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RESPUESTA DEL RENDIMIENTO A LA DENSIDAD EN HÍBRIDOS COMERCIALES DE MAÍZ LIBERADOS EN LAS ÚLTIMAS 4 DÉCADAS: EFECTOS DE FECHA DE SIEMBRA

Amas, J. I.[1*]; Cirilo, A. G.[2] y Otegui, M. E.[123]
[1] CONICET;
[2] EEA INTA Pergamino, Ruta 32 Km 4.5, Pergamino, Buenos Aires, Argentina;
[3] FAUBA, Avenida San Martín 4453, C.A.B.A., Argentina.
[*]amas.juan@inta.gob.ar

YIELD RESPONSE TO STAND DENSITY IN COMMERCIAL MAIZE HYBRIDS RELEASED DURING LAST 4 DECADES: SOWING DATE EFFECTS

ABSTRACT

Maize grain yield (GY) has an optimum-type response to stand density (SD). Optimum stand density (OSD) varies across environments and hybrids. The objective of current research was to analyze breeding effects on the variation in OSD across F1 hybrids (H) released to the Argentine market when grown in a contrasting environment (LSw: late sowing date) respect to the target breeding environment (ESw: early sowing date). GY response to SD (from 6 to 12 plants m^{-2}) was analyzed for 4 F1 hybrids released between 1980 and 2012, and grown under ESw (16-Oct) and LSw (28-Dec). Hybrids differed in their GY response to SD. Genetic gain in maximum GY was only detected under ESw environment ($p<0.05$). OSD range was 8.6-14 plants m^{-2} for ESw and 8.5-11.1 plants m^{-2} for LSw. Differences in OSD across hybrids were not related to year of release. A sowing date×H effect was detected for kernel number m^{-2} (KN/m^2) and kernel weight (KW) ($p<0.001$). Observed variations in GY were linked exclusively to (i) variations in KN/m^2 for ESw (r2=0.48, $p<0.05$), and (ii) variations in KW for LSw ($r^2=0.29$, $p=0.06$). These trends are in agreement with variations in relative solar radiation offer along the cycle between sowing dates.

Palabras Clave
Zea mays L., Densidad óptima, Mejoramiento, Fecha de siembra.

Keywords
Zea mays L., Optimum stand density, Breeding, Sowing date.

INTRODUCTION

Maize grain yield (GY) has a parabolic response to stand density (SD), which defines an optimum stand density (OSD) that varies across environments. GY increases with improved environmental conditions and is maximized at larger SDs in rich than in poor environments (Al-Kaisi y Yin, 2003). Additionally, hybrids differ in GY response to SD within and across environments (Sarlangue *et al.*, 2007; Hernandez *et al.*, 2014). At a given site, sowing date (Sw) is expected to produce large variations in growing conditions, which modify the occurrence of critical growth stages (Otegui *et al.*, 1995) and could affect OSD. Delayed sowing date for reducing water-deficit risk at flowering has become a common practice among Argentine farmers of the main maize producing region since the introduction of transgenic Bt hybrids. Interannual variation in GY is reduced in late (LSw) as compared to early sowing dates (ESw) in this environment (Mercau and Otegui, 2014), but grain filling takes place under reduced incident solar radiation and temperature levels (Maddonni, 2012; Bonelli *et al.*, 2016).

In the mentioned region, breeding efforts have traditionally focused in ESw. In these environments, observed genetic gain in GY has been associated with increases in kernel numbers (KN) and improved crop growth during grain filling (Luque *et al.*, 2006). The latter avoided a trade-off between KN and kernel weight (KW). Moreover, current hybrids have an increased GY at OSD as well as an improved tolerance to above OSD (Di Matteo *et al.*, 2016). However, there is no report of changes in OSD introduced by the year of release (YOR) and its possible variation across environments with contrasting photothermal offer, as expected between ESw and LSw. The objective of current research was to analyze breeding effects on the variation in OSD for GY and its components among F1 hybrids released to the Argentine market in the last decades when grown in contrasting environments produced by contrasting sowing dates.

