Responses of Maize Hybrids with Contrasting Maturity to Planting Date in Northeast China

Xinglin Ma (maxinglin@caas.cn)
Chinese Academy of Agricultural Sciences
Fulai Ke
Chinese Academy of Agricultural Sciences

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Abstract

Maize planting date in semi-humid region of Jilin province can often be delayed beyond the optimum planting time window because of soil water stress typically occured before or during the planting season. Research was conducted at Lishu city, Jilin from 2009 through 2010 to determine the responses of maize hybrids with contrasting maturity to planting date. Short-season hybrid Jidan27, mid-season hybrid Xianyu335, and full-season hybrid Zhengdan958 which were widely used in Northeast China maize production were planted in early May and mid-May and thinned to populations of 67500 plants ha^{-1}. Durations from emergence to silking stage for all the hybrids consistently shortened as the planting delayed, but interaction effects of hybrids, planting date and year existed for the duration of silking to physiological maturity stage. The longer maturity hybrid usually had grain yield advantage over earlier maturity hybrid when planting at early May, but the earlier maturity hybrid often showed a greater yield than longer maturity hybrid when planting was delayed. The highest yield occurred at the treatment combination of the mid-season hybrid and delayed planting date, and the shorter season hybrid typically showed stable and higher grain yield across planting dates. Changes in grain volume per unit of land area among hybrids and planting date treatment combination were consistent with the changes in grain yields, indicating that the yield is determined usually by the sink capacity. Further research is needed to evaluate the effects of hybrids maturity and planting date on maize under different planting densities.

Introduction

Maize in Northeast China (includes the three provinces of Heilongjiang, Jilin, and Liaoning, as well as the prefectures of northeastern Inner Mongolia) account for approximately 37.3% of maize area and 41.5% of total Chinese maize production (Ministry of Agriculture, PRC., 2011). Most of the maize grown in the Northeast China is planted during April and so is termed “spring corn” and is mainly rain fed (Li Yu et al. 2011). Theoretically, planting full season hybrids early generally produced more grain because the entire growing season can be used (Lauer 1999). However, this consideration was contingent on if soil water stresses occurs before or during the optimum window of planting date in Northeast China. Planting maize in this region can be delayed beyond the optimum late April to early May time window when severe drought typically or excessive rainfall occasionally occurs before or during the planting season. Because delayed planting shortens the effective growing season, it can become an issue whether to switch to earlier-maturity hybrids to ensure that physiological grain maturity occurs before a killing fall frost and stable yield can be obtained.

In the U. S. Corn Belt, numerous researches have been documented about planting date-hybrids maturity effects on maize morphophysiological traits and grain yield . In Western Kansas, Norwood found dryland corn yield for the early May planting date were always higher than those for the mid-April planting date(Norwood 2001). In north-central and northeast Kansas, Staggenborg et al. (1999) found that planting in early April or early May produced similar yields. Traditionally, in Northeast China, full-season or ultra-full-season hybrids have been used by producers, even when delayed planting operations occurred, accordingly, researches in this region only focused on risk of late-maturity maize hybrids under extreme climate conditions (Shi et al. 2011) and difference in maize yield between mid- and late-maturing hybrids (Shi et al. 2008), and unbelievably, there is little research on the planting date- maize hybrid maturity effects.

Maize production in the Midsouth Jilin province typically entails planting hybrid that requires 120 to 130 d from emergence to physiological maturity (Li 2000). Planting dates are currently in late April or early May (Li 2000). But as mentioned above, this area characterized by typically low or occasionally high moisture content in the soil before or during the planting season. When the area encounters these soil water stress conditions, planting date have to be delayed. Then, the grain-filling period of full-season hybrids would be more affected by the unfavorable environmental conditions during reproductive growth stage than that of short or mid-season hybrids. Short-season hybrids would place reproductive stage under more favorable environmental conditions than their long-season counterparts as Lauer et al.(1999) observed in U. S. Corn Belt. Therefore, short-season maize hybrids (≈105d from emergence to maturity) would seemingly have potential for delayed planting resulted from spring drought or excessive rainfall in the Midsouth Jilin. However, since short-season maize hybrids are primarily grown in the northern part of Jilin and Heilongjiang, there is little research on the adaptability of short-season hybrids in this area. The objectives of this research were to (i) evaluate the potential of short-season maize hybrids for delayed planting in the Midsouth Jilin, and (ii) determine if yield of short-season maize in Midsouth Jilin was similar to full-season hybrids currently being produced in the area, and (iii) provide information for all the Northeast China(in where different heat units among different regions existed, but all of the regions has its own full-season and short-season hybrids) on the relationship between maize yield and hybrid maturity-planting date interaction.

Results

Climatic Conditions

Mean every ten days air minimum, maximum temperatures, rainfall and daily sunshine hours per month from April through September at experimental site are presented in table 1 and table 2 for the 2009 and 2010 growing season, as accompanied by 30-yrs averages.

