Pak. j. life soc. Sci. (2016), 14(2): 104-114 E-ISSN: 2221-7630;P-ISSN: 1727-4915

Pakistan Journal of Life and Social Sciences

www.pjlss.edu.pk

RESEARCH ARTICLE

Application of DSSAT Model for Sowing Date Management of C_4 Summer Cereals for Fodder and Grain Crops under Irrigated Arid Environment

Shakeel Ahmad[1], Sajjad Hussain[1], Zartash Fatima[1], Ghulam Abbas[1], Atique-ur-Rehman[1], Muhammad Rafique Khan[1], Haseeb Younis[1], Sahrish Naz[1], Muhammad Sohail[1], Muhammad Ajmal[1], Naseem Abbas[1], Muhammad Akhtar[1], Abdur Rauf[1], Mehrab Khan[1], Zeshan Ali[1], Muhammad Hassan[1], Muhammad Rizwan[1], Ruqia Safdar Bajwa[1], Amna Ajmal[1], Safina Naz[1], Hina Ali[2], Azhar Ali Khan[3], Muhammad Ali[4], Ghulam Sarwar[5], Muhammad Azam Khan[6] and Mirza Hasanuzzaman[7]

[1]Bahauddin Zakariya University, Multan-60800, Pakistan; [2]The Women University, Multan, Pakistan; [3]Pakistan Agricultural Research Council, Research and Training Station, Multan-60800, Pakistan; [4]Ghazi University, Dera Ghazi Khan-32200, Pakistan; [5]Cotton Research Station, Vehari, Pakistan; [6]Extension Wing of Agriculture, District Chiniot-35400, Punjab, Pakistan; [7]Sher-e-Bangla Agricultural University, Dhaka, Bangladesh

ARTICLE INFO

Received: Feb 20, 2016
Accepted: Jul 28, 2016
Online: Jul 31, 2016

Keywords
Crop modeling
DSSAT model application
Maize
Millet
Sorghum

***Corresponding Author:**
shakeelahmad@bzu.edu.pk

ABSTRACT

Fodder and grain yield of maize, millet and sorghum is constrained by environmental conditions by early or delay sowing dates instead optimum sowing dates. For optimization of fodder and grain yield, sowing at the suitable time to fit the cultivar physiological maturity duration and crop growing season is very important. Crop growth models could be used to find out the appropriate sowing time for a region. The purpose of this study was to evaluation and application of CSM-CERES models of maize, millet and sorghum for its capability to simulate growth, development, fodder and grain yield at various sowing dates. Three sowing dates treatments were applied for each crop experiment for grain purpose maize (SD_1=10 July, SD_2=17 July and SD_3=2 August) Millet (SD_1=20 July, SD_2=4 August and SD_3=10 August) and Sorghum (SD_1=15 August, SD_2=23 August and SD_3=27 August) in year 2015. Same sowing dates were applied as a treatment for fodder purpose for each crop experiment. Evaluation with the experimental data showed that performance of the CSM-CERES models of maize, millet and sorghum were well as indicated by good accurate simulation of crop phenology, total dry matter accumulation and fodder and grain yield against field trials observed data. For fodder production, d-value for maize, millet and sorghum was 0.98, 0.99 and 0.90; respectively. While, 0.98, 0.99 and 0.96 was the d-value for maize, millet and sorghum crops, respectively for grain yield. The RMSE value was 547.92, 272.11 and 299.73 for maize, millet and sorghum, respectively for fodder yield. 194.17, 122.62 and 143.64 was RMSE value for maize, millet and sorghum, respectively for grain yield. The simulation scenario showed that, mean maximum fodder and grain yield (at 50^{th} percentile) were recorded for maize crop sown on 10 July, millet on 20 July and 4 August, respectively and sorghum on 23 August. Therefore, DSSAT model could be applied effectively as a decision making tool for sowing date management of C_4 summer cereals to accomplish local demand of grain and fodder for human beings and animals, keeping in view, the climate change situations under irrigated arid environment.

INTRODUCTION

Maize, millet and sorghum are important crops, which are grown for dual purpose as a grain and fodder crops in Pakistan. Total sowing area of maize, millet and sorghum for grain purpose is 1.130, 0.171 and 0.408 M hectares, respectively. Total production for grain purpose of maize, millet and sorghum is 4.695, 0.103 and 0.258 M tones, respectively. Total sowing area of maize, millet and sorghum for fodder purpose is 0.09, 0.11 and 0.41 M hectares, respectively. Total production for fodder purpose of maize, millet and sorghum is 0.96, 0.76 and 6.31 M tones, respectively (GOP, 2015).

Several earlier studies have confirmed that the assessment of the crop sowing time influence the crop biological and economic yield (Ahmad et al., 2015; Gueye et al., 2015; Bussmann et al., 2016; Waongo et al., 2015; Mahmood et al., 2016). Varying the sowing time can be consequence in advantages and disadvantages (Marteau et al., 2011; Wolf et al., 2015; Xingfen et al., 2015; Tovignan et al., 2016). An optimum sowing time can expand the growing period, which permit crop plants to take up additional solar radiation, generate more photosynthates, as well as build up more dry matter accumulation (Lindquist et al., 2005; Rahman et al., 2004; Maton et al., 2007; Sun et al., 2007; Chunrong et al., 2013; Liu et al., 2013; Tsimba et al., 2013; Iizumi et al., 2014; Choi et al., 2016). Consequently, the optimum sowing time enabled through the growth and development of the cultivars with superior tolerance of sub-optimal circumstances normally yields more productivity, predominantly in regions with higher variations in growing season (Zhou et al., 2005; Soler et al., 2007, 2008; Dahmardeh and Dahmardeh 2010; Akponikpe et al., 2011; Teetor et al., 2011; Azrag and Dagash, 2015; Rezaei et al., 2014; Ibrahim et al., 2015; Ahmad et al., 2016a, b; Mubeen et al., 2016). Nevertheless, earlier or later sowing dates than optimal sowing time can increases the risks of reduction in agricultural resources use efficiency in arid and semi-arid regions and the risks of weeds, pests and diseases damage to crop plants. These harmful impacts can consequence in crop failure or noteworthy loss of biological and economic yield (Iken and Amusa, 2004; Berzsenyi and Lap, 2005; Aziz et al., 2007; Dera et al., 2014). Consequently, consideration of optimization in the sowing time decision is of very important. For the reason that the shifting of sowing time is the lowest-cost adaptation strategy to weather changes, it has previously been separately applied by agriculturists in numerous parts of the globe and it can be useful in the rest of the agricultural community with comparatively little attempt (Kucharik, 2008; El-Lattief, 2011; Erickson et al., 2011; Han et al., 2012a, b; Li et al., 2013; Tao et al., 2014). Changes in favorable situation such as the commencement of rainy or the wet period and harsh seasonal weather circumstances such as cold and dry spell can alter the optimal sowing times. These variations can higher crop production (Wajid et al., 2004; Laux et al., 2010; Tariq et al., 2011; Grassini et al., 2011; Han et al., 2012; Opsi et al., 2013; Florio et al., 2014). The remaining very important problem is that the climatic impact on the sowing time is extremely reliant on the regional geographical conditions, which prevents exact prediction of grain and fodder production of agricultural crops (Gesch and Archer, 2005; Liu et al., 2013; Verma et al., 2013; Waha et al., 2013; Gerardeaux et al., 2016).

