Path analysis of drought tolerant maize hybrid yield and yield components across planting dates

Path analiza prinosa hibrida kukuruza tolerantnih na sušu i komponente prinosa s obzirom na datum sjetve

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Abstract

Analysis of yield components in maize (*Zea mays* L.) hybrids across planting dates is limited. Research was conducted in 2013 and 2014 at Mead, Nebraska, United States with the objective to determine the influence of year, hybrid, drought tolerance type, and maturity classification across planting dates on maize yield and yield components. Early- and late-maturity DroughtGard (with CspB transgene) maize hybrids, and a late-maturity non-DroughtGard maize hybrid were planted at three dates in each year. Average maize yields were 10.8 ± 1.3 t/ha in 2013 and 13.6 ± 1.6 t/ha in 2014 with little difference across planting dates. Yield for 109 to 114 CRM (610 to 650 FAO maturity) hybrids was 13 ± 1.9 t/ha compared to 11 ± 1.6 t/ha for 97 to 100 CRM (450 to 480 FAO maturity) hybrids, and similar yields for late DroughtGard and non-DroughtGard hybrids were found. The yield of the early-maturity DroughtGard hybrids was associated most with direct effects of the number of ears per square meter (R = 0.53**) and kernels per ear (R = 0.44**) while the late-maturity DroughtGard hybrids were affected most by the direct effects of ears per square meter (R = 0.54**) and kernel weight (R = 0.57**). Yield components accounted for most yield differences between hybrids with different maturity classifications. Yield component compensation which occurred between DroughtGard and non-DroughtGard hybrids led to similar grain yields across planting dates.

Keywords: maize, path analysis, yield, yield components

Sažetak

Postoji relativno malo podataka o utjecaju različitih rokova sjetve na komponente prinosa zrna kukuruza (*Zea mays* L.). Istraživanje s ciljem određivanja utjecaja klimatskih prilika i svojstava hibrida na prinos i komponente prinosa kada se hibridi siju u različitim rokovima, provedeno je u 2013. i 2014. godini u Mead-u, Nebraska, SAD. Rani (FAO 450 i 480) i kasni (FAO 630 i 650) hibridi kukuruza s povećanom tolerantnošću na sušu (DroughtGard) te kasni (FAO 610) hibrid kukuruza slabije tolerantnosti na sušu (non-DroughtGard) posijani su u 3 različita roka u obje godine istraživanja. Prosječni prinos zrna iznosio je u 2013. godini 10,8 ± 1,3 t/ha, a u 2014. godini 13,6 ± 1,6 t/ha i malo se razlikovao između rokova sjetve. Prinos zrna kasnih DroughtGard i non-DroughtGard hibrida (109, 112 i 114 CRM) bio je 13 ± 1,9 t/ha, a ranih DroughtGard hibrida (97 do 100 CRM), 11 ± 1,6 t/ha, pri čemu su kasni DroughtGard hibridi i non-DroughtGard hibrid ostvarili slične prinose. Najveći direktni utjecaj na prinos ranih DroughtGard hibrida pokazali su broj klipova po metru kvadratnom (R = 0,53**) i broj zrna na klipu (R = 0,44**), a kasnih DroughtGard hibrida, broj klipova po metru kvadratnom (R = 0,54**) i masa zrna (R = 0,57**). Na razlike u prinosu zrna između hibrida koji su pripadali različitim vegetacijskim skupinama, najviše su utjecale komponente prinosa. Slični prinosi zrna između DroughtGard i non-DroughtGard hibrida koji su ostvareni u različitim rokovima sjetve, nastali su zbog razlika u kompenzaciji komponenata prinosa.

Ključne riječi: komponente prinosa, kukuruz, path analiza, prinos

Introduction

Maize (*Zea mays* L.) producers have been adopting drought-tolerant hybrids (Nemali et al., 2015) and planting at earlier dates during recent decades in the United States (Kucharik, 2008). Rainfed maize grain yields have increased at a rate of 50 to 120 kg/ha per year in the Great Plains of the United States during the last 75 years (Mason et al., 2008; Assefa et al., 2012). Selection of maize hybrids for native drought tolerance has always been important for rainfed conditions, but recently there is increasing interest in use of biotechnology-driven drought-tolerant maize hybrids containing the bacterial cold shock protein B (CspB), hereafter termed DroughtGard (Nemali et al., 2015). Under well-watered conditions, the DroughtGard maize hybrids have been reported to produce similar yields to non-DroughtGard hybrids (Chang et al., 2014; Nemali et al., 2015), and higher grain yield under water-limited conditions (Castiglioni et al., 2008; Nemali et al., 2015).