Mean air minimum temperatures for the month of May both are higher than the 30-yr value in the two growing seasons, while the maximum temperature for May is higher in 2009 but lower in 2010 than the 30-yr average value, resulting in emergence and seedling growth in 2009 presented an advantage over in 2010.

Both mean air minimum and maximum temperatures for the month of June are lower in 2009 compared with 2010, while comparing with the 30-yr average value, the data in 2009 is lower, and the data in 2010 is higher.

Mean air minimum temperature for July is lower in 2009 compared with 2010 and 30-yr, while the value in 2010 is greater than that in 30-yr. As for the maximum temperature for July, the value of 2009 is similar to that of 2010, and both of the 2009 and 2010 values are lower compared with the 30-yr value. The warm conditions for 2010 are favorable to the crop development and the vegetative organ construction rapidly, especially for the shorter-season hybrid.

In August, mean air minimum temperature (MAMinT) for the first and second 10-day is greater in 2009 than in 2010, and MAMinT of the third 10-day is markedly lower in 2009 than in 2010. MAMinT for August is similar between 2009 and 2010 growing seasons, and both of them are lower compared with 30-yr value. For the mean air maximum temperature (MAMaxT) of the August, the value in 2009 markedly greater than the values in 2010 and 30-yr, and the value of 2010 is slightly lower than that of 30-yr. The warmer condition for August in 2009 is favorable for maize kernel set and grain filling, especially for the shorter-season hybrid.

In September, MAMinT for the first and second 10-day exhibited markedly lower in 2009 compared with 2010, and the MAMinT for the third 10-day is slightly greater in 2009 than 2010, MAMinT for the September is markedly lower compared with 2010 and 30-yr, and the value of 2010 slightly greater than that of 30-yr. MAMaxT for the first and second 10-day is slightly lower in 2009 compared with 2010, and the MAMaxT for the third 10-day is markedly greater in 2009 compared with 2010, MAMaxT for the September is greater in 2009 compared with 2010 and 30-yr. Such air temperature condition in 2010 growing season is favorable for grain filling event both for the mid- and full-season hybrids.

Total precipitation during 2010 growing season surprisingly greater than 2009 growing season, which is also markedly greater than the value of 30-yr. Total precipitation during 2009 growing season is highly lower the 30-yr value.

The highly greater precipitation in 2010 resulted from rainfall events in the three month of May, August and September. The total precipitation occurred in May is 63% more than 30-yr average value, resulting in favorable for water supplying for seedling development. Rainfall in the third 10-day in July and the first 10-day in August are highly above the 30-yr average value, resulting in unfavorable for maize pollination and kernel set for the mid- and full-season hybrid tested in this study.

Rainfall for each month in 2009 growing season is lower compared with 30-yr average value, but the rainfall is fairly well distributed this growing season excluding September. In 2009 growing season, rainfall for the first, second, and third 10-day in September is 0.5, 3.0, and 0.4 mm respectively, expectedly resulting in unfavorable effects on grain filling at the later growing season.

Mean daily sunshine hours (MDSHs) in 2009 growing season is slightly greater compared with the 30-yr average value, while the MDSHs in 2010 growing season is markedly lower than the average value of 30-yr(76.2% lower), especially at each 10-day in the July and at the first 10-day in August in 2010 growing season when MDSHs is below the average 30-yr value of 50%, and 80% respectively, resulting in a highly unfavorable light condition for maize kernel set for mid- and full-season hybrids tested in this study.

Contrarily, MDSHs for the months of July and August in 2009 growing season are highly greater compared with the 30-yr average value, especially at the third 10-day in July and at the first 10-day in August when the MDSHs is 1.7, and 1.4 times as much as the 30-yr average value respectively, resulting in a highly favorable light condition for maize kernel set.

Table 1
Mean every ten days air minimum (min) and maximum (max) temperatures from April through September at experimental site in 2009 and 2010 growing season

Month	Every ten days	Min			Max		
		2009	2010	Average over 30 yrs	2009	2010	Average over 30 yrs
May	Early ten days	12.5	9.2	8.57	24.8	19.7	20.59
	Mid ten days	11.0	10.1	10.51	22.8	20.7	22.32
	Late ten days	12.3	14.5	12.60	26.3	25.3	24.63
	Average	11.9	11.3	10.56	24.6	21.9	22.52
June	Early ten days	12.6	16.1	14.66	23.4	31.1	26.25
	Mid ten days	14.6	19.0	16.59	23.1	27.9	27.18
	Late ten days	17.7	18.1	17.84	27.7	30.1	27.75
	Average	15.0	17.7	16.36	24.7	29.7	27.06
July	Early ten days	17.5	19.1	18.83	26.5	27.1	27.80
	Mid ten days	18.7	20.3	19.75	28.3	28.4	28.18
	Late ten days	17.9	20.7	20.34	28.2	27.6	28.43
	Average	18.0	20.0	19.64	27.7	27.7	28.14
August	Early ten days	19.4	17.4	19.93	30.8	25.8	28.41
	Mid ten days	20.1	19.2	18.53	31.1	28.5	27.56
	Late ten days	12.8	17.2	16.53	25.9	25.0	26.56
	Average	17.4	17.9	18.33	29.3	26.4	27.51
September	Early ten days	11.9	14.4	13.68	24.2	26.2	24.88
	Mid ten days	10.9	13.0	10.82	23.9	24.2	22.85
	Late ten days	6.8	6.3	8.33	21.4	18.4	20.81
	Average e	9.9	11.2	10.94	23.2	22.9	22.85

