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Full Length Research Paper

Simulating planting date and cultivar effects on dryland maize production using CERES-maize model

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Maize farmers and extension agents in dry sudan savanna need information on how planting date and the choice of variety affect grain yield. This study was conducted to test the ability of model to predict maize yields under varying planting dates. Data on two open-pollinated maize cultivars (TSB-SR and TZE-COMP4) sown on different dates (June 29th, July 13th, July 21st and July 28th) in 2006 and 2007 at Azir (11° 01.820´ N, 12°37.714´ E; 441 m) and Damboa (11° 10.379´; 12° 47.145´E; 396 m) in the Sudan Savanna of Nigeria were used in running the model. Experimental data from Azir in 2006 was used to calibrate the model, while the data for 2007 at Azir 2006 and 2007 at Damboa were used for model validation. The model predicted days to anthesis at Damboa as reasonably well in both 2006 and 2007 (*d-index* >0.8), while at Azir, the prediction of days to anthesis was very poor in 2007. The match between predicted and observed grain yield were very good in 2007 at both locations. The root mean square error (RMSE) values for grain yield in 2007 were 431.5 and 226.5 kg ha^{-1} at Azir, and 799.5 and 611.5 kg ha^{-1} at Damboa for TZB SR and TZE COMP4, respectively, while the *d*-index values were all greater than 0.94. Generally, the model predicted decrease in grain yield with delay in planting date except for TZB-SR at Azir in 2006 where planting on July 13th gave higher yield than planting on June 29th. The grain yield values from the simulations suggested late June to early July as the optimum planting window for both varieties at both Azir and Damboa.

Key words: CERES-maize, planting date, Sudan savanna.

INTRODUCTION

In the past three decades, maize production has increased greatly in the savannas of Nigeria, including semi-arid Sudan savanna zone (Manyong et al., 1996; FAOSTAT, 2010). The total annual national production has increased from 658, 000 tons in 1978 to about 7,338,840 tons in 2009 (FAOSTAT, 2011). Traditionally, maize production in Nigeria has mainly been in the humid forest and the guinea savannas (Kassam et al., 1975; Manyong et al., 1996) where the annual rainfall is greater than 1,000 mm, the length of the growing season is greater than 120 days and there is low likelihood of drought during the growing season (Carsky and Iwuafor, 1999). The development of early and extra-early maturing maize cultivars in recent years has led to increase in cultivation of the crop even in the drier Sudan savanna zone where agriculture is heavily dependent on the seasonal characteristics of rainfall (Fakorede et al., 2003). The zone has a semi-arid climate with a monomodal rainfall that ranges between 500 to 800 mm per annum and a growing season of 100 to 120 days (Ogungbile et al., 1998; Kamara et al., 2009). The amount and duration of rainfall diminishes as one moves from south to north of the zone (Nnoli et al., 2006).

In addition, there is a very high year to year variability in the onset, amount and duration of rainfall (Ati et al., 2002). There is high incidence of crop failure in the zone

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because of dry spells after planting. Farmers usually plant with the first rains in order to achieve early food security and also capture the flush of soil N that comes with the first rains (Jagtap and Abamu, 2003; Sachs et al., 2010), however, they risk crop failure and the need to replant. Because higher yielding maize varieties take longer to mature, farmers trade-off yield and risk in selecting which varieties to grow (Laurensen and Ninomiya, 2001). Maize is very sensitive to drought stress during flowering stage in order to achieve high yield and as such planting should be timed to avoid moisture stress at this critical stage (Heisey and Edmeades, 1999; Kamara et al., 2009). Maize farmers and extension agents in the Sudan savanna zone need information on how planting date and the choice of variety affect grain yield.

Cropping system simulation models such as CERES-Maize, present very promising opportunity for extrapolating short-duration field experimental results to other years and other locations making use of long-term weather and soil information (Mathews et al., 2002; Anapalli et al., 2005). The objective of this study was to assess the potential of CERES-Maize for simulating the performance of two open-pollinated maize cultivars (TZB-SR, TZE COMP 4) at four planting dates (from late June to late July) during two growing seasons (2006, 2007) at Azir and Damboa in the semi-arid sudan savanna of Nigeria.

