Effects of planting timing on maize productivity in Zambia

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Abstract

Optimal planting date is essential to attain high maize (*Zea mays* L.) productivity despite environmental variation in low-input agriculture in Zambia. Local farmers generally plant maize as soon as possible after the rainy season begins, but there is no scientific evidence that this timing is optimal for attaining high productivity using local practices. To test this, we grew maize at three planting dates (normal timing, then 10 and 20 days later) in six fields of Zambia's Southern Province in the 2008/09 and 2009/10 growing seasons. Grain yield was reduced by delayed planting, by an average of 19% for all years and locations combined. The reduction resulted from decreased biomass production and harvest index. The yield was closely correlated with the mean air temperature and wind speed during the 30 days after planting; cooler and windier conditions increased the magnitude of the yield reduction due to delayed planting. These results support the early planting used by local farmers.

1. Introduction

Maize (*Zea mays* L.) is a major food source in southern Arica, including Zambia, but its productivity is low compared to yields obtained elsewhere in the world; the mean yield in Zambia (1742 kg ha^{-1}; 10-year average from 1999 to 2008) is only 37% of the world average (4671 kg ha^{-1}), and the coefficient of variation in Zambia is roughly twice that in other countries (FAO, 2010). A slight decline in maize productivity can have detrimental effects on the lives of local farmers and their families, jeopardizing both their health and their lives. Stabilization of maize productivity in Zambia is therefore essential, particularly given current prospects for future climate change (IPCC, 2007).

The precipitation pattern is one of the most critical factors that affects maize production in Africa (Cane *et al.*, 1994; Phillips *et al.*, 1998; Stige *et al.*, 2006), where precipitation occurs primarily during the wet season. Choosing the most appropriate planting date is therefore essential for increasing crop productivity by taking advantage of the available climatic resources under conditions in which farmers have no access to inputs such as synthetic fertilizers or pesticides.

To analyze the impact of planting date on maize productivity, simulation models have proven to be a powerful option (Tsubo *et al.*, 2005ab; Abraha and Savage, 2006). These models have shown that too-early planting before the rainy season begins increases the risk that severe drought will prevent germination and establishment when young plants do not have root systems to absorb enough soil water. On the other hand, too-late planting might reduce the total growing period and total biomass by limiting crop absorption of solar radiation. Most simulation models, however, were developed based on data obtained from experiments conducted under well-fertilized conditions and well-controlled management practices. Unfortunately, huge gaps exist between the potential productivity and the actual productivity achieved by farmers due to differences in several key factors, such as fertilizer, pesticide, and herbicide inputs. Sileshi *et al.* (2008) analyzed the published maize yield data, and showed that actual maize productivity was almost half of the productivity obtained under well-fertilized conditions, with a high coefficient of variation for yield under field conditions. Thus, it is necessary to test the effects of planting date on maize productivity under local environmental and cultivation conditions to calibrate the predictions of simulation models.

There have been few field studies of the effects of planting timing on maize productivity in Africa (Tsubo *et al.*, 2003, for South Africa; Tittonell *et al.*, 2008, for Kenya; Kamara *et al.*, 2009, for Nigeria), leading to weak scientific evidence for the optimal planting date that will maximize maize yield by smallholders in southern Africa. In the present study, we examined the effects of planting date on maize productivity at six smallholder fields in Zambia, at three altitudes that differ in weather conditions.