Table 2
Mean every ten days rainfall and daily sunshine hours from April through September at experimental site in 2009 and 2010 growing season

Month	Every ten days	Rainfall			Daily sunshine hours		
		2009	2010	Average Over 30 yrs	2009	2010	Average over 30 yrs
May	Early ten days	32.8	61.3	18.65	89.2	60.1	82.39
	Mid ten days	1.7	11.8	15.39	101.2	59.9	81.89
	Late ten days	6.0	9.2	16.47	99.4	68.8	96.49
	Monthly total	40.5	82.3	50.50	289.8	188.8	260.77
June	Early ten days	29.7	0.0	30.67	73.1	119.8	84.14
	Mid ten days	34.8	12.3	28.46	75.2	53.3	78.28
	Late ten days	5.1	3.8	32.92	96.6	83.7	73.45
	Monthly total	69.6	16.1	92.04	244.9	256.8	235.88
July	Early ten days	31.3	88.8	48.40	72.0	31.1	67.67
	Mid ten days	20.0	60.3	52.31	81.2	30.6	61.06
	Late ten days	29.3	130.3	65.26	117.8	29.3	67.94
	Monthly total	80.6	279.4	165.98	271.0	91.0	196.67
August	Early ten days	1.0	108.3	61.32	88.2	49.7	62.38
	Mid ten days	16.1	61.2	44.33	82.0	64.3	66.96
	Late ten days	40.3	47.7	40.68	110.1	43.2	84.89
	Monthly total	57.4	217.2	146.32	280.3	157.2	214.22
September	Early ten days	0.5	0.0	18.48	88.1	45.9	80.59
	Mid ten days	3.0	34.8	13.66	85.6	53.9	81.45
	Late ten days	0.4	1.8	11.86	71.3	82.4	80.35
	Monthly total	3.9	36.6	43.99	245.0	182.2	242.40
Total from May to September		252.0	631.6	498.84	1331.0	876.0	1149.94

Days from Emergence to Silking, Silking to Physiological Maturity, and Emergence to Physiological Maturity, and Number of Leaves per Plant

Days from emergence to silking (DES) was significantly decreased by delayed planting except for mid-season hybrid XY335 in 2009 when the difference presenting only numerically (Table 3). In both years, short-season hybrid JD27 had significantly lower DES than the mid- and full-season hybrids at each planting date treatment. Difference for DES between mid- and full-season hybrid at D1 was not significant in both years, but at D2 treatment, the mid-season hybrid XY335 had significant higher DES than the full-season hybrid ZD958($P<0.01$) in 2009, and had significant lower DES than ZD958 in 2010 ($P<0.05$).

Days from silking to physiological maturity(DSPM) significantly($P<0.01$) increased with hybrid maturity (Table 3). In both seasons, there were no significant effects of planting date on DSPM for JD27; In 2009, DSPM of D1 significantly ($P<0.05$) higher than that of D2 for XY335, but in 2010, DSPM of D1 significantly ($P<0.05$) lower than that of D2 for XY335; In both seasons, DSPMs of D1 significantly ($P<0.01$) lower than those of D2 for ZD958.

Days from emergence to physiological maturity (DEPM) significantly ($P<0.01$) increased with hybrid maturity (Table 3). In both seasons, D2 resulted in statistically lower DEPM than D1 for JD27; In 2009, D1 showed higher DEPM than D2 for XY335, but in 2010, the difference between planting date treatments for DEPM for XY335 was not significant; In both seasons, no significant difference was found between the two planting date treatment for ZD958.

The shorter season hybrid JD27 had a significantly lower number of leaves per plant (NLPP) than the longer season hybrids (i.e. mid- and full- season hybrid) (Table 3). Difference of NLPP between mid- and full-season hybrids was not observed. No difference of NLPP between planting dates was found except for ZD958 in 2009 when D2 resulting in statistically more leaves than D1.

Table 3

Effects of planting date and hybrid maturity on days from emergence to silking, silking to physiological maturity, and emergence to physiological maturity, and number of leaves per plant of dryland corn at Lishu city, Northeast China during 2009 and 2010 growing seasons.

