table 1). Increasing plant population density up to 11.11 plants m^{-2} resulted in 17%, 27% and 35% reductions in KNER of 'SC108' , SC301 and 'SC604', respectively.

Increasing plant population density from 8.33 to 11.11 plants m^{-2} also affected kernel row number per ear (KRNE) in all hybrids (Table 1).

Furthermore, weight per kernel (WK) of all hybrids was significantly reduced with increase in plant population density (Table 1).

Table 2. Influence of plant density on effective grain filling period and rate of grain filling in three maize hybrids.

Hybrid	Plant density (plants m^{-2})	Effective grain filling period (GDD)†	Rate of grain filling ($g\ m^{-2}\ GDD^{-1}$)
SC 108	5.56	408.6c§	1.589 f
	6.67	418.8c	1.752 e
	8.33	407.0 c	2.040 d
	11.11	402.1 c	2.223 c
SC 301	5.56	486.1 ab	2.011 d
	6.67	479.9 b	2.224 d
	8.33	478.7 b	2.459 ab
	11.11	473.8 b	2.512 a
SC 604	5.56	478.7 b	2.240 c
	6.67	502.2ab	2.347 bc
	8.33	536.3a	2.505 a
	11.11	523.7ab	2.386 ab
SE (d.f.=17		16.21	0.0403

† Growing degree days.

§ Means followed by the same letter in each column are not significantly different (P>0.05).

Rate and Duration of the Grain Filling

Differences in effective grain filling period among hybrids were detected, however, plant population density had almost no significant effect on it (Table 3). Increasing plant population density up to 11.11 plants m^{-2} resulted in a significant increase in the rate of grain filling in 'SC108' (Table 3). In 'SC301' and 'SC604' the rate of grain filling was also accelerated by plant population density, although only up to plant population densities of 8.33 plants m^{-2} (Table 3).

Leaf Area Index (LAI)

Results indicated that LAI increased with increasing plant population density up to 11.11 plants m^{-2} in 'SC108' and 'SC301' hybrids throughout the whole experimental period (Figs. 2 and 3). However, in 'SC604', LAI increased with increasing plant population density only up to 8.33 plants m^{-2}. At the 11.11 plants m^{-2} density, LAI increased slightly only during the first half of the experimental period, during the second half LAI was decreased (Fig. 4).

Table 3. Actual and estimated optimum plant density for three maize hybrids.

Optimum Plant density (plants m^{-2})	Hybrid 'SC108'	'SC301'	'SC604'
Actual†	11.11	11.11	8.33
Estimated§	12.28	9.98	9.31

† Plant density resulted in maximum grain yield in the present study.

§ Plant density resulted in maximum grain yield accovding to quadratic regression equation.

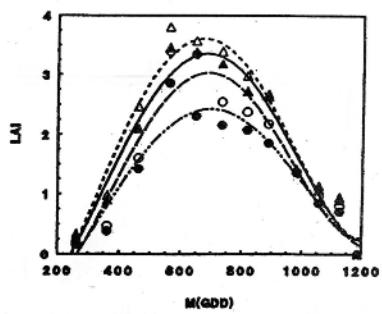

Fig. 2. Influence of plant density (---●--, 5.56; —○—, 6.67; —▲—, 8.33; and- -△- - 11.11 plants m^{-2}) on LAI of 'SC108' relative to accumulative growing degree days [M(GDD)].

DISCUSSION

In all three hybrids the response of grain yield to population density was similar to that of LAI and rate of grain filling. Thus, it might be concluded that increase in grain yield was directly related to the effect of plant density on LAI and rate of grain filling. It appeared that higher plant population densities (i.e., more than 8.33 plants m^{-2}) imposed some limitations on assimilate partitioning to the grains of the normal maturity hybrid, 'SC604'.

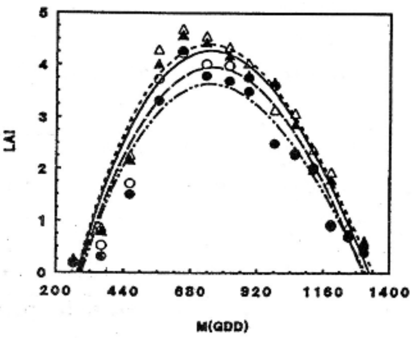

Fig. 3. Influence of plant density (- - -●— 5.56; —○— 6.67; —▲— 8.33; and - -△- - 11.11 plants m^{-2}) on LAI of 'SC301' relative to accumulative growing degree days [M(GDD)].

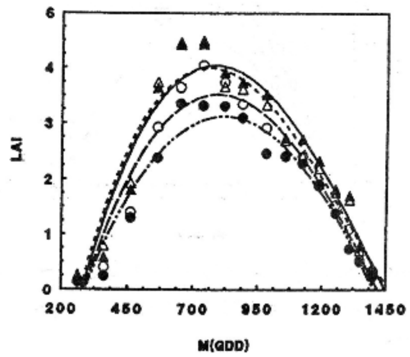

Fig 4. Influence of plant density (- - -●—,5.56; —○— , 6.67; —▲—,8.33; and - -△- - ,11.11 plants m^{-2}) on LAI of 'SC604' relative to accumulative growing degree days [M(GDD)].