2. Materials and Methods

In Zambia's Southern Province, the local maize cultivar 'Jileile' was planted in six fields of villages at three different altitudes: A = Sianemba and Siameja villages (17°05'S, 27°30'E, 517 m in altitude, two fields), B = Chanzika village (17°05'S, 27°20'E, 769 m in altitude, one field), and C = Siachaya village (16°59'S, 27°20'E, 1075 m in altitude, three fields). Planting was conducted on three dates from late November to early December in 2008 (starting on the normal date, then at ca. 10-d intervals) to produce a final density of 33.3×10^3 plants ha^{-1} (1 m between rows × 0.3 m between plants; planting two to three seeds per spot for an initial density of from 67×10^3 to 100×10^3 plants ha^{-1}). The plants were thinned after emergence, leaving only a single plant per spot. Table 1 summarizes the planting dates and other key dates. We defined the normal planting date based on the decision of the local farmers as the control, then chose planting dates that were approximately 10 and 20 days later as the delayed planting treatments; at some sites, we used only one of the two treatments and at other sites we used both. Farmers in Zambia's Southern Province have learned from experience to plant maize a few days after the second large rainfall of the year, which is judged to represent the start of the wet season. The plot size in the control treatment was 20 × 20 m, whereas those in the 10-d-later and 20-d-later plots were about 10 × 20 m. Agronomic practices followed local methods: weeding by hand, and no irrigation, fertilizer, herbicide, or pesticide application in any field. A similar experimental design was used in 2009/10, but the planting was delayed in two plots (to 47 days later in ASn1 and 31 days later in CSa1).

Table 1. Growth stages and grain yield of maize sown on different dates in the 2008/09 and 2009/10 growing seasons in Zambia.

Season	Site	Field ID	Treatment	Sowing		Emergence		Flowering		Period from sowing to flowering	
2008/09	A	ASn1	Control	4-Dec		7-Dec		30-Jan		57	
			10d later	13-Dec	(+9)	17-Dec	(+10)	7-Feb	(+8)	56	(-1)
			20d later	23-Dec	(+19)	27-Dec	(+20)	19-Feb	(+20)	58	(+1)
		ASm2	Control	4-Dec		-		30-Jan		57	
			10d later	13-Dec	(+9)	-		-		-	-
	B	BCh2	Control	29-Nov		-		17-Jan		49	
			10d later	8-Dec	(+9)	-		5-Feb	(+19)	59	(+10)
	C	CSa1	Control	28-Nov		-		2-Feb		66	
			10d later	7-Dec	(+9)	13-Dec		27-Feb	(+25)	82	(+16)
			20d later	17-Dec	(+19)	23-Dec		20-Mar	(+46)	93	(+27)
		CSa2	Control	28-Nov		-		2-Feb		66	
			10d later	7-Dec	(+9)	13-Dec		27-Feb	(+25)	82	(+16)
		CSa3	Control	28-Nov		-		1-Feb		65	
			10d later	7-Dec	(+9)	13-Dec		27-Feb	(+26)	82	(+17)
2009/10	A	ASn1	Control	17-Dec		21-Dec		1-Feb		46	
			10d later	30-Dec	(+13)	5-Jan	(+15)	16-Mar	(+43)	76	(+30)
			20d later	2-Feb	(+47)	6-Feb	(+47)	2-Apr	(+60)	59	(+13)
		ASm2	Control	17-Dec		22-Dec				-	-
			10d later	30-Dec	(+13)	3-Jan	(+12)			-	-
	B	BCh2	Control	12-Dec		17-Dec		26-Jan		45	
			10d later	22-Dec	(+10)	29-Dec	(+12)			-	-
	C	CSa1	Control	8-Dec		13-Dec		28-Jan		51	
			10d later	18-Dec	(+10)	23-Dec	(+10)	16-Feb	(+19)	60	(+9)
			20d later	8-Jan	(+31)	13-Jan	(+31)	12-Mar	(+43)	63	(+12)
		CSa2	Control	8-Dec		13-Dec		28-Jan		51	
			10d later	18-Dec	(+10)	23-Dec	(+10)	16-Feb	(+19)	60	(+9)
		CSa3	Control	8-Dec		13-Dec		28-Jan		51	
			10d later	18-Dec	(+10)	23-Dec	(+10)	16-Feb	(+19)	60	(+9)

Values in parenthesis indicate differences from the control. -, data not available.

We recorded the emergence and flowering dates in each plot. At harvesting time (in early April), maize yield was determined for the whole control plot (divided into 12 subplots of 5×6 m, for a total area of 360 m^2), but we used four subplots (2×2 m, for a total of 16 m^2) at each site in the 10-d-later and 20-d-later plots. The yield was expressed as the oven-dried (70°C) seed weight. The 100-grain weight was also measured. From the 100-grain weight and grain yield, the grain density was estimated. Total oven-dried aboveground biomass was also measured. We calculated harvest index by dividing the total grain yield by the total aboveground biomass of an oven-dry basis.