	2009			2010		
	JD27	XY335	ZD958	JD27	XY335	ZD958
Plamting date	days from emergence to silking (d)					
D1	66.3B[‡]	70.3A	70.3A	61.3B	65.3A	66.3A
D2	64.3C	69.3A	67.7B	56.3Bc	61.7Ab	63.0Aa
Difference	2.0**	1.0NS[§]	2.7**	5.0**	3.7**	3.3**
	days from silking to physiological maturity (d)					
D1	44.0C	53.0B	58.0A	46.0C	52.0B	58.0A
D2	43.0C	51.0B	59.7A	46.0C	55.0B	61.3A
Difference	1.0NS	2.0*	1.7*	0.0NS	3.0**	3.3**
	days from emergence to physiological maturity (d)					
D1	110.3C	123.3B	128.3A	107.3C	117.3B	124.3A
D2	107.3C	120.3B	127.3A	102.3C	116.7B	124.3A
Difference	3.0**	3.0**	1.0NS	5.0**	0.7NS	0NS
	number of leaves per plant					
D1	19.3B	20.5A	20.3A	19.2B	20.6A	20.6A
D2	19.5B	20.5A	20.8A	19.6b	19.9ab	20.5a
Difference	0.2NS	0NS	0.5*	0.5NS	0.7NS	0.1NS

* Significant at the 0.05 level.

** Significant at the 0.01 level.

‡ Means within a row followed by a different lower-case letter differ at $P < 0.05$. Means within a row followed by a different upper-case letter differ at $P < 0.01$.

§ NS, not significant.

Grain Yield, Kernel Water Content at Harvest Stage, and Kernel Density

Significant interactions between hybrid maturity and planting date for grain yield were found both in 2009 and 2010 seasons (Table 4). In both seasons, D1 showed significantly ($P<0.01$) lower grain yield than D2 both for JD27 and XY335, but grain yield of D1 was significantly ($P<0.01$) higher than that of D2 for ZD958.

In 2009, XY335 and ZD958 produced significantly ($P<0.05$) greater grain than JD27 and the difference between XY335 and ZD958 was not significant D1. When compared in D2, XY335 and JD27 showed significantly ($P<0.01$) higher grain yield than ZD958 and the difference between XY335 and JD27 was not significant. In 2010, grain yield significantly ($P<0.01$) increased with hybrid maturity in D1, but XY335 exhibited the highest grain yield, and ZD958 the least in D2. Delayed planting significantly affected grain yield for all three hybrids, but D2 resulted in greater yield than D1 both for JD27 and XY335, and the ZD958 showed the opposite situation.

The results also showed that the highest yield occurring at the treatment combination of the mid season hybrid and D2 planting date, and the shorter season hybrid typically exhibited stable and higher grain yield across planting dates and growing seasons. In general, the results suggested that the longer maturity hybrid evaluated in the study usually had grain yield advantage over earlier maturity hybrid evaluated when planting at D1, but the earlier maturity hybrids often showed a greater yield than longer maturity hybrid when planting was delayed.

As expected, kernel water content at harvest stage (KWCHS) significantly ($P<0.01$) increased with hybrid maturity, and the KWCHS significantly ($P<0.01$) increased when planting was delayed (Table 4). This would be associated with unfavorable profitability of maize production resulted from drying costs

Significant interactions between hybrid maturity and planting date for kernel density were found both in 2009 and 2010 growing seasons (Table 4). In 2009, XY335 had significantly ($P<0.05$) higher kernel density than JD27 and ZD958 following D1, and there was no significant difference among hybrids for kernel density following D2. In 2010, significant difference only exist between XY335 and ZD958 following D1, and between XY335 and JD27 following D2. As for the difference between planting date treatments, the only difference was found showing that kernel density of D1 was higher than that of D2 for XY335 in 2009 and for ZD958 in 2010. It seems that delayed planting exhibited a trend of decrease in kernel density.

Table 4
Effects of planting date and hybrid maturity on grain yield, kernel water content at harvest stage and kernel density of dryland corn at Lishu city, Northeast China during 2009 and 2010 growing seasons.

	2009			2010		
	JD27	XY335	ZD958	JD27	XY335	ZD958
Plamting date	grain yield kg ha^{-1}					
D1	10064b‡	10549a	10409a	7986C	9022B	10718A
D2	10889A	11176A	8560B	8686B	10061A	7700C
Difference	825**	627**	1849**	700**	1039**	3018**
	kernel water content at harvest stage %					
D1	15.13C	20.77B	28.79A	14.16C	18.38B	24.90A
D2	16.59C	22.90B	31.93A	15.41C	21.03B	27.87A
Difference	1.46**	2.13**	3.15**	1.25**	2.66**	2.96**
	kernel density g cm^{-3}					
D1	1.30b	1.33a	1.30b	1.30ab	1.27b	1.32a
D2	1.31a	1.29a	1.28a	1.27b	1.31a	1.28ab
Difference	0.02NS§	0.04*	0.02NS	0.03NS	0.04NS	0.04*

* Significant at the 0.05 level.

** Significant at the 0.01 level.

‡ Means within a row followed by a different lower-case letter differ at $P < 0.05$. Means within a row followed by a different upper-case letter differ at $P < 0.01$.

§ NS, not significant.