Crop growth models put together by integrating the interdisciplinary research based information's obtained with the help of experimentations and technological novelty in various fields of biological, physical, and chemical science linking to production systems in Agriculture sector (Boote et al., 2010; Hoogenboom et al., 2015; Santos et al., 2016). Agricultural simulation models could be helpful tools in support of the assessment of alternative management choices for particular sites, counting sowing dates, fertilizers application levels, planting density and others (Folliard et al., 2004; Ma et al., 2006; Akponikpe et al., 2010; Waha et al., 2012). Consequently, these models may be able to enhance understanding as well as managements of the farming systems in a holistic approach (Fang et al., 2008; Fatondji et al., 2012). Cereal crops simulation models have been employed to study the performance of various management practices (Gungula et al., 2003). Crop growth models also provide the means to meet the requirements of influence of weather, soil, and crop managements on crop development, productivity as well as sustainability of farming systems (Matthews and Pilbeam 2005; Saseendran et al., 2005; Murty et al., 2007; Mubeen et al., 2013). Crop modeling as a tool can decrease the need for costly and time-consuming field experiments and could be utilized to analyze biological and economic yield gaps in an assortment of crops counting both cereal grain and fodder crops (Nouna et al., 2000; Saseendran et al., 2009).

The overall objective of the research was to evaluation of the performance of the CSM-CERES-Maize, CSM-CERES-Millet and CSM-CERES-Sorghum models for sowing date management for C_4 summer cereals for fodder and grain yields for irrigated-arid environment of Multan.

MATERIALS AND METHODS

Experimental location description

Field studies were carried out in 2015 at the research area of Faculty of Agricultural Sciences and Technology (FAST), Bahauddin Zakariya University (BZU) Multan (Latitude = 30.21º N Longitude = 71.46º E Elevation = 122 m). The study location is situated in cotton-based cropping region in arid region of Punjab. Soil texture class is silty-loam belonging to miani soil series. Soil sections which obtained at sowing time during 2015 having pH of 8.1, organic matter percentage 0.45%, whole nitrogen 0.032%, and obtainable phosphorus of 8.52 ppm as well as obtainable K of 164 ppm. The climatic condition of the area is arid with mean yearly highest and lowest temperatures of 46.5 and 19.4 °C, respectively yearly precipitation ranged from 50 to 150 mm. Monthly mean solar radiations throughout ranged from 16.2 to 32.5 MJ m^{-2} d^{-1}. The complete weather record is given in Fig. 1.

Experimental procedures

Maize, millet and sorghum crops were grown at various sowing dates for both fodder and grain purpose during 2015. Six field experiments were carried out in which three experiments were for grain purpose and three were for fodder purpose. Three sowing dates treatments were applied for each crop experiment for grain purpose maize (SD_1 = 10 July, SD_2 = 17 July and SD_3 = 2 August) Millet (SD_1 = 20 July, SD_2 = 4 August and SD_3 = 10 August) and Sorghum (SD_1 = 15 August, SD_2 = 23 August and SD_3 = 27 August). Similar sowing dates were applied as a treatment for fodder purpose for each crop experiment. Maize, millet and sorghum cultivar for grain purpose were Monsento-5219, HP-50 and JS-263, respectively. Maize, millet and sorghum cultivar for fodder purpose were Sargodha 2002, MB-87 and JS-2002, respectively. Field was ploughed 3-5 times with tractor mount cultivator and subsequently, followed by planking at field capacity.

Sowing of maize, millet and sorghum for grain and fodder purpose was done at particular sowing date treatment. Sowing of maize, millet and sorghum crop for grain purpose crop was done with the help of a hand drill, in which plant to plant distance was 20 cm and row to row distance was 65 cm. Fodder crops were sown by broadcast method using 98, 80 and 15 kg ha^{-1} seed rate for maize, millet and sorghum, respectively. However, the respective seed rate for grain crops was 37, 25 and 8 kg ha^{-1}. Manual and mechanical weeding was done for remove weeds. No weeding was done for maize, millet and sorghum fodder purpose. Tube-well irrigation water was applied to each experiment. Total 8, 5 and 4 irrigations were applied to each treatment of maize, millet and sorghum crop, respectively for grain purpose. Total 10, 7 and 6 irrigations were applied to each treatment of maize, millet and sorghum crop, respectively for fodder purpose. Recommended dose of nitrogen (215, 85 and 65 kg ha^{-1} for maize, millet and sorghum respectively) phosphorus (113, 55 and 43 kg ha^{-1} for maize, millet and sorghum respectively) and potassium (60, 35 and 30 kg ha^{-1} for maize, millet and sorghum respectively) fertilizer were applied. Sources of nitrogen, phosphorus and potassium were urea, Di ammonium phosphate (DAP) and Potassium sulphate (SOP), respectively. Whole Phosphorus and potassium fertilizer was applied at sowing time. Two splits of nitrogen fertilizer were applied at sowing and 35 days after sowing for each treatment for each crop. Manual harvesting was done with the help of sickle at physiological maturity for grain purpose. Fodder crops were harvested at 50% an thesis date.