MATERIALS AND METHODS

Field experiments

The field experiments were conducted in 2006 and 2007 in Borno State, Nigeria at the International Institute for Tropical Agriculture (IITA) research sites at Azir (11° 01.820´ N, 12°37.714´ E; 441 m) and Damboa (11° 10.379´; 12° 47.145´E; 396 m) in the Sudan Savanna ecological zone. The annual rainfall in the area ranges between 600 to 800 mm. The land, which was previously under fallow for five years, was ploughed and ridged using draft animals. Four planting dates (29th June, 13th, 21st, and 28th July) and two open-pollinated maize cultivars (TZB-SR and TZE COMP4 C2) were evaluated in the experiment. TZB-SR is a widely used late maturing cultivar (120 days to maturity), while TZE COMP4 C2 is an early-maturing cultivar (90 days to maturity). The treatments were arranged in a split plot design with three replications. Planting date was assigned to main plot and maize cultivars to subplots. Planting distance was 0.75 m between rows and 0.25 m between plants to give a plant population of 53,333 plants ha^{-1}. Each subplot was arranged in four rows of 5 m length. At planting, fertilizer in the form of NPK was applied at the rate of 40 kg ha^{-1} for each nutrient. Top dressing of N fertilizer, in the form of urea, was done at the rate of 60 kg N ha^{-1} at 5 weeks after planting (WAP).

Model calibration

The CERES-Maize model of DSSAT 4.5 (Hoogenboom et al., 2009) was used to evaluate the performance of maize under the different planting dates. The model integrates numerous factors that affect growth and development and predict maize growth and development on a daily basis throughout the life cycle of the crop (Jones et al., 2003; Staggenborg and Vanderlip, 2005). The management practices carried out during field experimentation at Azir and Damboa were used to create the experimental file (file X) of the DSSAT shell. Soil physical and chemical properties from profiles dug at the experimental sites were added into the soil file. Daily records of minimum and maximum temperature and precipitation were used to generate the weather file used in the simulation. Data on solar radiation was generated in the DSSAT weatherman shell from daily minimum and maximum temperature.

The genetic coefficients of TZB SR and TZE COMP4 are already in DSSAT 4.5; the CERES maize model was therefore calibrated by comparing observed and predicted days to tasselling and grain yield at Azir in 2006 and adjusting the genetic coefficients until a close agreement was found.

Model evaluation

The experimental data at Azir in 2007 and Damboa in 2006 and 2007 were used to evaluate the model by comparing with simulation results. The statistics used in the model evaluation were:

Root mean square error, *RMSE*

$$RMSE = \left[N^{-1} \sum_{i=1}^{n} (P_i - O_i)^2 \right]^{0.5}$$

An index of agreement, *d*

$$d = 1 - \left[\sum_{i=1}^{n} (P_i - O_i)^2 / \sum_{i=1}^{n} (|P_i'| + |O_i'|)^2 \right]$$

where N = number of observed values; Pi = predicted value for the ith data; O_i = observed value for the ith data; $P' = P_i - \bar{O}$ $(average\ of\ the\ observed)$; $O' = O_i - \bar{O}$

The smaller the RMSE, the better the agreement between predicted and observed values (Willmott, 1982). The values for *d* ranged from 0 to 1, as the value approaches 1, the agreement between prediction and observation improved (Confalonieri et al., 2009).

RESULTS AND DISCUSSION

Soil and weather conditions

The field at Azir was imperfectly drained, level to nearly level crest with dull yellowish brown surface soil and a sandy clay loam texture. While at Damboa, the field was a poorly drained level crest with dark brown sandy clay loam surface horizon. The soils at both locations were characterized as Gleyic Luvisol following the FAO classification system. Tables 1 and 2 showed some physico-chemical properties from soil profiles dug at the two locations. Figure 1 shows the decadal rainfall at Azir and Damboa in 2006 and 2007. The total rainfall at Azir was higher in 2007 (1051.8 mm) than in 2006(764.6 mm), while at Damboa, the total rainfall was similar in both years (864 and 839 mm in 2006 and 2007, respectively). At both locations, the rainfall was unevenly distributed in

Table 1. Soil physical and chemical properties at Azir.