Aboveground Biomass at Harvest Stage, and Harvest Index

In both seasons, significant interactions between hybrid maturity and planting date for aboveground biomass at harvest stage (ABHS) were observed (Table 5). No significant differences were observed between D1 and D2 for JD27 in both seasons; and D1 produced lower ABHS than D2 for XY335, but the difference was significant (P<0.01) only in 2009; Contrarily, D1 had greater ABHS than D2 for ZD958, while the difference was not significant in 2010.

In 2009, ABHS of XY335 was significantly (P<0.01) higher than those of JD27 and ZD958, and ABHS of ZD958 was significantly (P<0.05) higher than that of JD27 following D1; when compared following D2, ABHS of XY335 was significantly (P<0.01) higher than that of JD27, and ABHS of JD27 significantly (P<0.01) higher than that of ZD958. In 2010, ZD 958 produced significantly (P<0.05) greater ABHS than JD27 and XY335, and no difference in ABHS between JD27 and XY335 was found following D1; when compared following D2, JD27 had significantly (P<0.05) lower ABHS than XY335 and ZD958, and the difference between XY335 and ZD958 was not significant.

The results suggested that the longer maturity hybrid typically exhibited greater ABHS than earlier maturity hybrid following D1, and the mid- season hybrid had the highest ABHS compared with other hybrids following D2; On the other hand, D1 often had higher ABHS than D2 for full- season hybrid, and D2 usually produced greater ABHS than D1 for shorter season hybrids.

Generally, the values of harvest index (HI) in the experiment were higher than those in the other cases (dates were not showed), this attributed partially to the characteristics of the tested hybrids in the experiment, in which dry matter partitioned much more to the reproductive organs. Significant interactions between hybrid maturity and planting date for HI were found in both seasons (Table 5). In 2009, D1 had significantly (P<0.01) lower HI than D2 both for JD27 and XY335; In 2010, D1 also had lower HI than D2 both for JD27 and XY335, but only for JD27 the difference reached significant (P<0.05); In both seasons, D1 had significantly (P<0.01) greater HI than D2 for ZD958.

In 2009, differences in HI among hybrids were significant (P<0.01), in which JD27 exhibited highest HI at both planting date treatments, and XY335 the least following D1, and ZD958 the least following D2. In 2010, ZD958 had significantly (P<0.05) higher HI than JD27, and there were no significant differences between ZD958 and XY335, and between XY335 and JD27 following D1; but when compared following D2, ZD958 exhibited significantly (P<0.01) lower HI than JD27 and XY335, and no significant difference in HI between JD27 and XY335 was found.

The results suggested that both aboveground biomass at harvest and harvest index contributed to grain yield differences between treatments of the experiment.

Table 5
Effects of planting date and hybrid maturity on aboveground biomass at harvest stage, and harvest index of dryland corn at Lishu city, Northeast China during 2009 and 2010 growing seasons.

	2009			2010		
	JD27	XY335	ZD958	JD27	XY335	ZD958
Plamting date	aboveground biomass at harvest stage kg ha^{-1}					
D1	16487Bb‡	19054A	17273Ba	16323b	17158b	19496a
D2	16904B	19859A	15975C	15289b	18774a	17724a
Difference	418NS§	805**	1298**	1034NS	1616NS	1772NS
	harvest index %					
D1	61.04A	55.37C	60.26B	49.17b	52.58ab	55.07a
D2	64.42A	56.28B	53.58C	56.80A	53.60A	43.93B
Difference	3.38**	0.91**	6.68**	7.64*	1.02NS	11.14**

* Significant at the 0.05 level.

** Significant at the 0.01 level.

‡ Means within a row followed by a different lower-case letter differ at $P < 0.05$. Means within a row followed by a different upper-case letter differ at $P < 0.01$.

§ NS, not significant.

Yield components

There were no significant effects of hybrid maturity and planting date on number of ears m^{-2} in 2009. In 2010, significant interaction between hybrid maturity and planting date for number of ears m^{-2} was found. No significant difference in number of ears m^{-2} among hybrid was found following D1, but following D2, XY335 exhibited significantly (P<0.01) lower number of ears m^{-2} than JD27 and ZD958. As for planting date difference, D2 exhibited significantly (P<0.01) lower number of ears m^{-2} than D1 for XY335 (Table 6).

In both seasons, significant interaction between hybrid maturity and planting date for grain weight per ear (GWPE) was observed (Table 6). In 2009, GWPE difference among hybrids was at the P<0.01 level, in which JD27 produced lower GWPE than XY335 and ZD958 following D1, and ZD958 produced lower GWPE than XY335 and JD27 following D2. GWPE of D2 was significantly greater than that of D1 for both JD27 (P<0.01) and XY335 (P<0.05), adversely, GWPE of D2 was significantly (P<0.01) lower than that of

D1 for ZD958. In 2010, GWPE difference among hybrids also was at the $P<0.01$ level. ZD958 produced the highest GWPE, and JD27 the least following D1, but following D2, XY335 produced the highest GWPE, and ZD958 the least. GWPE of D2 was significantly ($P<0.01$) greater than those of D1 for both JD27 and XY335, but for ZD958, D2 had the significantly (P) lower GWPE than D1.