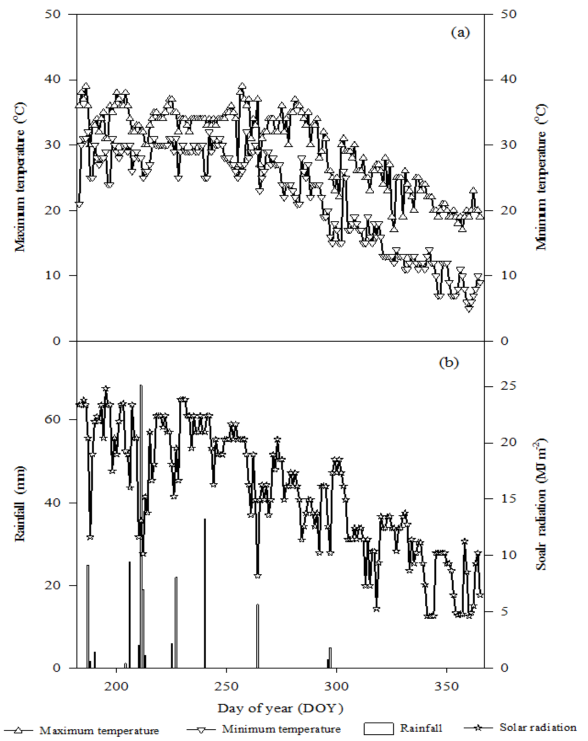

Fig. 1: Daily maximum temperature, minimum temperature (a), rainfall and solar radiation (b) during maize, millet and sorghum crops growing season at Multan, Pakistan.

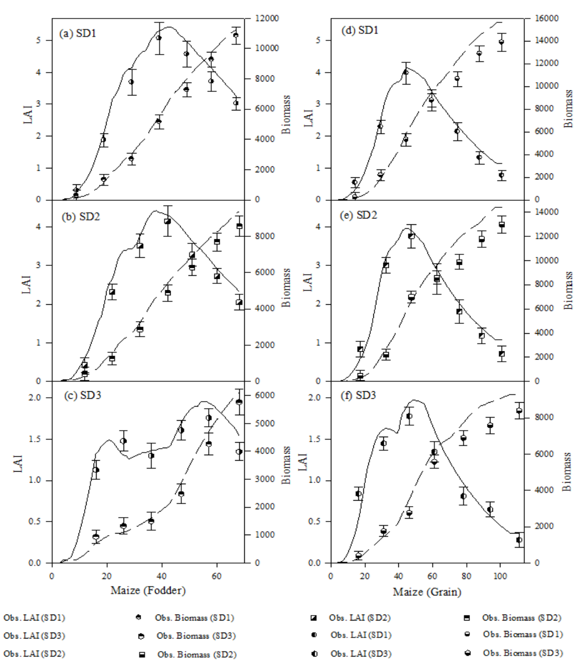

Fig. 2: Observed and simulated leaf area index (LAI) and biomass of maize for fodder (a, b, and c) and grain (d, e, and f) crops as effected by sowing dates under irrigated arid environment of Multan, Pakistan.

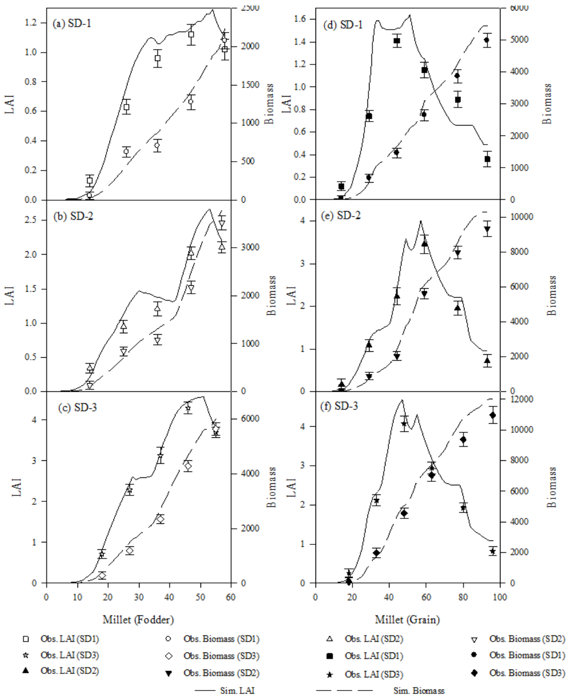

Fig. 3: Observed and simulated leaf area index (LAI) and biomass of millet for fodder (a, b, and c) and grain (d, e, and f) crops as effected by sowing dates under irrigated arid environment of Multan, Pakistan.

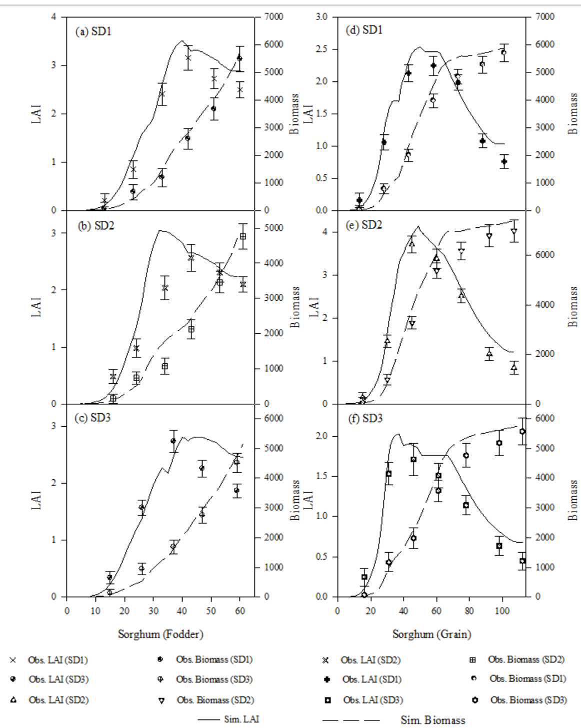

Fig. 4: Observed and simulated leaf area index (LAI) and biomass of sorghum for fodder (a, b, and c) and grain (d, e, and f) crops as effected by sowing dates under irrigated arid environment of Multan, Pakistan

Plant sampling and measurements

Maize, millet and sorghum crops phonological and developmental data for both grain and fodder purpose were recorded by standard procedure. Anthesis and physiological maturity dates were recorded at 50% level. Samples of 150-200 g fresh biomass were oven-dried at 75 ºC temperature for dry matter weights. Sample of 150–200 g leaves were gained, then leaf area was recorded with leaf area meter. Leaf area index (LAI) was considered as ratio of leaf area to ground area. Harvesting conducted manually from three middle rows (1 m^2) of every row to find out of biomass, fodder and seed yield.