Depth (cm)	Bulk density (Mg m^{-3})	Sand (g kg^{-1})	Silt (g kg^{-1})	Clay (g kg^{-1})	pH	Organic C (g kg^{-1})	Total N (g kg^{-1})	Exchangeable bases Ca (cmol kg^{-1})	Mg (cmol kg^{-1})	K (cmol kg^{-1})	Na (cmol kg^{-1})	Exchangeable acidity (cmol kg^{-1})	ECEC (cmol kg^{-1})
0 - 14	1.3	505	207	288	7.8	4.68	2.38	4.4	2.0	0.33	0.46	0.20	7.39
14 -32	1.25	380	357	263	7.5	10.92	2.10	6.4	0.4	0.23	0.36	0.30	7.69
32 -43	1.43	355	357	288	7.3	7.02	2.52	6.4	1.2	0.21	0.40	0.20	8.41
43 - 64	1.62	355	207	438	7.4	4.68	2.38	4.4	1.6	0.19	0.49	0.30	6.98
64 - 90	1.54	330	232	438	7.4	2.34	3.08	7.2	2.8	0.36	0.60	0.20	11.16
90 - 160	1.40	380	157	463	7.5	0.98	2.66	22.8	4.4	0.67	0.96	0.30	29.13

Table 2. Soil physical and chemical properties at Damboa.

Depth (cm)	Bulk density (Mg m^{-3})	Sand (g kg^{-1})	Silt (g kg^{-1})	Clay (g kg^{-1})	pH	Organic C (g kg^{-1})	Total N (g kg^{-1})	Exchangeable bases Ca (cmol kg^{-1})	Mg (cmol kg^{-1})	K (cmol kg^{-1})	Na (cmol kg^{-1})	Exchangeable acidity (cmol kg^{-1})	ECEC (cmol kg^{-1})
0 - 19	1.23	480	182	338	6.8	4.29	2.10	4.8	1.2	0.26	0.45	0.2	6.91
19 - 37	1.40	505	232	263	6.9	4.29	3.92	4.8	0.4	0.19	0.53	0.2	6.12
37 - 52	1.44	330	257	413	7.1	3.90	3.36	4.8	2.0	0.27	0.45	0.3	7.82
52 - 80	1.36	380	282	338	7.1	1.56	3.50	6.4	0.4	0.33	0.44	0.1	7.67
80 - 100	1.56	330	182	488	7.1	1.17	3.22	5.2	0.8	0.32	0.42	0.2	6.94
100 - 120	1.23	380	232	380	6.3	3.12	3.64	3.6	1.2	0.26	0.57	0.2	5.83

both years. More than a quarter of the total rainfall at Damboa in 2007 fell within the first ten days of August.

The maximum air temperature at Azir was 36.9°C in 2006 and 35.8°C in 2007, while the average minimum air temperatures were 23.7 and 25.9°C in 2006 and 2007, respectively (Kamara et al., 2009). At Damboa, the average maximum air temperatures were 37.8 and 36.5°C, and average minimum temperatures were 22.0 and 22.4°C in 2006 and 2007, respectively. The maximum and minimum air temperatures at both locations fell within the optimum range for maize production.

Model validation

Data from planting date experiment at Azir in 2007 and at Damboa in 2006 and 2007 were used for validating the model. The validation datasets comprised of days to anthesis, grain yield, tops weight and harvest index and number of kernels per plant. In calibrating the model using 2006 data from Azir, a very good agreement was found between observed and predicted days to anthesis, with RMSE of 1.5 and 0.5 days and d-index values of 0.9689 and 0.9958 for TZB SR and TZE COMP4, respectively (Table 3), but in validating the model using 2007 experimental data from Azir in 2007, a poor match was observed between simulated and observed days to anthesis for both cultivars, with RMSE of up to 15 days (Table 3). However, the simulated days to anthesis at Damboa in both 2006 and 2007 showed very good correspondence with observed values, with TZE COMP 4 showing better correspondence