In both seasons, significant interaction between hybrid maturity and planting date for number of grains per ear (NGPE) were found (Table6). NGPE of D2 was greater than that of D1 both for JD27 and XY335, but only for JD27 in 2010 the difference was significant ($P<0.05$), and for ZD958, D2 exhibited significantly ($P<0.01$) lower NGPE than D1 in both seasons. As for the difference among hybrids, in both seasons, JD27 had significantly ($P<0.05$ or <0.01) lower NGPE than XY335 and ZD958 following D1, and ZD958 had significantly ($P<0.01$) lower NGPE than XY335 following D2.

Generally, effects of hybrid maturity and planting date on 100-grain weight were weaker when compared with parameters mentioned above. Since 100-grain weight difference between planting date treatments was not found, and the difference in 100-grain weight among hybrids showed that JD27 had significantly ($P<0.05$) greater 100-grain weight than the other hybrid following D2 in 2009, and JD27 had significantly ($P<0.05$) greater 100-grain weight than XY335 following D1 in 2010 (Table 6).

Table 6

Effects of planting date and hybrid maturity on number of ears m^{-2}, grain weight per ear, number of grains per ear, and 100-grain weight of dryland corn at Lishu city, Northeast China during 2009 and 2010 growing seasons.

	2009			2010		
	JD27	XY335	ZD958	JD27	XY335	ZD958
Plamting date	number of ears m^{-2}					
D1	6.68a‡	6.47a	6.47a	6.68a	6.75a	6.75a
D2	6.54a	6.47a	6.47a	6.68A	6.40B	6.75A
Difference	0.14NS§	0NS	0NS	0NS	0.35**	0.00NS
	grain weight per ear g ear^{-1}					
D1	150.66B	163.10A	160.94A	119.58C	133.65B	158.79A
D2	166.69A	172.80A	132.32B	130.09B	157.27A	114.07C
Difference	16.03**	9.69*	28.62**	10.51**	23.62**	44.72**
	number of grains per ear					
D1	417.65b	508.22a	498.35a	315.28B	430.83A	449.37A
D2	451.23ABb	529.54Aa	435.27Bb	400.74AB	446.37A	336.67B
Difference	33.58NS	21.32NS	63.08*	85.47*	15.54NS	112.69**
	100-grain weight g					
D1	36.35a	32.10a	32.33a	37.96a	31.04b	36.06ab
D2	37.02a	32.65b	30.68b	32.65a	35.29a	34.04a
Difference	0.67NS	0.55NS	1.65NS	5.32NS	4.25NS	2.02NS

* Significant at the 0.05 level.

** Significant at the 0.01 level.

‡ Means within a row followed by a different lower-case letter differ at $P < 0.05$. Means within a row followed by a different upper-case letter differ at $P < 0.01$.

§ NS, not significant.

Number of grains m^{-2}, and grain volume m^{-2}

In both years, significant interactions between hybrid maturity and planting date for Number of grains m^{-2} (NGM) were observed (Table 7). D2 had greater NGM than D1 for JD27, but the difference in 2009 was not significant; differences in NGM between planting date treatments for XY335 were not significant in both years; D1 exhibited greater NGM than D2 for ZD958 in both seasons. As for the difference among hybrids, in 2009, JD27 exhibited significantly lower NGM than XY335 ($P<0.01$) and ZD958 ($P<0.05$) following D1, both JD27 and ZD958 exhibited significantly ($P<0.01$) lower NGM than XY335 following D2. In 2010, JD27 exhibited significantly ($P<0.01$) lower NGM than XY335 and ZD958 following D1, and ZD958 exhibited significantly ($P<0.05$) lower NGM than XY335 following D2. These results showed that differences in Number of grains m^{-2} between treatments were not consistent with the differences in grain yield

In both seasons, significant interaction between hybrid maturity and planting date treatment for volume of grains m^{-2} (VGM) was found (Table 7). In both seasons, D2 exhibited significant ($P<0.01$) greater VGM than D1 for both JD27 and XY335, contrarily, D2 exhibited significant ($P<0.01$) lower VGM than D1 for ZD958. As for differences in VGM among hybrids, JD27 had significantly ($P<0.05$) lower VGM than ZD958 following D1 in 2009, and VGM significantly ($P<0.01$) increased with hybrid maturity following D1 in 2010; In both seasons following D2, XY335 had significantly ($P<0.01$) greater VGM than JD27, and JD27 had significantly ($P<0.01$) greater VGM than ZD958. The results showed that differences in VGM among treatments were consistent with the differences in grain yield among treatments.

Table 7
Effects of planting date and hybrid maturity on number of grains m^{-2}, and volume of grains m^{-2} of dryland corn at Lishu city, Northeast China during 2009 and 2010 growing seasons.