Description of the CSM-CERES-Maize, CSM-CERES- Millet and CSM-CERES-Sorghum models

The CERES model of maize, millet and sorghum is embedded in DSSAT 4.6.1 (Decision Support System for Agro-technology Transfer) (Jones et al., 2003; Hoogenboom et al., 2015) was employed in the research. It is physio-biological based crop managing practices focused model which exploits C, N, water and energy equilibrium principles' to imitate growth-development of maize, millet and sorghum crops for both grain and fodder purpose (Folliard et al., 2004; Ma et al., 2006; Akponikpe et al., 2010; Waha et al., 2012). The models compute the growth and developmental stages and phases of crops plants on each day steps and as well as final grain and fodder yield is measured on the day of harvesting (Matthews and Pilbeam, 2005; Saseendran et al., 2005; Murty et al., 2007; Mubeen et al., 2013). Inputs necessary for model executions comprised crop managements practices, which are included crop plant genetics, sowing and harvesting dates, nitrogen, phosphorus, potassium fertilizer use levels, application dates/methods), ecological aspects comprising physico-chemical properties of soil along with weather circumstances including day-to-day minimum/maximum temperatures, radiation, rainfall.

Statistics analysis

Performance of the DSSAT-CSM-CERES models of maize, millet and sorghum crops for both fodder and grain purpose were determined by RMSE (Wallach and Goffinet, 1987) and d-index:

$$\text{RMSE (root mean square error)} = \left[\sqrt{\frac{\sum_{i=1}^{n} (P_i - O_i)^2}{n}} \right] \quad (Equation-I)$$

$$\text{d-index} = 1 - \left[\frac{\sum_{i=1}^{n} (P_i - O_i)^2}{\sum_{i=1}^{n} (|P'_i| + |O'_i|)^2} \right] \quad (Equation-II)$$

According to Wilmot (1982), the model fit increases when d-index and RMSE approaches to unity and zero, respectively.

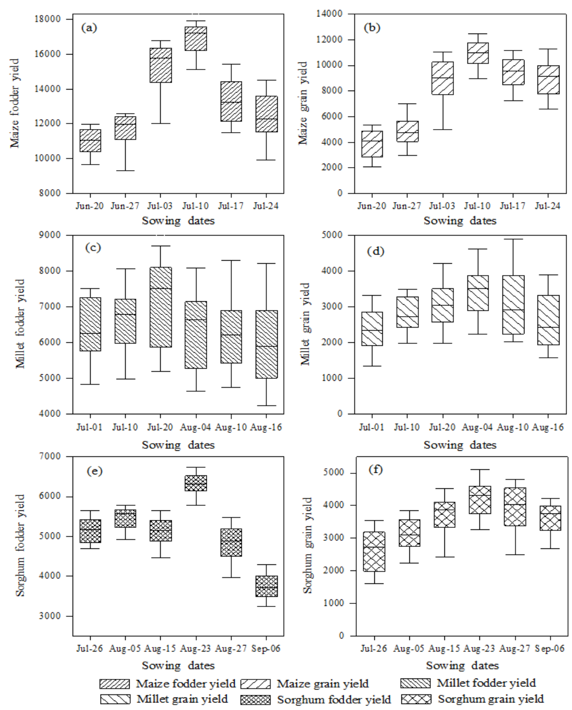

Fig. 5: Simulated fodder and grain yield, respectively for maize (a, b), millet (c, d) and sorghum (e, f) at different sowing dates. Box limits represent 25^{th} and 75^{th} percentiles, box central line represents median, and outliers represent minimum and maximum values. Simulated results were obtained using combination of historical weather data for 34 years, maize, millet and sorghum crops and six sowing dates under irrigated arid environment of Multan, Pakistan.

RESULTS

Model calibration

The CSM-CERES models of maize, millet and sorghum were calibrated with the field trials data collected with sowing dates 10 July, 10 August and 27 August, respectively for both grain and fodder purpose. Calibrations of models were done with those sowing dates which performed well as compare to other treatments. The cultivars coefficients of Monsento-5219, HP-50 and JS-263 for grain purpose and Sargodha 2002, MB-87 and JS-2002 for fodder purpose were estimated with the help of trial-error along with comparing with field observed and model predicted employing CSM-CERES models of maize, millet and sorghum.

A well agreement was gained between observed phenological data of field experiments and model simulated for both fodder and grain purpose (Table 1). Difference between model simulated and field trials was one day for anthesis and physiological maturity for both grain and fodder purpose crops. Leaf area index, biomass and grain yield data of field experiments was close agreed with model predicted data for both fodder and grain purpose. The lower values for root mean square error (RMSE) and higher d-values close to one revealed that the model predicted LAI and above-ground biomass quite well.

Range of d-value was from 0.96 to 0.99 for both fodder and grain purpose. RMSE value for leaf area index (LAI) was 0.32, 0.11 and 0.26 for maize, millet and sorghum, respectively for fodder purpose. 420.25, 298.04 and 268.36 was RMSE value for biomass for maize, millet and sorghum fodder purpose crops, respectively. The RMSE value for LAI was 0.25, 0.25 and 0.21 for maize, millet and sorghum, respectively for grain purpose. 1169.91, 801.91 and 396.29 was RMSE value for biomass for maize, millet and sorghum grain purpose crops, respectively. Observed fodder and grain yield for maize, millet and sorghum was well agreed with simulated data of model. For fodder yield, d-value was 0.98, 0.99 and 0.90 for maize, millet and sorghum, respectively and 0.98, 0.99 and 0.96 was the d-value for maize, millet and sorghum crops, respectively for grain yield (Table 1; Figs. 2-4).

Model evaluation

Evaluation of CSM-CERES models of maize, millet and sorghum for fodder purpose were done with the field experimental data recorded from remaining sowing dates 17 July and 2 August for maize, 4 and 10 August for millet, 15 and 23 august for sorghum. For grain purpose, same sowing date's data was used for model evaluation. A good agreement was obtained between observed phenological stages data of field experiments and model simulated for both fodder and grain purpose. Difference between model simulated and field trials was 1-2 days for anthesis and physiological maturity for both grain and fodder purpose crops. The LAI, biomass and grain yield data of field experiments was well agreed with model predicted data for both fodder and grain purpose. The lower values for root mean square error and higher d-values close to one showed that the model predicted LAI and above-ground biomass quite well (Table 2).

Range of d-value was from 0.98 to 0.99 for both fodder and grain purpose. RMSE value for leaf area index (LAI) was 0.20, 0.14 and 0.11 for maize, millet and sorghum, respectively for fodder purpose.