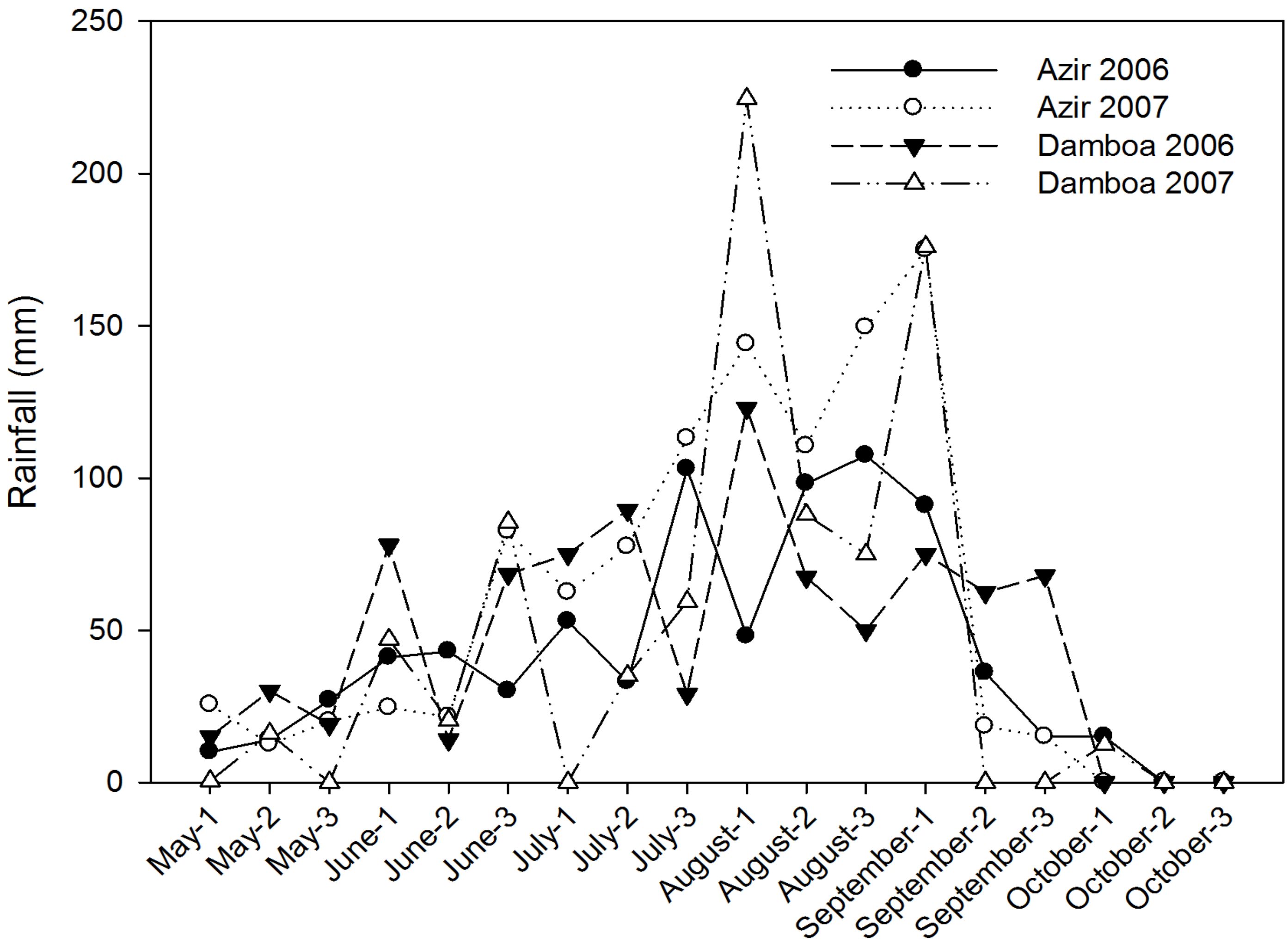

Figure 1. Ten-day rainfall at Azir and Damboa in 2006 and 2007.

than TZB SR in both years (Table 4).

Comparisons of simulated and observed grain yields showed good agreement in 2007 for both cultivars at both locations. The respective RMSE values for TZB SR and TZE COMP4 were 431.5 and 226.5 kg ha^{-1} at Azir, and 799.5 and 611.5 kg ha^{-1} at Damboa, while the d-index values for TZB SR and TZE COMP 4 were 0.979 and 0.991 at Azir, and 0.949 and 0.965 at Damboa, respectively. For both cultivars at both locations, the match between observed and predicted yield values was better in 2007 as reflected by the higher d-index values compared to 2006 (Tables 3 and 4 and Figure 2). Generally, the model predicted decrease in grain yield with each delay in planting date except for TZB-SR at Azir in 2006 where planting on July 13th gave higher yield than planting on June 29th (Figure 2). The widest differences between observed and simulated yields were at Azir in 2006 with July 13th planting. Dry spell in the second and third weeks of July 2006 at Azir affected crop establishment and consequently yield. The model did not capture the moisture stress at this period and predicted much higher yields than were observed. The results of the simulation at both locations showed higher grain yields with June 29th planting date for both TZB-SR and TZE COMP4 at both locations as compared to later planting dates. This result is in line with the experimental data.