MATERIALS & METHODS

Field experiments were performed at the INTA Pergamino station (33°57'34"S, 60°34'20"O), and included two environments, an irrigated ESw (16-Oct) in 2014/15 and a non-irrigated LSw (28-Dec) in 2016/17. In each environment we evaluated a factorial combination of (i) four F1 hybrids (H) broadly used among Argentine farmers in the last four decades and released to the market in 1980 (DK 2F10), 1993 (DK 752), 2002 (DK 190) and 2012 (DK 72-10), and (ii) three SDs (6, 9 and 12 plants m^{-2}). A split-plot design was used in each environment, with SDs in the main plot and three replicates. Experiments were kept free of weeds, insects and diseases all along the cycle. Daily weather records (Tm: mean temperature; SR: incident solar radiation) were obtained from a nearby meteorological station, and used to compute photothermal quotients (Q; eq. 1). A base temperature (Tb) of 8°C was used for the vegetative phase and of 0°C for the grain-filling phase.

(1) Q= SR/(Tm-Tb).

All ears present in 1 m^{-2} were harvested at physiological maturity and dried at 65°C until constant weight. Ears were threshed individually for the determination of (i) plant GY (PGY) and GY/m^2, (ii) kernel number per plant (KNP) and KN/m^2, and (iii) kernel weight (KW= PGY/KNP).

Estimation of OSD was based on Duncan (1958), and described in eq. 2.

(2) OSD= -1/(0.932 x *b*).

Parameter *b* represents the slope of the linear relationship between natural logarithm of PGY (ln PGY) and SD in eq. 3.

(3) ln PGY = a + *b* SD.

An individual model was fitted to each Sw×H combination, and PGY at OSD (PGY_{OSD}) was obtained subsequently by means of the same equation. Finally, GY/m2 at OSD was computed as the product between PGY_{OSD} and OSD.

Main and interaction effects on all evaluated traits were analyzed by ANOVA, with replicates nested within sowing dates. Means were compared by Fisher's LSD test. Regression analysis was applied to the relationship between variables.

RESULTS

Meteorological conditions differed markedly between Sw environments. Delayed sowing promoted a 14.6% increase in mean temperature during the vegetative stages (20.5ºC in ESw and 23.5ºC in LSw) but a decrease of 10% from flowering onwards (21.0ºC in ESw and 19.0ºC in LSw). Contrary, delayed Sw exposed the crops to a constant decrease in solar radiation offer, which averaged a mild 14% during vegetative stages (25 MJ m^{-2} day^{-1} in ESw and 22 MJ m^{-2} day^{-1} in LSw) but heightened to -42% during grain filling (24 MJ m^{-2} day^{-1} for ESw and 14 MJ m^{-2} day^{-1} for LSw). These figures gave photothermal quotients (Qs) of (i) 2.0 for ESw and 1.4 for LSw, during the vegetative stage (i.e. a 29% decrease), and (ii) 1.14 and 0.74, respectively, during grain filling (i.e. a 36% decrease).

Mean GY ranged between 7793 and 12269 kg ha^{-1} (Table 1). Delayed sowing caused a significant ($p<0.01$) 14% decrease in GY, but this effect did not differ among hybrids. A moderate ($p=0.07$) SD×H effect was detected for GY, which did not vary between sowing dates. A similar trend was detected for both GY components, for which the SD×H effect was similar in both sowing dates (Table 2). KN/m^2 was not affected by sowing date, but delayed sowing caused an 11% reduction in KW ($p<0.001$). Observed variations in GY were linked to (i) variations in KN/m^2 for ESw ($r^2=0.48$, $p<0.05$), and (ii) variations in KW for LSw ($r^2=0.29$, $p=0.06$).

When maximum GYs of each Sw×H combination were analyzed, a significant gain across YORs was detected only in the ESw environment (40 kg ha^{-1} $year^{-1}$; $R^2=0.92$, $p<0.05$). This gain could not be explained by an equivalent trend in a particular GY component ($r^2=0.13$, $p=0.64$ for KN/m^2 and $r^2=0.01$, $p=0.88$ for KW).

OSDs computed for each Sw×H combination ranged between 8.6-14 plants m^{-2} for ESw and 8.5-11.1 plants m^{-2} for LSw and were not related to the YOR (Figure 1a). Modern hybrids DK 190 and DK 72-10 tended to have similar OSDs across Sw, whereas OSD of old hybrids DK 2F10 and DK 752 was larger in the ESw than in the LSw. GY/m^2 at OSD were generally higher at the ESw than at the LSw (Figure 1b). No significant genetic gains could be detected for calculated OSDs or GY/m^2 at OSD for both Sw environments.