617.96, 216.76 and 239.85 was RMSE value for biomass for maize, millet and sorghum fodder purpose crops, respectively. RMSE value for LAI was 0.12, 0.17 and 0.19 for maize, millet and sorghum, respectively for grain purpose. 1180.21, 753.43 and 298.36 was RMSE value for biomass for maize, millet and sorghum for grain purpose crops, respectively. Maize, millet and sorghum observed fodder and grain yield was well agreed with simulated data of models. For fodder production, d-value for maize, millet and sorghum was 0.98, 0.99 and 0.90; respectively. 0.98, 0.99 and 0.96 was the d-value for maize, millet and sorghum crops, respectively for grain yield. RMSE value was 547.92, 272.11 and 299.73 for maize, millet and sorghum, respectively for fodder yield. 194.17, 122.62 and 143.64 was RMSE value for maize, millet and sorghum, respectively for grain yield (Table 3; Figs. 2-4).

Model application

The CSM-CERES models of maize, millet and sorghum was applied to determine the optimum sowing date for long term scenario for both fodder and grain yield simulation purpose. Historical weather data from 1980 to 2014 was used for long term simulation for both fodder and grain yield simulation purpose (Fig. 5).

Each 6varioussowing dates for each crop separately for grain and fodder yield were simulated employing seasonal strategy of DSSAT Version 4.6.1 under irrigated arid conditions. Simulation consequences were analyzed by means of the strategy analysis program of DSSAT to comparing the percentile distributions for fodder and grain yield. Simulation scenario showed that, average maximum fodder and grain yield at 50% percentile for maize crop was obtained with sowing date 10 July. Sowing date 4 August and 20 July gave maximum average grain and fodder yield, respectively for millet crop for long term simulation. Sorghum crop produced maximum mean grain and fodder yield at sowing date 23 August (Fig. 5).

DISCUSSION

Research results demonstrated that the CSM-CERES-models of maize, millet and sorghum for both fodder and grain purpose can be applied as an appropriate tool to investigate optimum sowing date options and to find out the best ones to apply in better simulation of fodder and grain yield (Folliard et al., 2004; Ma et al., 2006; Akponikpe et al., 2010; Waha et al., 2012; Mubeen et al., 2016). The ability of the CSM-CERES-models of maize, millet and sorghum to predict grain yield at physiological maturity in arid and semi-arid environment was verified by various research studies. The results of model simulations illustrated that the yield of early sowing dates was lower than the yield of delay sowing date in all grain and fodder crops (Bussmann et al., 2016; Waongo et al., 2015; Mahmood et al., 2016). It was for the reason that of reduction in crop growth cycle predominantly the time from sowing to the anthesis stage. The high crop environmental temperature in early sowing dates has resulted in accelerating crop growth stages, decreasing of crop canopy and reduction in biomass production which in turn have led to decrease the fodder, grain yield and its components (Gesch and Archer, 2005; Liu et al., 2013; Verma et al., 2013; Waha et al., 2013; Gerardeaux et al., 2016). Optimum sowing date increased resources use efficiency like fertilizer, irrigation etc (Murty et al., 2007; Mubeen et al., 2013). More earlier or more delay sowing dates in these environmental conditions result in diminish efficiency of solar radiation of a maize, millet and sorghum crop and result in reduction the accumulation of total dry matter (Akponikpe et al., 2011; Teetor et al., 2011; Azrag and Dagash, 2015; Rezaei et al., 2014). Delaying the sowing date beyond the optimum sowing date led to reduced fodder and grain production because of the existence of low temperatures during vegetative stage which decreases the crop growth rate as it was simulated by the CSM-CERES-models of maize, millet and sorghum.

Table 1: Calibration of DSSAT model for C_4 cereals at variable sowing dates for fodder and grain purpose crops under irrigated arid environment of Multan, Pakistan

Fodder crops characteristics	Maize		Millet		Sorghum	
	(DAS)		(DAS)		(DAS)	
	Obs.	Sim.	Obs.	Sim.	Obs.	Sim.
Phenology						
Anthesis	66	67	54	55	60	61
Growth	RMSE	d-value	RMSE	d-value	RMSE	d-value
LAI (m^2 m^{-2})	0.32	0.99	0.11	0.99	0.26	0.97
Biomass (kg ha^{-1})	420.25	0.99	298.04	0.99	268.36	0.99
Grain crops						
Characteristics	(DAS)		(DAS)		(DAS)	
	Obs.	Sim.	Obs.	Sim.	Obs.	Sim.
Phenology						
Anthesis	55	56	51	51	56	57
Maturity	99	100	95	96	111	112
Growth	RMSE	d-value	RMSE	d-value	RMSE	d-value
LAI (m^2 m^{-2})	0.25	0.98	0.25	0.99	0.21	0.96
Biomass (kg ha^{-1})	1169.91	0.99	801.91	0.99	396.29	0.99

DAS = days after sowing; Obs. = observed; Sim = simulated; RMSE = root mean square error; LAI = leaf area index.

Table 2: Evaluation of DSSAT model for C_4 cereals at variable sowing dates for fodder and grain purpose crops under irrigated arid environment of Multan, Pakistan

Fodder crops characteristics	Maize (DAS)		Millet (DAS)		Sorghum (DAS)	
	Obs.	Sim.	Obs.	Sim.	Obs.	Sim.
Phenology						
Anthesis	67	68	56	58	58	60
Growth	RMSE	d-value	RMSE	d-value	RMSE	d-value
LAI (m^2 m^{-2})	0.20	0.98	0.14	0.98	0.11	0.98
Biomass (kg ha^{-1})	617.96	0.95	216.76	0.97	239.85	0.95
Grain crops Characteristics	(DAS)		(DAS)		(DAS)	
	Obs.	Sim.	Obs.	Sim.	Obs.	Sim.
Phenology						
Anthesis	54	55	52	54	56	57
Maturity	104	106	92	93	103	104
Growth	RMSE	d-value	RMSE	d-value	RMSE	d-value
LAI (m^2 m^{-2})	0.12	0.98	0.17	0.99	0.19	0.98
Biomass (kg ha^{-1})	1180.21	0.94	753.43	0.97	298.36	0.95

DAS = days after sowing; Obs. = observed; Sim = simulated; RMSE = root mean square error; LAI = leaf area index

Table 3: Observed and simulated fodder and grain yields of C_4 cereals at variable sowing dates at final harvesting under irrigated arid environment of Multan, Pakistan