Solar radiation, wind speed, and relative humidity were measured at sites A and C, at one location per site, using a CMP3 solar radiation sensor (Campbell Scientific Inc., Logan, UT, USA), a 034B-Lx wind set (Campbell Scientific Inc.), and a CS215-Lx temperature and relative humidity sensor (Campbell Scientific Inc.) covered by a 41303-5A radiation shield (Campbell Scientific Inc.), respectively. Air temperature was measured at three locations at sites A and B and four locations at site C, at 1.2 m in height, with a TR-52 sensor (T&D Corporation, Nagano, Japan) covered by a 41303-5A radiation shield. Precipitation was measured at 16 locations at each site using CTK-15PC tipping-bucket rain gauges (Climatec Inc., Tokyo, Japan). All measurements were conducted at 30-minute intervals.

We used Excel statistics to perform simple linear regression analysis of the relationship between yield and environmental parameters, and to calculate Pearson's correlation coefficient between total grain yield and the yield and weather parameters.

3. Results

3.1. Weather

The total precipitation was greater in 2009/10 than in 2008/09, but did not differ between locations (Table 2). The seasonal precipitation trend differed between years; the precipitation was greater during the early growing season in 2008/09, but was greater during the late growing season in 2009/10. The precipitation during the early growing season (December and January) was higher at site C than at sites A and B in both years. Figure 1 illustrates the changes in daily precipitation at the three sites around the maize planting dates (from November to December) and during the rest of the growing season. The precipitation started earlier in the 2008/09 season than in the 2009/10 season.

The seasonal mean air temperature (December to March) was lowest at the high elevation of site C (average 21 to 23°C, maximum 26 to 27°C, minimum 18 to 19°C), followed by site B at an intermediate elevation (average 23 to 24°C, maximum 28 to 29°C, minimum 19 to 20°C), and was highest at the low altitude of site A (average 25 to 26°C, maximum 30 to 31°C, minimum 21 to 22°C) (Table 2). Air temperature in the 2008/09 was about 1°C lower than that in 2009/10, and decreased during both growing seasons. Wind speed was faster at site C than site A (by 60%) throughout the growing season in both years. Relative humidity was generally higher at site C than site A. Solar radiation at site C was only about 90% of that at site A. Thus, the weather at the higher altitude of site C was cooler, windier, and wetter, with less solar radiation, and the 2008/09 season was cooler and wetter than the 2009/10 season.

Table 2. Climate conditions at the three study locations in Zambia during the 2008/09 and 2009/10 growing seasons. Elevations: site A < site B < site C.