Kucharik (2008) found that earlier planting increased maize grain yield by 60 to 140 kg/ha per day in the states with relatively shorter growing seasons including Iowa, Michigan, Minnesota, Nebraska, South Dakota and Wisconsin, but not in the longer growing season states of Kansas, Missouri, Illinois, Indiana, Ohio and Kentucky. In Nebraska, Swanson and Wilhelm (1996) found the highest maize yield when planted 10 to 12 May while grain yields were lower at earlier and later dates. Irmak and Djaman (2016) found a decreasing maize yield with delayed planting under irrigation in contrast to a variable and small yield response under rainfed conditions. The maize yield increase from earlier planting in states such as Nebraska with shorter growing seasons were likely associated with longer growing seasons due to climate change (Skaggs and Irmak, 2012) combined with use of longer maturity maize hybrids (Lauer et al., 1999; Kucharik, 2008), and planting maize hybrids with greater early-season cold tolerance. Planting date influence on grain yield is greater for maize following maize than for rotation with maize following soybean [*Glycine max* (L.) Merrill] (Seifert et al., 2017) as in this study.

Early-maturity maize hybrids have lower yields than late-maturity hybrids (Milander et al., 2017) and late-maturity maize hybrids experience greater yield reduction due to delayed planting than early-maturity hybrids (Lauer et al., 1999; Kucharik, 2008). Initial maize hybrids in the United States were developed by crossing lines that were good "pollen producers" and good "seed parents" together to optimize grain yield (Tracy and Chandler, 2006), and today maize inbred lines are largely developed through recycling of closely related inbred lines (Mikel, 2011). Modern hybrids have a large contribution of southern dent maize races (Brown and Anderson, 1948) which is a major contributor to Reid Yellow Dent (Tracy and Chandler, 2006) and Iowa Stiff Stalk Synthetic (Tracy and Chandler, 2006; Mikel, 2008) heterotic groups used in breeding programs today. Modern hybrids have little content of the early-maturity northern flint germplasm, which is often termed the Lancaster heterotic group, having decreased from 15% in the 1940s to only 3% in the 1990s (Mikel and Dudley, 2006; Tracy and Chandler, 2006). The southern dent maize race was characterized by ears with up to 24 rows of deep kernels, commonly with girthy ears (Brown and Anderson, 1948) while the early-maturity northern flint germplasm was characterized by multiple ears per plant, and long, slender ears with 8 to 10 rows per ear of broad and shallow kernels (Brown and Anderson, 1947). Yield component studies regarding other maize heterotic groups have not been published. Modern studies show no connection between maize maturity classification and heterotic groups (Mikel and Dudley, 2006; Tracy and Chandler, 2006; Mikel, 2008; Mikel, 2011). However, Milander et al. (2017) found that modern early-maturity maize hybrids had longer ears, fewer rows per ear, and more kernels per row than mid- and late-maturity maize hybrids over a range of plant populations.

DroughtGard and non-DroughtGard maize hybrids have been shown to produce similar yields under moderate- to high-yield environments (Castiglioni et al., 2008; Chang et al., 2014; Kisekka et al., 2015). DroughtGard hybrids produce greater yield under water-limited conditions due to production of more kernels per ear (Castiglioni et al., 2008; Nemali et al., 2015). Castiglioni et al. (2008) reported that DroughtGard produced more ears per square meter and greater number of kernels per ear along with similar kernel weights compared to non-DroughtGard hybrids.

Maize grain yield is determined directly by the interrelated yield components of the number of ears per square meter and kernels per ear, and kernel weight, and indirectly by the number of rows per ear and kernels per row, and kernel depth, ear length and circumference. Yield components develop sequentially and have compensatory effects (Milander et al., 2016, 2017). Detailed yield component studies using path correlation analysis have been reported for many crops, but few comprehensive studies have been reported for maize (Mohammadi et al., 2003; Milander et al., 2016, 2017). None of these path correlation analysis studies were related to hybrid differences across planting dates.

