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MODELING GROWTH, DEVELOPMENT AND SEED-COTTON YIELD FOR VARYING NITROGEN INCREMENTS AND PLANTING DATES USING DSSAT

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CSM-CROPGRO-Cotton Model under DSSAT V 4.0.2.0 has been extensively tested and validated in many studies, mainly in United States. The objective of this study was to test and validate this model in three cotton growing regions of Pakistan (Faisalabad, Multan and Sahiwal) for dynamic simulation of development, growth and seed cotton yield of four cotton cultivars (CIM-496, CIM-506, NIAB-111 and SLH-284) at varying nitrogen increments (50, 100, 150 and 200 kg ha^{-1}) sown at different timings (20 May and 10 June). The model was first calibrated with data (phenology, biomass, LAI, and yield components) collected during 2009 at all locations against the best performing treatment May 15 sowing, cv. CIM-496 and 200 kg N ha^{-1} ($D_1V_1N_4$) in field trials. The model was then tested with data recorded against remaining thirty-one treatments for all locations. Similarly, the data of year 2010 was used for validation. The simulated values of crop phenology (days to anthesis and maturity) by the model were reliable with the recorded data, with root mean square error (RMSE) less than 2 days during both years. Although RMSE values for LAI approached higher than 1 in many of the treatments, these values for total dry matter and seed-cotton yield were reasonably good (367 to 497 kg ha^{-1}and 122 to 227 kg ha^{-1}, respectively). There is a dire need to assess impact of climate variation on seed cotton yield under various climatic regions of Pakistan to ensure fiber quality and yield in future.
Keywords: *Gossypium hirsutum* L., CSM-CROPGRO-Cotton, simulation, crop growth, phenology

INTRODUCTION

Cotton is the most important cash crop and plays a vital role in the economy of Pakistan. It accounts for 7.8% of value added in agriculture and 1.6% of GDP (Government of Pakistan, 2012). The cotton plant due to its narrow range of ecological adaptability is very much influenced by the climatic conditions and various agronomic factors, such as sowing time, genotypes and nitrogen fertilization. A great number of studies have been conducted on the effect of these factors on growth and yield of seed-cotton in Pakistan (Soomro *et al.*, 2001; Akhtar *et al.*, 2002; Ali *et al.,* 2004; Arshad *et al.,* 2007). However, to study the interaction of all these management strategies in different agro-ecological conditions needs long and costly field experiments.

Crop growth models can assist in the synthesis of research understandings about the interaction of genetics, physiological and the environmental interaction across disciplines and organization of data and are important tools for agronomic management strategy evaluation (Jones *et al.,* 2003; Hoogenboom *et al.,* 2004; Boote *et al.,* 2010, Wajid *et al.,* 2013; Mubeen *et al.,* 2013). During the last decade, these models have been used extensively in agriculture to simulate crop responses to different abiotic factors. Recently many mechanistic simulations have been reported on both the development and yield of cotton crop from sowing to maturity in response to nonspecific site environment (Hima *et al.*, 2004; Kakni *et al.,* 2005). The cotton boll maturation period module in these models took solar radiation and N nutrition factors into account in addition to temperature and variety maturity profile. Crop growth models take parameters in consideration like cultivar characteristics, minimum temperature, maximum temperature, solar radiation and crop management's factors (Mahamood *et al.,* 2003; Hoogenboom *et al.,* 2011). Li *et al.* (2009) used the new semi empirical model to simulate the cotton leaf and boll nitrogen concentration and also worked on direct indicator of nitrogen fertilizer effect on growth, development and cotton seed. The Cropping System Model (CSM)-CROPGRO-Cotton model is part of the suite of crop simulation models that encompass the Decision Support System for Agro technology Transfer (DSSAT) (Jones *et al.*, 2003; Hoogenboom *et al.*, 2004). The model simulates growth, development, and yield of cotton for different weather and soil conditions and management practices (Ortiz *et al.*, 2009). CROPGRO (DSSAT) is one of the first packages that modified weather simulation generators/or introduced a package to evaluate the performance of models for climate change situations (Murthy, 2004).

CROPGRO-Cotton is a newly developed crop model and has many parameters (Pathak *et al.,* 2009). In Pakistan, studies on the use of crop models in cotton for evaluation and validation have not been reported. The present study was, therefore, conducted with the objectives to evaluate CROPGRO-Cotton model for growth, development and seed cotton yield, and to validate model under various climatic conditions with independent set of data.

MATERIALS AND METHODS

Two field experiments at three locations Post Graduate Agricultural Research Station (PARS) Faisalabad (31.26°N, 73.06°E), Cotton Research Station (CRS) Sahiwal (31.58°N, 72.20°E) and Central Cotton Research Institute (CCRI) Multan (30.12°N, 71.26°E) were conducted to predict the phenology, growth and development of cotton *(Gossypium hirsutum* L.) productivity in Punjab, during 2009 and 2010. The experiment was conducted in split-split plot design in both seasons at three locations. There were two sowing dates D_1=20 May and D_2=10 June in main plots, four cultivars Viz. V_1=CIM-496, V_2=CIM-506, V_3=NIAB-111and V_4=SLH-284 in sub plots and four nitrogen levels N_1=50 kg ha^{-1}, N_2=100 kg ha^{-1} (farmers' practice, control), N_3=150 kg ha^{-1}, N_4 =200 kg ha^{-1} in sub-sub plots. Each experiment consisted of three replications with a net plot size of 3x10m.