Season	Year	Month	Precipitation (mm)			Air temperature (°C)									Relative (%)		Solar (MJ m^{-2} d^{-1})		Wind speed (m s^{-1})	
						Average			Maximum			Minimum								
			A	B	C	A	B	C	A	B	C	A	B	C	A	C	A	C	A	C
2008/09	2008	Dec.	339	365	397	25.4	23.5	22.3	29.9	27.7	26.6	21.9	20.2	19.2	79.0	84.1	20.5	18.9	0.7	1.4
	2009	Jan.	225	348	358	25.7	23.6	22.2	30.5	27.9	27.0	22.0	20.3	18.9	80.7	87.1	22.9	20.2	0.8	1.2
		Feb.	234	211	246	25.4	23.2	21.7	30.6	28.3	26.9	21.1	19.5	18.0	80.3	86.2	24.9	21.4	0.8	1.2
		Mar.	369	274	180	23.9	21.9	20.5	29.4	27.0	25.5	20.0	18.4	17.0	83.0	87.2	20.8	18.9	0.7	1.1
	Seasonal mean		***292***	***300***	***295***	***25.1***	***23.1***	***21.7***	***30.1***	***27.7***	***26.5***	***21.3***	***19.6***	***18.3***	***80.8***	***86.1***	***22.3***	***19.8***	***0.8***	***1.2***
	SD		***73***	***71***	***100***	***0.8***	***0.8***	***0.8***	***0.5***	***0.5***	***0.7***	***0.9***	***0.9***	***1.0***	***1.7***	***1.4***	***2.0***	***1.2***	***0.1***	***0.1***
2009/10	2009	Dec.	176	150	219	26.8	24.9	23.4	31.8	29.7	28.3	22.3	21.0	19.5	73.5	78.8	23.9	22.4	1.1	1.4
	2010	Jan.	64	194	243	27.0	24.6	23.1	32.5	29.3	28.0	22.7	21.0	19.7	72.9	82.0	23.6	20.7	0.9	1.2
		Feb.	848	650	478	25.6	23.7	22.4	30.4	28.4	26.5	22.2	20.6	19.6	83.3	88.0	19.1	17.6	0.5	1.1
		Mar.	450	375	301	25.3	23.3	21.8	30.8	28.7	26.7	21.1	19.4	18.2	82.7	86.9	21.7	19.0	0.5	1.0
	Seasonal mean		***384***	***342***	***310***	***26.2***	***24.1***	***22.7***	***31.4***	***29.0***	***27.4***	***22.1***	***20.5***	***19.2***	***78.1***	***83.9***	***22.1***	***19.9***	***0.8***	***1.2***
	SD		***349***	***227***	***117***	***0.8***	***0.7***	***0.7***	***1.0***	***0.6***	***0.9***	***0.7***	***0.7***	***0.7***	***5.7***	***4.3***	***2.2***	***2.1***	***0.3***	***0.2***
	Relative value 1		*0.76*	*0.88*	*0.95*	*0.96*	*0.96*	*0.96*	*0.96*	*0.96*	*0.97*	*0.96*	*0.96*	*0.95*	*1.03*	*1.03*	*1.01*	*1.00*	*1.01*	*1.04*
	Relative value 2		-	*0.95*	*0.90*	-	*0.92*	*0.86*	-	*0.92*	*0.88*	-	*0.92*	*0.87*	-	*1.07*	-	*0.90*	-	*1.60*

Relative value 1 = mean in 2008/09 divided by mean in 2009/10 (i.e., annual difference). Relative value 2 = mean at site A in both years divided by mean at sites B or C (i.e., regional difference).

3.2. Cropping schedule and growth stage

The planting date in the control plots in 2008/09 (30 November ± 3.0 d, mean ± standard deviation) was an average of 11 days earlier than that in 2009/10 (11 December ± 4.4 d) (Table 1) because the rainy season started earlier (Fig. 1). The planting date was earlier at the high-elevation site C than at the lower elevations of sites A and B (Table 1). The flowering date in the control was earlier at sites A and B than at site C, even though the planting date was earliest at site C.

The delayed planting date did not affect the duration from planting to seedling emergence

(Table 1). The period from planting to flowering was prolonged by 10 to 27 days in 2008/09 as a result of the delayed planting, except at site A, where there appeared to be no significant difference. In 2009/10, flowering was delayed by 9 to 30 days compared with the control.