	2009			2010		
	JD27	XY335	ZD958	JD27	XY335	ZD958
Plamting date	number of grains m^{-2}					
D1	2786Bb	3287Aa	3222ABa	2106B	2908A	3033A
D2	2946B	3424A	2812B	2673ab	2857a	2273b
Difference	160NS	137NS	410*	568*	51NS	761**
	Volume of grains m^{-2} cm^3 m^{-2}					
D1	776.18b	791.35ab	801.04a	613.15C	707.31B	809.35A
D2	830.59B	865.54A	667.52C	685.75B	768.19A	600.79C
Difference	54.41**	74.18**	133.53**	72.61**	60.89**	208.56**

* Significant at the 0.05 level.

** Significant at the 0.01 level.

‡ Means within a row followed by a different lower-case letter differ at $P < 0.05$. Means within a row followed by a different upper-case letter differ at $P < 0.01$.

§ NS, not significant.

Discussion

The evaluated hybrids showed different duration from emergence to silking and silking to physiological maturity stages. Short season hybrid JD27 exhibited both lower durations from emergence to silking and silking to physiological maturity stage compared with mid- and full-season hybrids; but the duration from emergence to silking stage between mid- and full-season hybrids was similar; and the notable difference of duration from silking to physiological maturity stage between them was observed. These results differ from those observed by Major et al. (1983) in Canada, who found that the difference in the hybrid cycle were mainly explained by changes in the duration of the period from emergence to flowering.

The results also showed maize physiological response to delayed planting among hybrids was different. Durations of emergence to silking stage for all the hybrids consistently shortened as the planting delayed. As for the duration from silking to physiological maturity stage (DSPMS), the short-season hybrid showed numerically difference between planting date treatments; DSPMS of the mid-season hybrid became shorter in 2009 and longer in 2010 respectively as the planting delayed; DSPMS of the full-season hybrid showed longer in both year as the planting delayed. The results differs from the observations by Liu at el. (2009) in Wuqiao, Hebei province in where the thermal time were plentiful for spring planting maize, who reported that both the durations from emergence to silking and silking to physiological maturity stage for late April planting became longer compared with the mid May planting treatment. Delayed planting effects on flowering and grain maturation of corn also observed by Nielsen et al. (2002) in the eastern U. S. Corn Belt, who found that thermal time from planting to silk emergence decreased an average of 34 GDDs(Growing degree days) for June vs. early May plantings while the grain-fill period decreased an addition 110 GDDs with late planting. They also reported that the three hybrids responded differently to delayed planting with greater GDD decreases occurring with late-maturity hybrids.

Several researchers have investigated the difference in number of leaves among maize hybrids with contrasting maturity, who reported that the longer the hybrids cycle length, the greater the number of leaves（Cao and Wu 1996）. Our results do not agree with the observation. In our experiment, the number of leaves was lowest for short-season hybrid and did not vary much between mid and full-season hybrids. As mentioned above, the duration from emergence to silking was similar between mid- and full-season hybrids. Thus，we concluded that the number of leaves was more closely related with the duration from emergence to silking compared with the hybrid cycle length.

As hypothesized, the longer maturity hybrid evaluated in the study usually had grain yield advantage over earlier maturity hybrid evaluated when planting at the date of early May, but the earlier maturity hybrid often showed a greater yield than longer maturity hybrid when planting was delayed. These results agree with data obtained by Norwood (2001), who reported a full-season hybrid generally produced more grain than a short-season hybrid when planted early and yields of a short-season hybrid were equal to or greater than yields of a full-season hybrid at later planting dates. Our data also exhibited that the highest yield occurring at the treatment combination of the mid-season hybrid and delayed planting date, and the shorter season hybrid typically showed stable and higher grain yield across planting dates.

Grain yield is the product of ears ha^{-1}, kernels ear^{-1}, and kernel weight, yield also can be expressed as the product of kernels ha^{-1} and kernel weight (Norwood 2001). Numerous researches have consistently demonstrated that grain yield increases were mostly related to an improved number of harvestable kernels per unit land area(Tollenaar et al. 1977; Kiniry and Ritchie 1985; Jacobs and Pearson 1991; Echarte et al. 2000, 2004). We investigated the response of maize hybrids with contrasting maturity to planting date in terms of dry matter accumulation and partitioning (biomass yield, harvest index), yield component(ears ha^{-1}, kernel ear^{-1}, 100- grain weight, number of grains m^{-2}, and grain volume m^{-2}). The results showed that (i) differences in grain yield among hybrids and planting dates treatment combination was closely related with the differences in biomass yield compared with harvest index. (ii) Grain weight per ear, grain number per ear, and 100-grain weight for short- and mid- season hybrids usually increased as the planting delayed, but for full-season hybrid, most of these yield components decreased following the later planting. (iii) Changes in grain volume per unit of land area among hybrids and planting date treatment combination were consistent with the changes in grain yields, indicating that the yield is determined usually by the sink capacity, this result is consistent with previous investigations. Interestingly, the results also showed that grain volume per unit of land area is more appropriate for measuring the parameter of grain sink capacity compared with the term of grain volume per unit of land area, this is mainly because difference usually existed in single grain size or/and weight among hybrids. Additional research is needed, however, to determine if the results holds true for all the Northeast China on the relationship between maize yield and hybrid maturity-planting date interaction. Farther more, it is reported that optimum planting density is usually higher for short-season than for full-season hybrids (Edwards et al., 2005). For short-season hybrids more plants are needed to reach the same amount of cumulative intercepted radiation (Edwards et al. 2005) because of their small leaf area per plant and a shorter duration of growth. Thus, further research is needed to evaluate the effects of planting density, hybrids maturity and planting date interactions on maize yield and relative morphophysiological traits.