Early-season stress reduces the number of ears per square meter or ears per plant (Evans et al., 2003) and rows per ear (Abendroth et al., 2011), while mid-season (mid-vegetative to mid-grain fill stages) stresses tend to influence the number of kernels per ear (Abendroth et al., 2011). Flowering (R2) is the growth stage most sensitive to water and heat stress that can reduce the number of kernels per ear (Westgate et al., 2004; Abendroth et al., 2011). Kernel abortion during early grain fill can also reduce the number of kernels per ear. Occurrence of stress during grain fill can result in light kernels while heavy kernels occur with high irradiance and long grain-fill duration (Abendroth et al., 2011; Novacek et al., 2013, 2014).

The objective of this research was to determine the influence of maize DroughtGard hybrids with different maturity classifications and a non-DroughtGard maize hybrid on grain yield and yield components across planting dates using path correlation analysis. Planting date influence from this study has previously been reported in Mason et al. (2018).

Materials and methods

Field experiments were conducted in 2013 and 2014 in rainfed environments at the University of Nebraska Agriculture Research and Development Center (ARDC) near Mead, Nebraska, United States (Table 1).

Table 1. Mean monthly precipitation and air temperature for Mead, NE in 2013 and 2014 during the maize growing season

Month	Air temperature (°C)			Precipitation (mm)		
	2013	2014	30-yr average	2013	2014	30-yr average
April	6.9	10.9	10.3	92	63	73
May	15.2	17.9	16.3	163	138	112
June	21.1	21.7	21.9	119	183	106
July	23.1	21.8	24.3	16	24	76
August	23.6	23.3	23	46	166	89
September	20.7	17.9	18.2	98	129	73
October	11	11.8	11.2	98	33	58
May-September total/average	20.7	20.5	20.7	442	640	456

The predominant soil type was Tomek silt loam (fine, smectitic, mesic, Pachic, Argiudoll) with 0 to 1% slope. The experiments were conducted in a randomized complete block design with split plot arrangement and 3 replications. Three planting dates of 27 April, 16 May, and 3 June in 2013 and 18 April, 5 May, and 20 May in 2014 were nested within year and considered the whole plot. DroughtGard early-maturity (450 to 480 FAO units), DroughtGard late-maturity (630 to 650 FAO units) and non-DroughtGard late-maturity (610 FAO units) hybrids were the split plot. More details about the experiment procedures can be found in Table 2 and Mason et al. (2018).

Table 2. Characteristics of maize hybrids used in this study (Monsanto and ChannelSeed Companies, no date)

Hybrid and Drought Classification	DKC 47-27 (Drought Gard)	DKC 50-57 (Drought Gard)	DKC 62-27 (Drought Gard)	Channel 214-00 (Drought Gard)	DKC 59-92 (Non-DroughtGard)
CRM†	97	100	112	114	109
GDU‡ to 50% Silking	1,253	1,269	1,338	1,350	1,335
GDU to Physiological Maturity	2,375	2,500	2,800	2,840	2,725
Estimated FAO Maturity	450	480	630	650	610
Emergence Score¶	2	3	3	NA£	2
Seedling Growth (Vigor) Score¶	2	3	3	2	2
Drought Tolerance Score¶	2	1	2	1	2

†CRM - Comparative Relative Maturity; ‡GDU - Growing Degree Unit, base temperature of 10 ºC; ¶1 - excellent, …, 9 – poor; £NA - Not Available.

Grain yield was measured by mechanically harvesting the middle three rows of the plots at approximately 200 g/kg water content. Grain was weighed, water content was measured, and yield for each plot adjusted to a water content of 155 g/kg. Prior to harvest, the number of ears was counted and six consecutive-ear samples were collected from each plot for measurement of yield components. Primary and secondary yield components measured were ears per square meter, kernels per ear, rows per ear, kernels per row, kernel depth, and kernel weight. Rows per ear, kernels per row, and kernels per ear were hand counted prior to hand shelling. Kernel depth was calculated by using calipers to determine the mid-ear diameter and cob diameter. The number of kernels per ear was hand counted and 100 kernels were randomly selected from each ear and used to determine the kernel weight, and corrected to a moisture content of 155 g/kg. Data were analyzed using PROC Mixed of SAS (SAS Institute, 2014). Initially analysis of variance, Pearson correlations and path analysis were conducted with year (Y), planting date within year [PD(Y)], and hybrid main effects and their interactions were considered fixed effects, while replication and interactions with replication were considered random effects. Path analysis indicated that early-maturity DroughtGard hybrids (97 and 100 CRMs) and late-maturity DroughtGard hybrids (112 and 114 CRMs) had similar models, so the 97 and 100 CRM, and 112 and 114 CRM hybrids were pooled together to increase the power-of-test for the Pearson correlations and path analysis. Pearson correlations were calculated to identify interrelationships among measured parameters. Path correlation analysis (Mohammadi et al., 2003; Kmail et al., 2016; Milander et al., 2017) of yield and the primary yield components of the number of ears per square meter and kernels per ear, and kernel weight, and secondary yield components of the number of rows per ear and kernels per row, and kernel depth was completed using PROC CALIS to determine model goodness-of-fit.