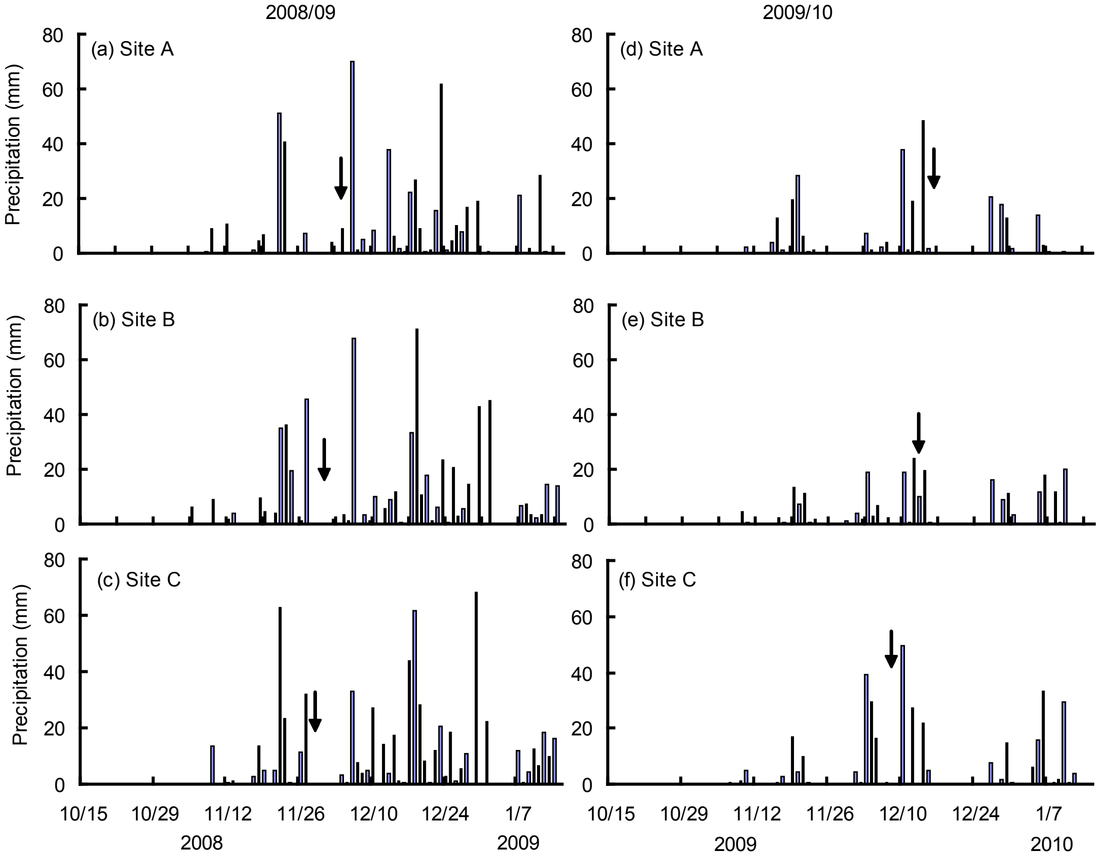

Fig. 1 Daily precipitation pattern at three villages in Zambia in (a, b, c) 2008/09 and (d, e, f) 2009/10. Arrows indicate the planting date in the control.

3.3. Grain yield

Grain yield in the control at sites A and B was greater than 1100 kg ha^{-1} in 2008/09 and greater than 700 kg ha^{-1} in 2009/10 season, with the exception of field ASm2 in 2009/10 (480 kg ha^{-1}) (Table 3). However, the yield at site C was less than 300 kg ha^{-1} in both years. The delayed planting date reduced grain yield significantly ($P < 0.001$), by an average of about 19% for all years and locations combined (Fig. 2).

The changes in biomass and harvest index also explained the variation in grain yield ($r > 0.65$, $P < 0.001$; Table 3). Of the yield components, the grain yield variations were explained best by grain density ($r = 0.956$, $P < 0.0001$), but individual grain size was also significant ($r = 0.529$, $P < 0.01$). No significant relationship between grain yield and the number of plants per hectare was observed ($r = 0.240$, ns).

Table 3. Grain yield, biomass yield, and harvest index of maize sown on three dates in the 2008-2009 and 2009-2010 growing seasons in Zambia. Elevations: site A < site B < site C.