Conclusions

(i) differences in grain yield among hybrids and planting dates treatment combination was closely related with the differences in biomass yield compared with harvest index.

(ii) Grain weight per ear, grain number per ear, and 100-grain weight for short- and mid- season hybrids usually increased as the planting delayed, but for full-season hybrid, most of these yield components decreased following the later planting.

(iii) Changes in grain volume per unit of land area among hybrids and planting date treatment combination were consistent with the changes in grain yields, indicating that the yield is determined usually by the sink capacity.

Materials And Methods

Experimental locations

The experiments were conducted at the Lishu Research Extension Center of CAAS near Siping City(43°18' N 124°18' E), Jilin province, from 2009 through 2010. The soil was a black loam with a pH of 7.5 and an organic matter content of 26 $g \cdot kg^{-1}$. Thirty-year average climatic data for Siping City are annual precipitation of 577.2 mm, mean temperature of 5.8 °C, and a frost-free period of 152 d. The experimental site located in Northeast China, which is a typical spring maize area and is mainly rain fed.

Management practice

The hybrids were planted by hand at a rate of 67500 hills ha^{-1}, three to four seeds per hill planted and hand-thinned after emergence to 67500 plants ha^{-1} populations. Herbicides used each year were atrazine [6-chloro-*N*- ethyl-*N*- (1-methlyethyl)- 1,3,5- triazine-2,4 -diamine] applied at a rate of 2.2 kg ha^{-1} after planting for weed control. The plots received 150 kg N ha^{-1} before planting and 75 kg N ha^{-1} at 12-leaf stage respectively each year. The soil P level averaged about 14.6 $mg{\cdot}kg^{-1}$, but 150 kg ha^{-1} P_2O_5 was applied, and 150 kg ha^{-1} K_2O also was applied at the beginning of the study to eliminate any potential deficiencies.

Experimental design and Data collection

The experimental design was a split plot with three replications. Planting date was the main plot, hybrid was the subplot. Each subplot was 4.8 m wide (eight 60-cm rows) by 6 m long. Maize was planted in early May (D1) and mid-May (D2) of each year. Three maize hybrids differing in relative maturities were planted in both of year. Hybrids were Jidan27 (JD27), Xianyu335 (XY335), and Zhengdan958 (ZD958), which had maturities of 109 d, 120 d, and 126 d according to recorded calendar time from crop emergence to kernel black layer formation, respectively. The full-season hybrid ZD958 was selected based on their adaptation to the area. The mid-season hybrid XY335 have been successfully grown under dryland conditions in the area. The short-season hybrid JD27 have been widely grown in northern part of Jinlin and southern part of Heilongjiang and was selected to represent hybrids with earlier relative maturities.

Silking date was measured to determine the traits of days from emergence to silking, silking to physiological maturity, and emergence to physiological maturity, while silking date was recorded when 60% of the ears showed silk emergence.

Number of leaves per plant was measured by the following method: Plants from the center four rows of each plot were marked by painting the sixth-leaf red at 8-leaf stage, and accordingly, painting the 12^{th}-leaf red at 14^{th}-leaf stage, and finally to count the leaves of each plant.

Aboveground dry matter, grain yield, and number of ears m^{-2} were determined at physiological maturity by hand harvesting all the plants from the center two rows of each plot, excluding the most exterior plants of each row, comprising an area of 5.93m^2. Grain moisture percentage was recorded and expressed as kernel water content at harvest stage, and grain yield was weighed and expressed on 14% moisture content basis. Kernel density was calculated from (100-kernel weight ×1000)/100-kernel volume, and 100-kernel weigh and 100-kernel volume (determined by the drainage methods) was recorded as the mean of 3×100 kernel random samples. The number of grains per unit surface area (number of grains m^{-2}) and per plant were calculated as quotient between grain yield and individual grain weight, both on a 14% moisture content basis. The volume of grains m^{-2} was calculated from (number of grains m^{-2} ×100-kernel volume/100). Harvest index was calculated as the ratio between grain yield and total aboveground biomass at physiological maturity.

Statistical analysis was by PROC ANOVA with mean separation by Fisher's protected LSD and by the linear forward selection component of PROC REG.

Declarations

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Authors' contributions

1. Lab work primarily conducted by F. Ke as a PhD .
2. X. Ma* provided technical guidance and advise for experiment design during the research.

Competing interests

The authors declare that they have no competing interests

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