Results

Grain yield and components

Average maize grain yield was 10.8 ± 1.3 (n = 45) t/ha in 2013 and 13.6 ± 1.6 (n = 45) t/ha in 2014, and planting date within year had no influence on maize yield (Table 3) as also presented in Mason et al. (2018).

Compensation among yield components to maintain grain yield occurred. In 2013, maize yield components were increased by 0.2 ears per square meter for late compared to early planting, and by reducing kernel depth by 0.7 mm, and kernel weight by 4.1 mg per 100-kernels. In contrast in 2014, maize yield components were decreased by late rather than early planting date by 0.7 ears per square meter and 0.3 mm increased kernel depth, and 4 mg per 100-kernels. Early-developing yield components of ears per square meter and number of kernels per ear were relatively more important for earlier planted maize while late-developing yield components of kernel depth and weight were relatively more important for late-planted maize. The late-maturity DroughtGard and non-DroughtGard hybrids produced 13 ± 1.9 (n = 54) t/ha compared to 11 ± 1.6 (n = 36) t/ha for the early-maturity DroughtGard maize hybrids.

Table 3. Mean squares and significance of grain yield and yield components influenced by year, planting date and maize hybrid

Parameters	Year	Planting Date (Year)	Hybrid	Year X Hybrid	Planting Date X Hybrid (Year)
Grain Yield	173.06**	3.04	21.06**	2.16	1.2
Ears per square meter	0.86	1.22**	1.1**	1.32**	0.25*
Rows per ear	0.24	1.76	28.25**	1.11*	0.34
Kernels per ear	87,672**	5,584	54,358	910	4,368**
Kernels per row	319.15**	1.85	8.54*	3.52	11.78**
Kernel depth	19.53	2.19*	3.32*	1.44*	0.28
Ear length	138.14**	0.64	4.24**	2.74*	2.23**
Ear circumference	19.41*	0.96	3.77**	1.87**	0.21
Kernel weight	663.7**	71.4**	70.3**	79.1**	1.88**
Bulk density	8,722**	1,315**	3,162**	871**	1

* and ** significant at the P≤0.05 and P≤0.01.

Pearson correlations

Maize grain yield was correlated with the number of kernels per ear and kernels per row, and kernel depth, and kernel weight for all hybrids (Table 4). The number of ears per square meter was associated with grain yield for the late-maturity DroughtGard hybrids, but not for the non-DroughtGard hybrid. The number of ears per square meter was weakly correlated with grain yield for the early-maturity DroughtGard hybrid. The number of kernels per ear was associated with the number of kernels per row, kernel depth, and kernel weight for the early-maturity DroughtGard hybrids; with kernels per row and kernel depth for the late-maturity DroughtGard hybrids, and only kernels per row for the non-DroughtGard hybrid.

Table 4. Pearson correlations for grain yield and yield components for early maturity Droughtgard maize hybrids, late-maturity Droughtgard maize hybrids and late maturity non-DroughtGard hybrid

	Ears per square meter	Rows per ear	Kernels per ear	Kernels per row	Kernel depth	Kernel weight
	Early-maturity Droughtgard (n = 36)					
Grain yield	0.34*	0.29	0.51**	0.52**	0.43**	0.37*
Ears per square meter		-0.11	-0.23	-0.17	-0.29	-0.36*
Rows per ear			0.52**	0.2	0.55**	0.12
Kernels per ear				0.88**	0.59**	0.59**
Kernels per row					0.38*	0.63**
Kernel depth						0.64**
	Late-maturity Droughtgard (n = 36)					
Grain yield	0.55**	0.21	0.53**	0.4*	0.57**	0.53**
Ears per square meter		0.53**	0.5**	0.17	0.05	-0.12
Rows per ear			0.58**	0.04	0.08	-0.23
Kernels per ear				0.72**	0.44**	0.17
Kernels per row					0.53**	0.44**
Kernel depth						0.83**
	Non-DroughtGard (control) (n = 18)					
Grain yield	0.3	-0.44	0.46*	0.63**	0.57*	0.52*
Ears per square meter		0.17	0.49*	0.48*	-0.12	-0.15
Rows per ear			0.24	-0.11	-0.43	-0.58*
Kernels per ear				0.86**	0.06	-0.07
Kernels per row					0.27	0.3
Kernel depth						0.82**