		Mean GY (kg ha^{-1})			ANOVA	
		6 pl m^{-2}	9 pl m^{-2}	12 pl m^{-2}		
ESw	DK 2F10	9980	10007	10937	Sw	*** (569)[1]
	DK 752	9050	10403	11283	SD	ns
	DK 190	9944	10423	11518	Sw×SD	ns
	DK 72-10	11064	12269	11223	H	**** (614)
LSw	DK 2F10	8356	7829	7793	Sw×H	ns
	DK 752	8976	9303	8921	SD×H	* (886)
	DK 190	8621	9141	9485	Sw×SD×H	ns
	DK 72-10	10204	11591	9870		

*: p<0.1; **: p<0.05; ***: p<0.01; ****: p<0.001; ns: not significant.
[1]Data in parenthesis is the LSD for comparison at the corresponding p value.

Table 1. Left: mean grain yield (GY) values of 4 commercial hybrids grown under contrasting sowing dates (ESw: 16-Oct, LSw: 28-Dec) and plant densities. Right: ANOVA results.

		KN/m²			KW (mg)		
		6 pl m⁻²	9 pl m⁻²	12 pl m⁻²	6 pl m⁻²	9 pl m⁻²	12 pl m⁻²
ESw	DK 2F10	4059	4156	4546	246	243	242
	DK 752	3440	4213	4636	263	247	244
	DK 190	3790	4762	5705	263	220	202
	DK 72-10	3715	4687	4811	298	264	232
LSw	DK 2F10	4018	3866	4035	208	203	194
	DK 752	4111	4984	5026	219	187	177
	DK 190	3517	4034	4332	245	226	218
	DK 72-10	3476	4752	4402	294	244	224
ANOVA					ANOVA		
	Sw	ns			****(8)		
	SD	****(312)[1]			***(16)		
	Sw×SD	ns			ns		
	H	**(199)			****(13)		
	Sw×H	****(281)			****(19)		
	SD×H	****(344)			**(23)		
	Sw×SD×H	ns			ns		

* p<0.1; ** p<0.05; *** p<0.01; ****p<0.001; ns: not significant.
[1] Data in parenthesis is the LSD for comparison at the corresponding p value.

Table 2. Top: mean values of kernel number m^{-2} (KN/m^2) and kernel weight (KW) of 4 commercial hybrids grown under contrasting sowing dates (ESw: 16-Oct, LSw: 28-Dec) and plant densities. Bottom: ANOVA results.

DISCUSSION & CONCLUSION

GY progress was detected only for the target breeding environment represented by the ESw, but gain computed was markedly lower than those obtained in previous reports in the same region (Luque *et al.*, 2006). This trend was probably due to differences in evaluated hybrids (Policastro *et al.*, 2016), represented only by F1s in current research. Lack of GY gain in the LSw environment could be explained by the poor photothermal environment (Q values) it explored during critical stages for GY determination, which caused the expected marked decrease in KW (Mercau and Otegui, 2014; Bonelli *et al.*, 2016). Neither KN/m^2 nor KW explained the described GY gains in the ESw environment, suggesting progress in GY of new F1 hybrids cannot be attributed to clear breeding focus on a given GY component. The same trend was observed for OSD, which was not related to YOR. In conclusion, as delayed sowing date has become a widely adopted management practice in the main maize production area of Argentina, further research on the determination GY and its components as well as on OSD under LSw is needed to guide future breeding efforts for this specific environment that currently represents 50% of the area cropped to maize.

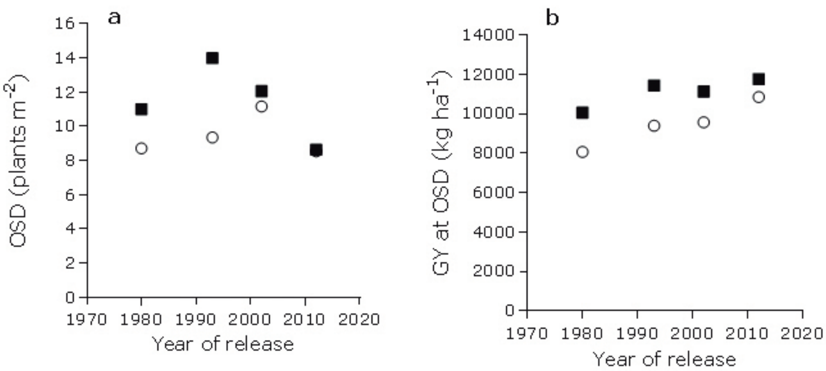

Figura 1. Área de espiga afectada por *Fusarium* en líneas de maíz derivadas por retrocruza (rombos), parentales (cuadrados) y el donante de resistencia LP4637 (triángulo).
Las barras representan los valores de DMS (prueba t, P < 0,05).

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