Year	Site	Farmer's field ID	Treatment	Grain yield			Plant establishment		Individual grain weight		Grain density		Biomass			Harvest index	
				kg ha^{-1}			10^{3} ha^{-1}		g 100-grains^{-}		10^{3} ha^{-1}		kg ha^{-1}				
2008/09	A	ASn1	Control	1157	±105		26.8		33.7		3430		2263			0.51	
			10d later	1205	±207	(1.04)	30.0	(1.12)	29.1	(0.86)	4144	(1.21)	4497	±682	(1.99)	0.27	(0.52)
			20d later	1214	±115	(1.05)	37.5	(1.40)	18.6	(0.55)	6537	(1.91)	11594	±633	(5.12)	0.10	(0.20)
		ASm2	Control	1117	±137		23.7		29.9		3729		2765			0.40	
			10d later	740	±162	(0.66)	45.0	(1.90)	23.0	(0.77)	3215	(0.86)	3794	±166	(1.37)	0.20	(0.48)
	B	BCh2	Control	1956	±166		24.6		32.8		5966		3733			0.52	
			10d later	1375	±261	(0.70)	30.0	(1.22)	28.2	(0.86)	4875	(0.82)	4324	±484	(1.16)	0.32	(0.61)
	C	CSa1	Control	197	±71		22.6		31.7		622		1161			0.17	
			10d later	10	±9	(0.05)	26.3	(1.16)	7.3	(0.23)	134	(0.22)	891	±139	(0.77)	0.01	(0.06)
			20d later	0	±0	(0.00)	17.5	(0.77)	0.0	(0.00)	0	(0.00)	501	±217	(0.43)	0.00	(0.00)
		CSa2	Control	252	±45		17.0		21.9		1149		1096			0.23	
			10d later	138	±67	(0.55)	33.8	(1.98)	19.0	(0.86)	728	(0.63)	1482	±140	(1.35)	0.09	(0.40)
		CSa3	Control	286	±87		18.9		25.4		1127		1002			0.29	
			10d later	26	±11	(0.09)	34.4	(1.82)	14.5	(0.57)	177	(0.16)	1209	±164	(1.21)	0.02	(0.07)
2009/10	A	ASn1	Control	766			15.7		32.7		2342		2153			0.36	
			10d later	478	-	(0.62)	35.0	(2.23)	24.7	(0.76)	1937	(0.83)	1207		(0.56)	0.40	(1.11)
			20d later	530	±0	(0.69)	23.8	(1.51)	24.3	(0.74)	2179	(0.93)	1654		(0.77)	0.32	(0.90)
		ASm2	Control	480			18.7		30.7		1565		1384			0.35	
			10d later	492	±109	(1.02)	23.8	(1.27)	26.0	(0.85)	1897	(1.21)	1099		(0.79)	0.45	(1.29)
	B	BCh2	Control	885			26.3	-		-			3169			0.28	
			10d later	996	±0	(1.13)	23.1	(0.88)	26.2		3801		3100		(0.98)	0.32	
	C	CSa1	Control	642			26.1		24.7		2600		2054			0.31	
			10d later	467	±61	(0.73)	23.8	(0.91)	22.0	(0.89)	2127	(0.82)	1511		(0.74)	0.31	(0.99)
			20d later	510	±97	(0.79)	28.1	(1.08)	24.7	(1.00)	2063	(0.79)	1954		(0.95)	0.26	(0.83)
		CSa2	Control	90			10.9		29.7		304		354			0.26	
			10d later	184	±46	(2.03)	19.4	(1.77)	22.2	(0.75)	828	(2.72)	1125		(3.18)	0.16	(0.64)
		CSa3	Control	58			23.0		24.7		236		857			0.07	
			10d later	103	±59	(1.76)	29.4	(1.28)	21.7	(0.88)	472	(2.00)	1153		(1.35)	0.09	(1.30)
	r			-			0.240	ns	0.529	**	0.956	***	0.656	***		0.662	***

Values in parentheses indicate the treatment value divided by the value in the control. Grain yield ± SE (n =12 plot for the control plots, n = 4 plot for the 10-d-later and 20-d-later plots). *r*, correlation coefficient with grain yield. ***, *P < 0.001* ; **, *P < 0.01* ; ns, not significant.