***Crop husbandry*:** The crop husbandry operations during both the seasons were kept normal according to the recommendations of Agriculture Department except varieties, sowing dates and nitrogen levels which were applied according to the treatments under study. The crop was sown on due dates i.e. on 20th, May and 10th June uniformly at 75 cm apart, using bed-furrow method with seed rate 25 kg ha^{-1}. Thinning was completed after crop emergence to maintain uniform plant-to-plant distance of 30 cm. Nitrogen was applied in the form of urea in two splits, 50 kg ha^{-1} at sowing, in first split to all experimental units and remaining in second split according to treatments at flower initiation before15th August in both seasons. All other agronomic practices such as irrigation, weeding, plant protection measures and earthing up etc. were kept normal and uniform for all the treatments.

***Crop growth modeling*:** Field data collected from the experiments during 2009 and 2010 growing seasons was used for calibration and validation of CROPGRO-Cotton model, respectively. Standard meteorological, soil, plant characteristic and crop management data were obtained for each site and used as input data for the model. Decision Support System for Agro technology Transfer (DSSAT) was used for estimation of crop genetic coefficients using sensitivity analysis selecting the best treatment simultaneously at three sites. The model was run using experimental data of year 2009 for calibration and for genetic co-efficient calculation but the validity of the model was assessed by using the independent set of data recorded during year 2010 with same set of crop genetic coefficients.

***Model calibration and evaluation*:** Calibration is a process of adjusting some model parameters to our own conditions. It is also necessary for getting genetic co-efficient for new cultivars used in modeling study. So the model was calibrated with data (that included phenology, biomass, LAI, and yield components) collected during 2009 at all locations against treatment May 15 sowing, cv. CIM-496 and 200 kg N ha^{-1} ($D_1V_1N_4$) that performed best in field trials. Cultivar coefficients successively started from CSDL (critical short day length) and PPSEN slope of the relative response to development to photoperiod with time to PODOUR, the time required for cultivar to reach final pod load under optimal conditions (Photo thermal days). Fifteen coefficients control the phenology, growth and seed cotton yield (Hoogenboom *et al.,* 1994) in CROPGRO-Cotton model. To select the most suitable set of coefficients, an iterative approach was used. Calculated coefficients for four cotton cultivars and their detailed descriptions are given in Table 1. To check the accuracy of the model simulations it was run with data recorded against remaining thirty-one treatments for all locations. The data on phenology, development and growth for year 2010 was used for validation of CROPGRO-Cotton model. During all this process available observed data on crop phenology (flowering and maturity date), crop growth (leaf area index and total dry matter production) and seed cotton yield was compared with simulated values using same genetic coefficients. Simulation performance was evaluated by calculating different statistical indices like root mean square error (RMSE) (Wallach and Goffinet, 1989) and mean percentage difference (MPD) across all locations. For individual treatments error (%) between simulated and observed values were calculated. These measurements were calculated as under.

$$RMSE = \left[\sum_{i=1}^{n} (p_i - o_i)^2 / n \right]^{0.5}$$

$$MPD = \left[\sum_{i=1}^{n} \left(\frac{|o_i - p_i|}{o_i} \right) 100 \right] / n$$

$$Error(\%) = \left(\frac{(p - o)}{o} \right) 100$$

Where P_i and O_i are the predicted and observed values for studied treatments, respectively and n is the number of observations. Linear regression analysis between predicted and observed seed cotton yield and total dry matter at harvest was done to evaluate the validity of model at various

Table 1. Calculated Genetic coefficients for four cotton cultivars

ECO #	VRNAME	CSDL	PPSEN	EM-FL	FL-SH	FL-SD	SD-PM	FL-LF	LFMAX	SLAVR	SIZLF	XRFT	WTPSD	SFDUR	SDPDV	PODUR
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
PA0001	CIM - 496	23	0.01	49.1	18.0	18.0	59.7	99.99	3.99	188	265	0.850	0.183	41.9	27	3.9
PA0002	CIM - 506	23	0.01	49.1	18.0	18.0	60.9	90.00	4.00	188	266	0.850	0.189	38.0	27	3.8
PA0003	NAIB-111	23	0.01	49.0	18.1	18.1	60.0	99.99	4.09	188	287	0.840	0.188	39.0	27	3.9
PA0004	SLH - 284	23	0.01	40.0	18.2	18.2	66.6	110.99	3.99	189	290	0.780	0.180	36.0	27	3.8