Crops	Sowing dates	Fodder yield (kg ha^{-1})		Fodder yield (d-stat)	LAI (d-stat)	Biomass (d-stat)
Maize		Sim.	Obs.			
	10 Jul	11225	10852		0.99	0.99
	17 Jul	9347	8539		0.98	0.99
	02 Aug	6094	5761		0.93	0.99
Statistics				0.98		
Millet	20 Jul	2237	2073		0.98	0.99
	04 Aug	3780	3521		0.98	0.98
	10 Aug	5995	5637		0.99	0.99
Statistics				0.99		
Sorghum	15 Aug	5746	5482		0.98	0.99
	23 Aug	4720	4507		0.97	0.99
	27 Aug	5155	4762		0.97	0.99
Statistics				0.90		
Crops	Sowing dates	Grain yield (kg ha^{-1})		Grain yield (d-stat)	LAI (d-stat)	Biomass (d-stat)
Maize		Obs.	Sim.			
	10 Jul	5573	5740		0.98	0.99
	17 Jul	4639	4881		0.98	0.98
	2 Aug	4071	4234		0.97	0.98
Statistics				0.98		
Millet	20 Jul	927	852		0.96	0.99
	04 Aug	1836	1697		0.99	0.99
	10 Aug	2506	2364		0.98	0.97
Statistics				0.99		
Sorghum	15 Aug	1543	1365		0.98	0.99
	23 Aug	2065	1892		0.98	0.99
	27 Aug	2206	2189		0.97	0.98
Statistics				0.96		

Obs. = observed; Sim = simulated; LAI = leaf area index

Conclusion

It can be conclude from the attained results that the CSM-CERES-models of maize, millet and sorghum were reasonable well as pointed out by comparison of data between simulated crop phenology, total dry matter accumulation, fodder and grain yields with field measured data. Crop growth models can support resource-poor farmer community of Pakistan by giving alternate management decisions for fodder and grain purpose crops. As such crop growth models can be applied to determine the best management practices in proportion with environmental circumstances. Further model evaluations might also be required for other cultivars which are introduced for this area.

Authors' contribution
ZF, GA, MRK, HY, SN, MS, MA, NA, MA, AR, MK, ZA conducted field trials and literature review, SH, A, MH, MR, RSB, AA, SN, HA, AAK, MA analyzed data along with Figure work GS, MAK and MH wrote this manuscript and SA supervised the study. All the authors contributed equally and read the manuscript final draft before submission.

Acknowledgements
This study was financially supported by the Bahauddin Zakariya University, Multan and the Higher Education Commission (HEC), Islamabad, Pakistan.

REFERENCES

Ahmad A, M Ashfaq, G Rasul, SA Wajid, T Khaliq, F Rasul, U Saeed, M Habib ur Rahman, J Hussain, IA Baig, SAA Naqvi, SAA Bokhari, S Ahmad, W Nasim, G Hoogenboom and RO Valdivia, 2015. Impact of climate change on the rice-wheat cropping system of Pakistan. In: Hillel D, and Rosenzweig C (eds.) Handbook of Climate Change and Agro-ecosystems, Vol. 3. Imperial College Press and the American Society of Agronomy, pp. 219-258.

Ahmad S, H Ali, U Farooq, SU Khan, Atique-ur-Rehman, N Sarwar, AN Shahzad, H Dogan, S Hussain, MT Sultan, A Waheed, M Zia-ul-Haq, K Hussain and MA Khan, 2016a. Improving nitrogen and radiation-use-efficiencies of C_4 summer cereals by split nitrogen applications under irrigated arid environment. Turkish Journal of Agriculture and Forestry, 40: 280-289.

Ahmad S, M Nadeem, G Abbas, Z Fatima, RJZ Khan, M Ahmed, A Ahmad, G Rasul and MA Khan, 2016b. Quantification of the effects of climate warming and crop management on sugarcane phenology. Climate Research, 71: 47-61.

Akponikpe PBI, J Minet, B Gerard, P Defourny and CL Bielders, 2011. Spatial fields' dispersion as a farmer strategy to reduce agro-climatic risk at the household level in pearl millet-based systems in the Sahel: a modeling perspective. Agricultural and Forest Meteorology, 151: 215-227.

Akponikpè PBI, B Gérard, K Michels and C Bielders, 2010. Use of the APSIM model in long term simulation to support decision making regarding nitrogen management for pearl millet in the Sahel. European Journal of Agronomy, 32: 144-154.

Aziz A, HU Rehman and N Khan, 2007. Maize cultivar response to population density and planting date for grain and biomass yield. Sarhad Journal of Agriculture, 23: 25-30.

Azrag AAD and YMI Dagash, 2015. Effect of sowing date and nitrogen rate on growth, yield components of sorghum (*Sorghum bicolor* L.) and nitrogen use efficiency. Journal of Progressive Research in Biology, 2: 78-87

Berzsenyi Z and DQ Lap, 2005. Responses of maize (*Zea mays* L.) hybrids to sowing date, N fertilizer and plant density in different years. Acta Agronomica Hungarica, 53: 119-131.

Boote KJ, JW Jones, G Hoogenboom and JW White, 2010. The role of crop systems simulation in agriculture and environment. International Journal of Agricultural and Environmental Information Systems 1: 41-54.

Bussmann A, NA Elagib, M Fayyad and L Ribbe, 2016. Sowing date determinants for Sahelian rainfed agriculture in the context of agricultural policies and water management. Land Use Policy, 52: 316-328.

Choi Y, H Gim, C Ho, S Jeong, SK Park and MJ Hayes, 2016. Climatic influence on corn sowing date in the Midwestern United States. International Journal of Climatology, In press. (doi: 10.1002/joc.4799).

Chunrong JI, Z Chen, Z Kuerban and YE Kai, 2013. Change of sugar contents and its relationship with meteorological factors among different sowing dates of sweet sorghum. Desert and Oasis Meteorology, 3: 016.

Dahmardeh M and M Dahmardeh, 2010. The effect of sowing date and some growth physiological index on grain yield in three maize hybrids in Southeastern Iran. Asian Journal of Plant Sciences, 9: 432-436.

Dera J, LT Mpofu and B Tavirimirwa, 2014. Response of pearl millet varieties to different dates of sowing at Makoholi and Kadoma research stations, Zimbabwe. Academia Journal of Agricultural Research, 2: 110-113.

El-Lattief EAA, 2011. Growth and fodder yield of forage pearl millet in newly cultivated land as affected by date of planting and integrated use of mineral and organic fertilizers. Asian Journal of Crop Science, 3: 35-42.

Erickson JE, ZR Helsel, KR Woodard, JMB Vendramini, Y Wang, LE Sollenberger and RA Gilbert, 2011. Planting date affects biomass and brix of sweet sorghum grown for biofuel across Florida. Agronomy Journal, 103: 1827-1833.