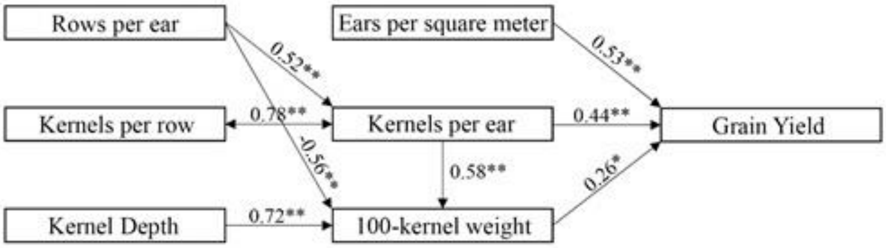
* and ** significant at the P≤0.05 and P≤0.01.

Path analysis by hybrid

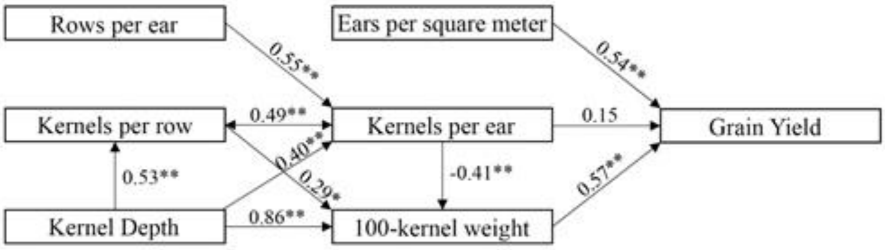
The path analysis models selected for the early-maturity DroughtGard, late-maturity DroughtGard, and non-DroughtGard maize hybrids had excellent goodness of fit (Figure 1). The results indicate that two-out-of-three primary yield components were associated with maize grain yield for late-maturity DroughtGard hybrids and non-

DroughtGard hybrids but varied by hybrid. Yield of early-maturity DroughtGard hybrids were associated with all primary yield components, but to a lesser extent for kernel weight than the other yield components. The number of ears per square meter had direct effects on grain yield of DroughtGard hybrids (Figures 1A and 1B), and kernel weight had high direct effect of greater than 0.55 on grain yield for late-maturity DroughtGard and non-DroughtGard hybrids (Figures 1B and 1C). The number of kernels per ear had direct effects on grain yield for early-maturity DroughtGard and non-DroughtGard hybrids (Figures 1A and 1C). The number of kernels per ear had a direct effect on kernel weight for DroughtGard hybrids, while the number of ears per square meter had a direct effect on the number of kernels per ear for non-DroughtGard hybrids.

A. Early-maturity (DKC47-27 and DKC50-57) droughtgard maize hybrids (Chi-square P-value = 0.13; GFI = 0.92; RMSE A = 0.13; $r^2 = 0.77$; Akaike Information Criterion = 53.18; Bozdogan CAIC Criterion = 107.4; and Schwarz Bayesian Criterion = 86.4).



B. Late-maturity (DKC62-27 and Channel 214-00) droughtgard maize hybrids (Chi-square P-value = 0.38; GFI = 0.94; RMSE A = 0.05; $r^2 = 0.95$; Akaike Information Criterion = 48.61; Bozdogan CAIC Criterion = 100.3; and Schwarz Bayesian Criterion = 80.3).



C. Non-droughtgard (DKC59-92) maize hybrid (Chi-square P-value = 0.29; GFI = 0.92; RMSE A = 0.12; $r^2 = 0.58$; Akaike Information Criterion = 52.20; Bozdogan CAIC Criterion = 95.68; and Schwarz Bayesian Criterion = 72.7).