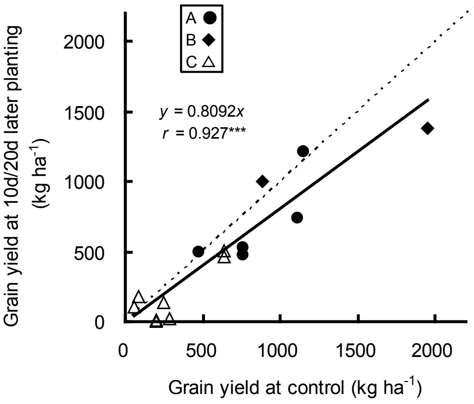

Fig. 2 Relationship between grain yield in the control (normal planting date) and grain yield in the delayed-planting treatments (ca. 10 or 20 days later). The dashed line represents the line y = x. ***, P < 0.001

To clarify the factors responsible for the yield decrease in response to the delayed planting, we plotted the ratio of grain yield in the delayed planting treatments to that in the control (the "relative yield") as a function of the mean weather conditions from planting to 30 days after planting (Fig. 3). The 30-day period after planting was chosen based on the duration of the most greatly delayed planting (ca. 20 d) and the period from planting to emergence (ca. 10 d). Note that because the CSa2 and CSa3 plots in 2009/10 showed extremely high relative values (>1.7) due to the exceptionally low yield in these plots (less than 100 kg ha^{-1}), which would have introduced excessive noise in the analysis (Table 3), we excluded these data from the regression analysis (circled points in the figures). To confirm that this approach was acceptable, we repeated the regression analysis with these data points included, and found weaker but still linear regressions (data not shown). Although precipitation, solar radiation, and relative humidity were not significantly correlated with relative yield (Fig. 3), wind speed and air temperature were both significantly correlated with the variations of the yield response; windier and cooler conditions both significantly decreased the relative yield.

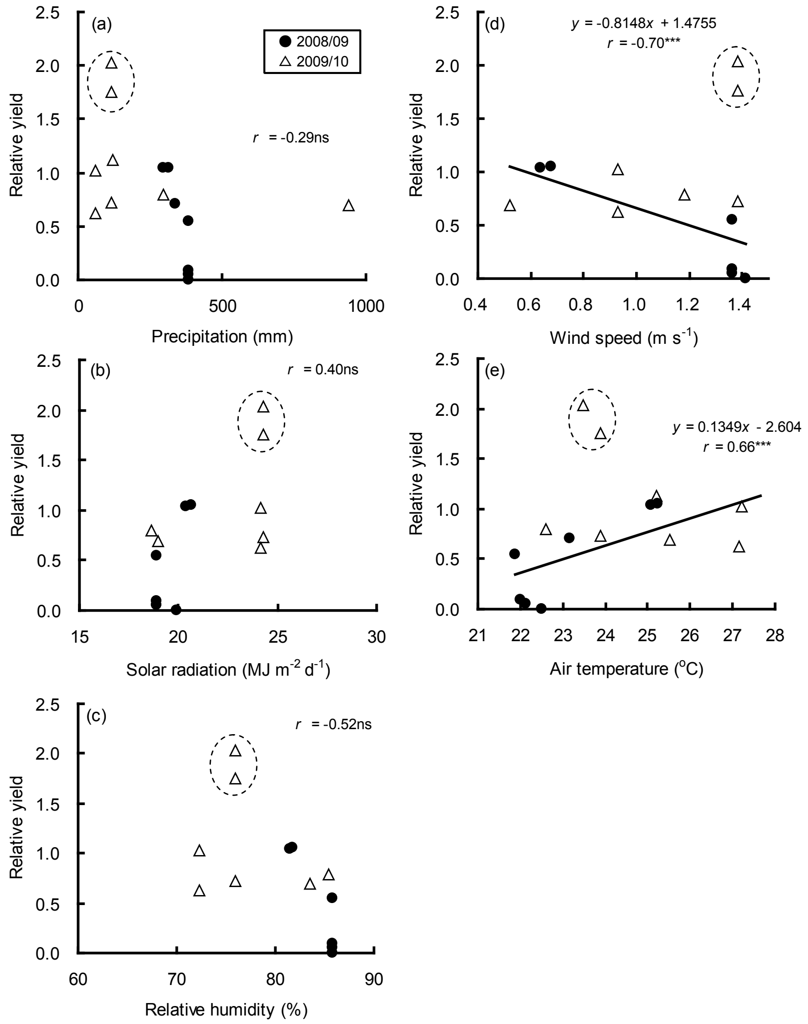

Fig. 3 Relationship between relative yield (defined as the ratio of the yield in the 10-d-later and 20-d-later treatments to that in the control) and mean weather conditions during the 30 days after planting.
***, $P < 0.001$; ns, not significant. Circled data was excluded from the regression analysis.