Fang H, S Liang, G Hoogenboom, J Teasdale and M Cavigelli, 2008. Corn-yield estimation through assimilation of remotely sensed data into the CSM-CERES-Maize model. International Journal of Remote Sensing, 29: 3011-3032.

Fatondji D, A Bationo, R Tabo, JW Jones, A Adamou and O Hassane, 2012. Water use and yield of millet under the zai system: understanding the processes using simulation. In: Improving Soil Fertility Recommendations in Africa using the Decision Support System for Agrotechnology Transfer (DSSAT), Springer Netherlands, pp. 77-100.

Florio EL, JL Mercau, EG Jobbágy and MD Nosetto, 2014. Interactive effects of water-table depth, rainfall variation, and sowing date on maize production in the Western Pampas. Agricultural Water Management, 146: 75-83.

Folliard A, PCS Traoré, M Vaksmann and M Kouressy, 2004. Modeling of sorghum response to photoperiod: a threshold–hyperbolic approach. Field Crops Research, 89: 59-70.

Gérardeaux E, F Affholder F, M Bernoux and B Muller, 2016. Relationships between tropical annual cropping systems and climate change. In Climate Change and Agriculture Worldwide, Springer, Netherlands, pp. 109-124.

Gesch RW and DW Archer, 2005. Influence of sowing date on emergence characteristics of maize seed coated with a temperature-activated polymer. Agronomy Journal, 97: 1543-1550.

GOP, 2015. Economic Survey of Pakistan, 2014-15. Economic Advisory Wing, Finance Division, Government of Pakistan, Islamabad, pp. 29–30.

Grassini P, J Thorburn, C Burr and KG Cassman, 2011. High-yield irrigated maize in the Western US Corn Belt: I. On-farm yield, yield potential, and impact of agronomic practices. Field Crops Research, 120: 142-150.

Gueye M, G Kanfany, AFofana, K Noba and JH Grove, 2015. Effect of planting date on growth and grain yield of fonio millet (DigitariaexilisStapf) in the Southeast of Senegal. International Journal of Biological and Chemical Sciences, 9: 581-592.

Gungula DT, JG Kling and AO Togun, 2003. CERES-Maize predictions of maize phenology under nitrogen-stressed conditions in Nigeria. Agronomy Journal, 95: 892-899.

Han KJ, MW Alison, WD Pitman, DF Day, M Kim and L Madsen, 2012. Planting date and harvest maturity impact on biofuel feedstock productivity and quality of sweet sorghum grown under temperate Louisiana conditions. Agronomy Journal, 104: 1618-1624.

Han KJ, WD Pitman, MW Alison, DL Harrell, HP Viator, ME McCormick and DF Day, 2012. Agronomic considerations for sweet sorghum biofuel production in the South-central USA. BioEnergy Research, 5: 748-758.

Hoogenboom G, JW Jones, PW Wilkens, CH Porter, KJ Boote, LA Hunt, U Singh, JI Lizaso, JW White, O Uryasev, R Ogoshi, J Koo, V Shelia and GY Tsuji, 2015. Decision Support System for Agrotechnology Transfer (DSSAT), Version 4.6.1 (www.dssat.net), DSSAT Foundation, Prosser, Washington, USA.

Ibrahim HI, SA Hassanen and EL Hassan, 2015. Performance of forage millet in response to different combinations of organic, inorganic- and bio-fertilizers. World Journal of Agricultural Sciences, 11: 423-431

Iizumi T, G Sakurai and M Yokozawa, 2014. Contributions of historical changes in sowing date and climate to US maize yield trend: An evaluation using large-area crop modeling and data assimilation. Journal of Agricultural Meteorology, 70: 73-90.

Iken JE and NA Amusa, 2004. Maize research and production in Nigeria. African Journal of Biotechnology, 3: 302-307.

Kucharik CJ, 2008. Contribution of planting date trends to increased maize yields in the central United States. Agronomy Journal, 100: 328-336.

Laux P, G Jäckel, RM Tingem and H Kunstmann, 2010. Impact of climate change on agricultural productivity under rainfed conditions in Cameroon—A method to improve attainable crop yields by planting date adaptations. Agricultural and Forest Meteorology, 150: 1258-1271.

Li CX, HS Feng, YG Zhao, XH Yao, SG Bai and YR Li, 2013. Sweet sorghum cultivation techniques. Acta Agrestia Sinica, 21: 114-122.

Lindquist JL, TJ Arkebauer, DT Walters, KG Cassman and A Dobermann, 2005. Maize radiation use efficiency under optimal growth conditions. Agronomy Journal, 97: 72-78.

Liu TP, GL Zhao, XL Ni, JL Hu, GM Chen and GX Ding, 2013. Effect of sowing time and nitrogen fertilizer rate on growth period and yield of hybrid glutinous sorghum. Hubei Agricultural Sciences, 52: 3498-3450.

Liu Z, KG Hubbard, X Lin and X Yang, 2013. Negative effects of climate warming on maize yield are reversed by the changing of sowing date and cultivar selection in Northeast China. Global Change Biology, 19: 3481-3492.

Ma L, G Hoogenboom, LR Ahuja, JC Ascough and SA Saseendran, 2006. Evaluation of the RZWQM-CERES-Maize hybrid model for maize production. Agricultural Systems, 87: 274-295.

Mahmood A, MM Javaid, M Aziz, AN Shahzad, A Rehman and B Honermeier, 2016. Yield and quality response of sorghum hybrids to different planting densities and sowing times. International Journal of Agriculture and Applied Sciences (Pakistan), 4: 42-47.

Marteau R, B Sultan, V Moron, A Alhassane, C Baron and SB Traoré, 2011. The onset of the rainy season and farmers' sowing strategy for pearl millet cultivation in Southwest Niger. Agricultural and Forest Meteorology, 151: 1356-1369.

Maton L, D Leenhardt and JE Bergez, 2007. Geo-referenced indicators of maize sowing and cultivar choice for better water management. Agronomy for Sustainable Development, 27: 377-386.

Matthews RB and C Pilbeam, 2005. Modelling the long-term productivity and soil fertility of maize/millet cropping systems in the mid-hills of Nepal. Agriculture, Ecosystems & Environment, 111: 119-139.

Mubeen M, A Ahmad, A Wajid, T Khaliq and A Bakhsh, 2013. Evaluating CSM-CERES-Maize model for irrigation scheduling in semi-arid conditions of Punjab, Pakistan. International Journal of Agriculture Biology, 15: 1-10.