In 2006, a very good correspondence was found between observed and predicted tops weight at Azir with both TZB-SR and TZE COMP4 (RMSE of 326.5 and 249.0 kg ha^{-1} and d-index values of 0.9932 and 0.9965, respectively). However, in 2007, the match was not very good with both cultivars (RMSE > 3000 kg ha^{-1}). At Damboa, the reverse was observed; the correspondence between observed and predicted tops weight being much better in 2007 than 2006.

The harvest index simulations showed reasonable agreement with observed values in both years for both

Table 3. *RMSE* and *d-index* values of the comparison between observed and predicted characters of maize at Azir, sudan savanna.

Statistics	Days to anthesis		Grain yield (kg ha^{-1})		Tops weight		Harvest index		Kernels/ear	
	TSB-SR	TZE COMP4	TSB-SR	TZE COMP4	TSB-SR	TZE COMP4	TSB-SR	TZE COMP4	TSB-SR	TZE COMP4
RMSE	1.5	0.5	352.0	808	326.5	249.0	0.0375	0.0785	159.5	158.5
d-index	0.9689	0.9958	0.9730	0.8833	0.9932	0.9965	0.9349	0.8337	0.6057	0.6012
RMSE	15.5	15.0	431.5	226.5	4198	3183.5	0.0825	0.0485	50.5	54.5
d-index	0.468	0.4232	0.9794	0.9911	0.7178	0.6253	0.8315	0.9232	0.9617	0.7611

Table 4. *RMSE* and *d-index* values of the comparison between observed and predicted characters of maize at Damboa, sudan savanna.

Statistics	Days to anthesis		Grain yield (kg ha^{-1})		Tops weight		Harvest index		Kernels/plant	
	TSB-SR	TZE COMP4	TSB-SR	TZE COMP4	TSB-SR	TZE COMP4	TSB-SR	TZE COMP4	TSB-SR	TZE COMP4
RMSE	2.0	0.5	1893	1646	5630	2887	0.074	0.057	54.4	50.8
d-index	0.8790	0.9669	0.6763	0.7506	0.5907	0.3885	0.6684	0.7696	0.8657	0.7744
RMSE	4.5	1.5	799.5	611.5	211	2179	0.1955	0.2005	416.3	191.8
d-index	0.8803	0.9751	0.9494	0.9648	0.9987	0.8929	0.5984	0.5830	0.2848	0.3327

cultivars at Azir. The RMSE ranged between 0.038 and 0.083, while the d-index ranged between 0.8315 and 0.9349 (Table 3). The correspondence between observed and predicted harvest index at Damboa was less (Table 4). The model poorly predicted the number of kernels per plant at both locations with both cultivars. Other researchers have also reported less accurate predictions of grain number per plant despite good predictions of yield (Piper and Weis, 1990; Jagtap et al., 1993; Lopez-Cedron et al., 2008).

Some of the discrepancies between predicted and observed values may be related to uncertainties associated with parameters and inputs used in any model calibration (Timsina et al., 2008). For example, the solar radiation data usedin running the model was estimated from records of daily minimum and maximum air temperatures due to unavailability of complete weather data for the experimental locations; this may result in inaccuracies in the model predictions. Management and methodological issues in the observation and recording of days to flowering could be responsible for the wide discrepancy between observed and simulated days to 50% anthesis at Azir in 2007.