Because the estimated optimum plant population density for the very early maturity hybrid, 'SC108', was higher than the actual optimum plant population density (11.11 plants m^{-2}) (Table 2) and in two later hybrids the estimated optimum plant population densities were lower than actual optimum plant density, it could be predicted that increase in plant population density to more than 11.11 plants m^{-2} could slightly increase the grain yield of very early maturity maize hybrid ('SC108').

According to Daynard *et al.* (3) the yield of a grain crop might be defined as the product of average rate of grain production and duration of grain formation. Since in our experiment the plant population density had no marked effect on the duration of grain filling period (Table 3), but did affect the rate of grain filling, it may be concluded that differences in grain yield due to plant population density could be attributed mainly to the differences in the rate of grain filling. Indeed, Daynard *et al.* (3) concluded that higher grain yield of maize hybrids at higher plant population densities was related to the faster rate of grain filling and plant population density had an effect on the grain filling period.

Percentage reduction (Table 1) in each yield component over the plant population densities (the lowest number value compared to the highest) was considered as the yield component vulnerability or sensitivity-adjustment to increasing plant population density (14). Results of the present experiment showed that KNE was the most sensitive yield component to increasing plant population density in maize hybrids (Table 1). Sensitivity of KNER was slightly less than KNE (Table 1). This finding is in agreement with that of Krishnamurthy *et al.* (9) and Tetio-Kagho and Gardner (14). Percentage reduction in KNE due to increase in plant population density varied among the hybrids. The hybrid with later maturity had the greater KNE reduction, i.e., 17%, 27% and 35% reduction for very early maturity hybrid ('SC108'), early maturity hybrid ('SC301') and normal maturity hybrid ('SC604'), respectively. Adjustments in kernel number per ear at higher plant population densities was perhaps a compensatory mechanism for the light reduction. This would allow remaining kernels to fill to a similar weight as those at lower densities. Hashemi-Dezfouli and Herbert (7) suggested this as a physiological mechanism in maize plants under reduced light intensities.

Kernel number per ear row (KNER) was reduced as plant population density increased, i.e., it was an active component in yield adjustment in non-prolific corn hybrids. This finding confirmed the results obtained by other workers (7, 14). It appeared that lower assimilate supply resulting from reduced light interception at higher plant population densities was the main reason for abortion of kernels, especially at the ear tip (also suggested by 13). It appeared that during the period that KNER is determined, the competition among sinks for assimilate is a limiting factor. Wilson and Allison (15) reported that although the number of florets per row of the ear at flowering was only slightly decreased with increase in plant population density, the number of kernels per row decreased with time after flowering.

Number of kernel rows per ear (KRNE) showed a little response to increasing plant population density in all three hybrids (i.e., 4%, 6% and 5% reduction in 'SC108', 'SC301' and 'SC604' , respectively). Since the KRNE is fixed earlier than other yield components (6), it could be concluded that during the period when KRNE is determined, the competition among sinks (i.e., florets) for assimilate was not limiting. Therefore, KRNE of these non-prolific corn hybrids appeared to be relatively stable in response to increasing plant population density and had a negligible effect in plant yield adjustment. Tetio-Kagho and Gardner (14) also reported similar results for prolific hybrids.

Our results also showed that WK had a slight response to increasing plant population density in all hybrids, i.e., 3%, 5% and 3% reduction in 'SC108', 'SC301' and 'SC604', respectively. This confirms results reported by Tetio-Kagho and Gardner (14). However, Poneleit and Egli (11) showed that in prolific hybrids, WK was active in yield adjustment though less sensitive than other yield components. Hashemi-Dezfouli and Herbert (7) also reported that weight per kernel was decreased more by plant population density than by row number per ear but less than kernel number per row and ear number per plant in non-prolific maize hybrids.

In the present experiment the ear number per plant (ENP) also showed little response to increasing plant population density (i.e., 4%, 7% and 5% reduction for 'SC108', 'SC301' and 'SC604', respectively). Tetio-Kagho and Gardner (14) reported that ENP was a sensitive yield adjustment strategy in prolific maize hybrids. Hashemi-Dezfouli and Herbert (7) also reported that the number of barren stalks of non-prolific hybrid increased linearly as the plant population density increased (from 3 to 12 plants m^{-2}). However, the results of our experiment showed that ENP was highly stable in response to increasing plant population density. This perhaps indicates the differences in yield components adjustment among maize genotypes in response to plant population density.

In summary, it was concluded that, the responses of LAI and rate of grain filling to the increasing plant population density were similar to that of grain yield, i.e. higher LAI, and rate of grain filling resulted in the higher grain yield. Optimum plant population density for normal maturity hybrid (i.e., 8.33 plants m^{-2}) was lower than that of earlier maturity hybrids (i.e., 11.11 plants m^{-2}). Sensitivity of the yield adjustment components in response to plant population density in non-prolific hybrids was similar to those of prolific hybrid. The exception to this was ear number per plant which is an active component in yield adjustment for prolific hybrids (e.g., 14), but had a negligible effect in plant yield adjustment for non-prolific hybrids. Kernel number per ear and kernel number per ear row were the most responsive yield adjustment components to increasing plant population density in the non-prolific hybrids studied in this experiment. Weight per kernel and ear number per plant had a negligible effect on yield adjustment.

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