Mubeen M, A Ahmad, A Wajid, T Khaliq, HM Hammad, SR Sultana, S Ahmad, S Fahad and W Nasim. 2016. Application of CSM-CERES-Maize model in optimizing irrigated conditions. Outlook on Agriculture, 45: 173-184.

Murty MVR, P. Singh, SP Wani, IS Khairwal and K Srinivas, 2007. Yield gap analysis of sorghum and pearl millet in India using simulation modeling. Global Theme on Agroecosystems Report No. 37. Patencheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics, pp. 82.

Nouna BB, N Katerji and M Mastrorilli, 2000.Using the CERES-Maize model in a semi-arid Mediterranean environment. Evaluation of model performance. European Journal of Agronomy, 13: 309-322.

Opsi F, R Fortina, G Borreani, E Tabaccoand and S López, 2013. Influence of cultivar, sowing date and maturity at harvest on yield, digestibility, rumen fermentation kinetics and estimated feeding value of maize silage. The Journal of Agricultural Science, 151: 740-753.

Rahman AA, EL Magboul and AE Nour, 2004. Effects of sowing date and cultivar on the yield and yield components of maize in northern Sudan. In: Integrated Approaches to Higher Maize Productivity in the New Millennium: Proceedings of the Seventh Eastern and Southern Africa Regional Maize Conference, Nairobi, Kenya, February 5-11, 2002, pp: 295.

Rezaei EE, T Gaiser, S Siebert, B Sultan and F Ewert, 2014. Combined impacts of climate and nutrient fertilization on yields of pearl millet in Niger. European Journal of Agronomy, 55: 77-88.

Santos RD, K Boote, L Sollenberger, AL Neves, LG Pereira, CB Scherer and LC Goncalves, 2016. Simulated optimum sowing date for forage pearl millet cultivars in multi location trials in Brazilian semi-arid region. Frontiers in Plant Science, 7: 1320.

Saseendran SA, DC Nielsen, DJ Lyon, L Ma, DG Felter, DD Baltensperger and LR Ahuja, 2009. Modeling responses of dryland spring triticale, proso millet and foxtail millet to initial soil water in the High Plains. Field Crops Research, 113: 48-63.

Saseendran SA, L Ma, DC Nielsen, MF Vigil and LR Ahuja, 2005. Simulating planting date effects on corn production using RZWQM and CERES-Maize models. Agronomy Journal, 97: 58-71.

Soler CMT, N Maman, X Zhang, SC Mason and G Hoogenboom, 2008. Determining optimum planting dates for pearl millet for two contrasting environments using a modelling approach. The Journal of Agricultural Science, 146: 445-459.

Soler CMT, PC Sentelhas and G Hoogenboom, 2007. Application of the CSM-CERES-Maize model for planting date evaluation and yield forecasting for maize grown off-season in a subtropical environment. European Journal of Agronomy, 27: 165-177.

Sun H, X Zhang, S Chen, D Pei and C Liu, 2007. Effects of harvest and sowing time on the performance of the rotation of winter wheat–summer maize in the North China Plain. Industrial Crops and Products, 25: 239-247.

Tao F, S Zhang, Z Zhang and RP Rötter, 2014. Maize growing duration was prolonged across China in the past three decades under the combined effects of temperature, agronomic management, and cultivar shift. Global Change Biology, 20: 3686-3699.

Tariq M, M Ayub, M Elahi, AH Ahmad, MN Chaudhary and MA Nadeem, 2011. Forage yield and some quality attributes of millet (*Pennisetum americannum* L.) hybrid under various regimes of nitrogen fertilization and harvesting dates. African Journal of Agricultural Research, 6: 3883-3890.

Teetor VH, DV Duclos, ET Wittenberg, KM Young, J Chawhuaymak, MR Riley and DT Ray, 2011. Effects of planting date on sugar and ethanol yield of sweet sorghum grown in Arizona. Industrial Crops and Products, 34: 1293-1300.

Tovignan TK, D Fonceka, I Ndoye, N Cisse and D Luquet, 2016. The sowing date and post-flowering water status affect the sugar and grain production of photoperiodic, sweet sorghum through the regulation of sink size and leaf area dynamics. Field Crops Research, 192: 67-77.

Tsimba R, GO Edmeades, JP Millner and PD Kemp, 2013. The effect of planting date on maize grain yields and yield components. Field Crops Research, 150: 135-144.

Verma NK, 2013. Integrated nutrient management in winter maize (*Zea mays* L.) sown at different dates. Journal of Plant Breeding and Crop Science, 3: 161-167.

Waha K, C Müller, ABondeau, JP Dietrich, P Kurukulasuriya, J Heinke and H Lotze-Campen, 2013. Adaptation to climate change through the choice of cropping system and sowing date in sub-Saharan Africa. Global Environmental Change, 23: 130-143.

Waha K, LGJ Van Bussel, C Müller and ABondeau, 2012. Climate-driven simulation of global crop sowing dates. Global Ecology and Biogeography, 21: 247-259.

Wajid A, A Hussain, A Ahmad, M Rafiq, AR Goheer and M Ibrahim, 2004. Effect of sowing date and plant density on growth, light interception and yield of wheat under semi-arid condition. International Journal of Agriculture and Biology, 6: 1119-1123.

Wallach D and B Goffinet, 1987. Mean squared error of prediction in models for studying ecological and agronomic systems. Biometrics, 43: 561-573.

Waongo M, P Laux and H Kunstmann, 2015. Adaptation to climate change: The impacts of optimized planting dates on attainable maize yields under rainfed conditions in Burkina Faso. Agricultural and Forest Meteorology, 205: 23-39.

Willmott CJ, 1982. Some comments on the evaluation of model performance. Bulletin American Meteorological Society, 63: 1309-1313.

Wolf J, K Ouattara and I Supit, 2015. Sowing rules for estimating rainfed yield potential of sorghum and maize in Burkina Faso. Agricultural and Forest Meteorology, 214: 208-218.

Xingfen M, Y Kejun, Y Song, J Xiju, W Liyan and B Lixia, 2015. Effects of different sowing dates on yield and main agronomic traits of foxtail millet. Journal of Heilongjiang Bayi Agricultural University, 5: 12.

Zhou SD, YF Zhou and RD Huang, 2005. Effects of sowing time on leaf characteristics of sweet sorghum at different growth stages. Journal-Shenyang Agricultural University, 36: 340.