Conclusions

The effects of planting date on yields of maize cultivars TZB-SR and TZE COMP 4 could be reasonably predicted for locations in the Sudan savanna agroecological zone using the CERES-Maize model. The predictions for tops weight and number of kernels per plant were less accurate. Due to the unavailability of long-term weather records it was not possible to carry out seasonal analysis to predict optimum plant window based on simulations using many years of weather records, however, results of the study showed that crop yield simulations with CERES-Maize could be useful in taking decision on planting and replanting so as to fit the crops maturity length and growth stages to growing season. The unavailability of detailed weather records is a serious limitation to the potential widespread use of the model in planning the cropping calendar in

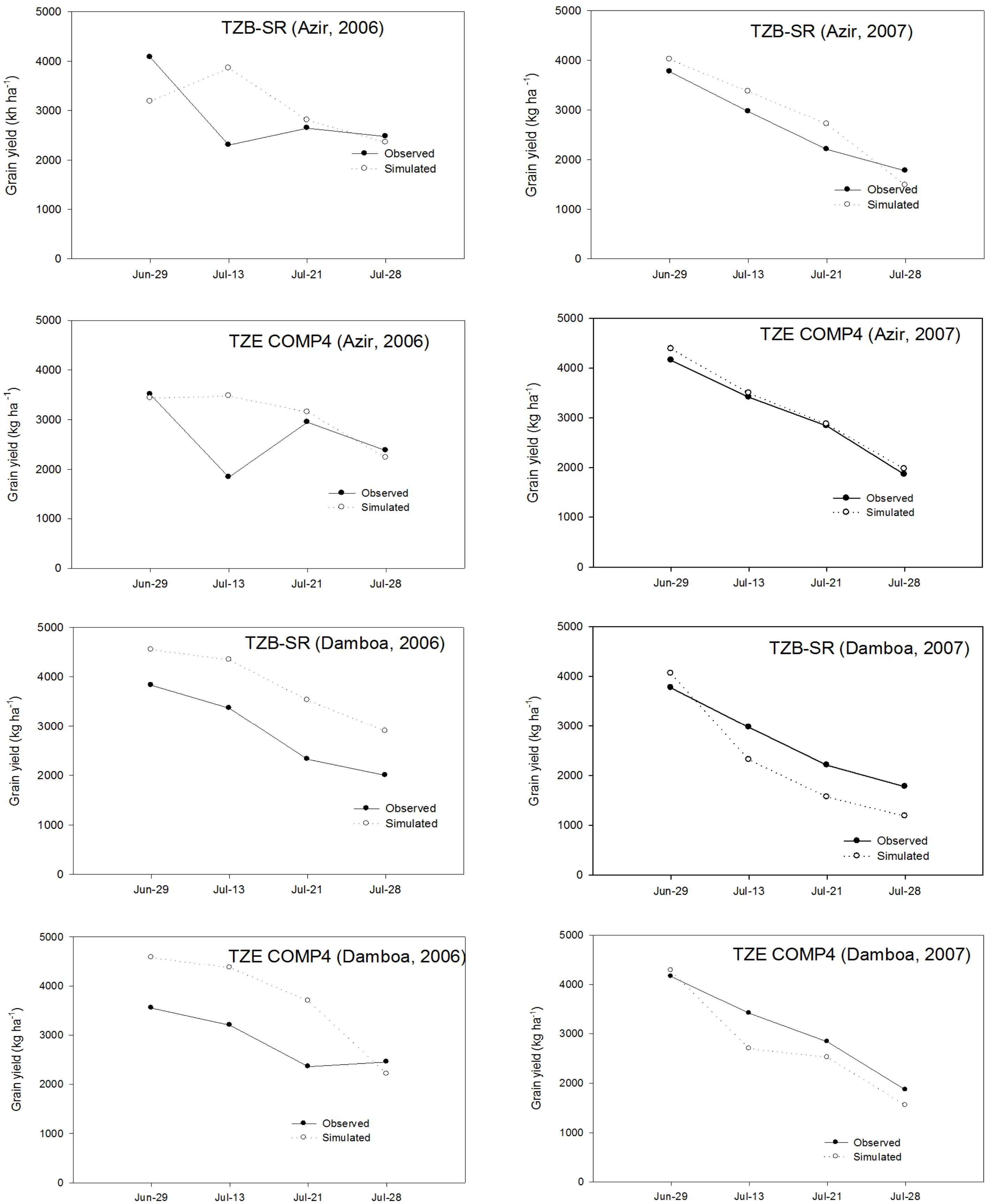

Figure 2. Effect of planting date on maize grain yield at Azir and Damboa in 2006 and 2007.

Nigeria.

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