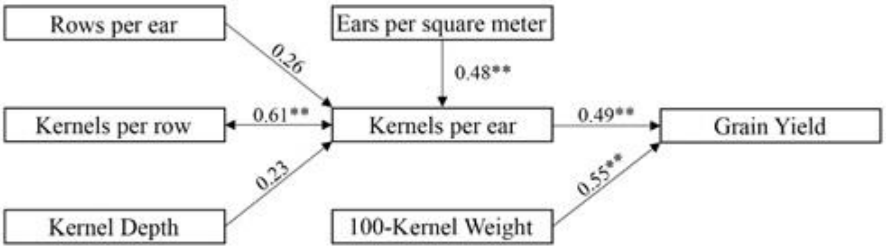


Figure 1. Path analysis model with direct effects for yield components for maize grain yield

Secondary yield component association with primary yield components were similar for DroughtGard hybrids except for the negative association of the number of rows per ear with kernel weight for early-maturity hybrids (Figure 1A). There was a positive association of kernel depth with both the number of kernels per row and kernels per ear, and the number of kernels per row with kernel weight for late-maturity hybrids (Figure 1B). The number of kernels per row with kernels per ear was the only association between secondary and primary yield components for non-DroughtGard hybrids (Figure 1C), partially due to presence of fewer degrees of freedom than for DroughtGard hybrids.

Discussion

Maize grain yield was not influenced by planting date regardless of hybrid drought tolerance and maturity classifications (Mason et al., 2018), in contrast to Lauer et al. (1999) and Kucharik (2008). This was unexpected, although Seifert et al. (2017) did find less effect of maize planting date following soybean as in this study than for maize following maize. Planting date variation among hybrids was small and had no influence on grain yield or yield components. Yield component compensation occurred to maintain grain yields across planting dates (Mason et al., 2018), as also found by Milander et al. (2016) across plant populations.

Grain yield was greater for late-maturity than early-maturity DroughtGard maize hybrids, consistent with findings of Milander et al. (2017). The greater yield of the late-maturity DroughtGard hybrids was associated with production of more kernels per ear and rows per ear combined with decreased kernel weight, more rows per ear and greater kernel depth. Grain yield of DroughtGard hybrids with different maturity classification was influenced by the number of ears per square meter. However, the early-maturity DroughtGard hybrids yield also had a direct effect of the primary yield component number of kernels per ear while the late-maturity hybrids had direct effect of kernel weight. Early-maturity DroughtGard hybrids had a direct effect of the number of early occurring rows per ear on kernel weight, while for the late-maturity DroughtGard hybrids, kernel depth had direct effects with the later occurring number of kernels per ear and kernels per row, which was similar to the results of Milander et al. (2017). Visual observations confirmed that early-maturity DroughtGard maize hybrids had longer ears with shallower kernel depth consistent with northern dent germplasm (Brown and Anderson, 1947), but present in only small amount in modern North American germplasm (Mikel and Dudley, 2006; Tracy and Chandler, 2006). In contrast, late-maturity DroughtGard maize hybrids had girthier ears and deeper kernels consistent with southern dent germplasm (Brown and Anderson, 1948) common in modern hybrids (Tracy and Chandler, 2006; Mikel, 2008). It appears that yield component differences across maturity classifications were likely due to differences in germplasm composition (Brown and Anderson, 1947; Brown and Anderson, 1948), although recent studies have not reported a connection between maturity classification and germplasm source (Mikel, 2001; Mikel and Dudley; 2006; Tracy and Chandler, 2006; Mikel, 2008).

In addition, the girthier ears and deeper kernels which developed late in the growing season are consistent with their greater importance for yield determination in late-maturity DroughtGard hybrids compared to early-maturity DroughtGard hybrids.

DroughtGard and non-DroughtGard corn hybrids with similar late maturity classification produced similar grain yield, however, great variation in yield components occurred. The DroughtGard hybrids had direct effects of the early-determined number of ears per square meter on grain yield, while the non-DroughtGard hybrid had a mid-season direct effect of number of kernels per ear on grain yield. Castiglioni et al. (2008) found that DroughtGard hybrids had increased production of ears per square meter and kernels per ear than non-DroughtGard hybrids. Although the understanding of the production of the similar yields with great differences in yield components is incomplete, it is speculated that germplasm differences associated with or without the CspB transgene were related to germplasm differences.

Conclusion

Planting date had no influence on maize yield but great yield component compensation occurred among planting dates. Late hybrid maturity increased grain yield over early-maturity hybrids, due to yield component differences detected by Pearson correlation and path analysis that were likely associated with germplasm source. These maturity classification differences were undoubtedly related to season-long interception of photosynthetically active radiation and accumulation of growing degree units (GDUs). Similar grain yields were produced by DroughtGard and non-DroughtGard maize hybrids, but yield components in this study varied greatly likely due to germplasm source. To understand yield response in crop management research, grain yield components should be measured and as possible, related to germplasm differences in the hybrids planted.

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