4. Discussion

Our study results demonstrated that the normal planting date, which smallholders have traditionally chosen, produced higher grain yields than the delayed planting dates, which had yields that averaged 19% lower than those in the control for all sites and years combined (Fig. 2, Table 3). We did not examine planting before the normal planting date, but the observed precipitation pattern (Fig. 1) suggested that because of low rainfall before the control date (i.e., the high risk of drought during seed germination and seedling establishment), the normal planting date in the control represents the early limit for planting at the study sites. Thus, our field trials in two seasons confirmed that the smallholders chose the optimal planting schedule for high productivity of maize in their part of Zambia under the current low-input management practices. However, the current grain yield for all villages in the present study was much lower than the national average (1742 kg ha^{-1}) at all sites except BCh2 in 2008/09 (Table 3).

The reduction of yield due to the delayed planting was attributed primarily to the reduction of grain density (number per hectare; Table 3). Because grain density is known to be determined by biomass production (Uhart and Andrade, 1995; Paponov *et al.*, 2005; Sadras, 2007), the reduced biomass production that resulted from delayed planting appears to be the key factor responsible for the smaller yields in these treatments. We initially assumed that water availability would be one of the most important factors that limits maize production in Zambia, but precipitation during the 30 days after planting did not significantly explain the yield variation (Fig. 3). Instead, wind speed and air temperature proved to be the most significant factors that determined the response to delayed planting. Because C_4 plants (including maize) grow better at higher temperatures, lower temperatures and windy conditions (which can decrease plant surface temperature) can both reduce growth (Lafitte *et al.*, 1997; Soldati *et al.*, 1999). Soldati *et al.* (1999) examined the effects of low temperature during vegetative growth of maize on final leaf number, and showed that low temperatures decreased the final leaf number. Lower temperatures during the vegetative stage in the present study might therefore have had a direct negative impact on biomass production. At the same time, the growth reduction caused by lower temperatures would decrease canopy development, resulting in a lower ability to compete with weed species that are adapted to those conditions. Tollenaar *et al.* (1997) examined the effects of weeding under different levels of N input, and showed that the yield losses caused by weed competition were greater at low N input (a 48 to 64% reduction) than at high N input (a 17 to 20% reduction). In our experiment, we did not apply any fertilizers or manure, and this would have decreased the ability of the corn to compete with weeds, resulting in decreased growth. However, we did not measure the weed biomass and therefore cannot confirm this hypothesis.

We used a single local cultivar in the present study, but genotypic variations in plant responses to environmental differences will be an important issue to consider both to optimize crop yield at the study sites and to preserve food security in the face of global climate change, particularly given the limited resources available to farmers in southern Africa. Paponov *et al.* (2005) tested the response of grain production per unit N uptake in two maize genotypes, and found that one cultivar had 34% higher N-use efficiency for producing grain of sink capcity. The use of such efficient cultivars might increase the harvest index under the conditions of limited biomass production observed at the study sites, resulting in higher grain yield.

Accurate prediction of future maize productivity is essential to let nations ensure food security during a time of global climate change. The yield responses observed in the present study correspond well to model predictions (Tsubo *et al.*, 2005ab; Abraha and Savage, 2006). However, the prediction of changes during developmental stages differed from model predictions. Models of maize growth usually predict that later planting would decrease the growth period and decrease canopy radiation capture, thereby decreasing plant biomass and yield (Tsubo *et al.*, 2005ab; Abraha and Savage, 2006). However, it is interesting that in the present study, the delayed planting generally increased the period from sowing to flowering (Table 1), though despite that increase, biomass and yield were both reduced.

Ongoing global climatic change will have a strong impact on African maize productivity and food security (Lobell *et al.*, 2008). To increase the accuracy of predictions of the future impact on African maize productivity, more detailed measurements using local farmers and their common cultivation practices will be required.

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