CSDL= Critical Short Day Length below which reproductive development progresses with no day length effect (for short day plants)
PPSEN = Slope of the relative response of development to photoperiod with time (positive for short day plants) (1/hour)
EM-FL = Time between plant emergence and flower appearance (R1) (photo thermal days)
FL-SH = Time between first flower and first pod (R3) (photo thermal days)
FL-SD = Time between first flower and first seed (R5) (photo thermal days)
SD-PM = Time between first seed (R5) and physiological maturity (R7) (photo thermal days)
FL-LF = Time between first flower (R1) and end of leaf expansion
LFMAX = Maximum leaf photosynthesis rate at 30 C, 360 vpm CO_2, and high light (mg CO_2/m^2-s)
SLAVR = Specific leaf area of cultivar under standard growth conditions (cm^2/g)
SIZLF= Maximum size of full leaf (three leaflets) (cm^2)
XFRT = Maximum fraction of daily growth that is partitioned to seed + shell
WTPSD = Maximum weight per seed (g)
SFDUR = Seed filling duration for pod cohort at standard growth conditions (photothermal days)
SDPDV = Average seed per pod under standard growing conditions (#/pod)
PODUR = Time required for cultivar to reach final pod load under optimal conditions (photothermal days)

experimental sites. Model performance improves as R^2 value approaches to one while RMSE, MPD and error proceed to zero.

RESULTS

The CROPGRO-Cotton model performed well in simulating crop phenology (days to flowering and maturity), crop growth (LAI and TDM) and final crop yield (seed-cotton yield) for three sites based on the estimation of the cultivar coefficients. The model performed equally well with the same set of Genetic coefficients for crop phenology, crop growth and seed cotton yield. The corresponding simulation results are described as below.

Days to anthesis: The pooled data of three sites presented in Table 2 shows that model simulated days to anthesis one day higher in both planting dates. At low fertilizer rate (50 kg N ha^{-1}) days taken to flowering were delayed than crop getting nitrogen @200 N kg ha^{-1}. Similarly the model showed one day higher in anthesis than observed in all the cultivars. According to model simulations crop reached flowering stage 62-66 days after sowing in all treatments during 2009 and the observed days ranged from 61-65 days which indicated that model was fit and worked well under our environmental conditions. Efficacy of the CROPGRO-Cotton model shows that error % for individual treatments ranged from 1.54 to 1.64 for observed and simulated days to flowering. Figure 1 shows fitness of the data between observed and simulated data during year 2009. Similarly, validation of model during year 2010 shows that crop reached at anthesis stage in 60-67 days after sowing. The observed values ranged from 59-66, closer to simulated which depicts the usefulness of model with independent set of data. Coefficient of determination (R^2), goodness of the model had high value of 0.96, simulated and observed values was closer to 1.1 line, showed that model simulated anthesis dates very well as it was displayed in the field (Fig. 1).

Days to maturity: The data presented in Table 3 reveals that

Table 2. Comparison between simulated and observed days to anthesis date different nitrogen levels, sowing dates and cotton cultivars during year 2009 and 2010

Treat.	Calibration (2009)				Validation (2010)			
	Obs.	Sim.	Error (%)	RMSE	Obs.	Sim.	Error (%)	RMSE
May Sown	63	64	1.59	1.37	66	67	1.52	0.98
June Sown	62	63	1.61	1.29	59	60	1.69	1.18
N 50 kg ha^{-1}	65	66	1.54	0.72	64	65	1.56	0.98
N 200 kg ha^{-1}	61	62	1.64	1.20	61	62	1.64	1.15
CIM-496	63	64	1.59	0.80	63	63	0.00	1.05
CIM-506	63	64	1.59	1.31	63	63	0.00	1.05
NIAB-111	63	64	1.59	0.99	63	64	1.59	1.07
SLH-284	63	64	1.59	0.97	62	63	1.61	1.12
MPD (%)	1.59				1.20			

model simulated 2 days more for days to maturity than the observed ones in both the plantings. The May sown crop matured in 173 days whereas June sown matured in 151 days according to model simulations. The observations for May and June sown crop for maturity were 171 and 149 days, respectively in year 2009. The two nitrogen levels showed simulation of one day higher. Similarly all the cultivars except NIAB-111 (difference of two days) showed a difference of one day in simulated and observed. Root mean square error ranged between 0.98-1.54 with MPD of 0.86 during this year.

Model evaluation for second year also remained satisfactory for early and late planting in which prediction remained 2 days and 1 day more in early vs late plantings. The early sown crop matured in 175 days vs late sown with 149 days according to model simulations with corresponding observed values of 173 days and 148 days in 2010. Cultivar CIM-496 and NIAB-111 gave same trend for days taken to maturity between observed and simulated (161 vs. 163) and other two cultivars CIM-506 and SLH-284 also took same number of days to maturity (160 vs. 162). Mean percent difference during 2010 was 1.16 showing acceptable limit. Simulated and observed maturity dates were very close to 1:1 line for both the years having higher values of R^2 (0.99) showed the goodness of the model during evaluation and validation (Fig. 2).

Leaf area inde

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LAI @ 200 kg N ha^{-1} than at low rate of 50 kg N ha^{-1} (3.18). As regards cultivars, SLH-284 produced higher leaf area index over rest of the cultivars. RMSE ranged from 0.83 to 1.50 during this year (Table 4).

When CROPGRO-Cotton model was validated with 2010 data, percentage error in observed and simulated LAI was higher than 2009 in some of the treatments. For instance, the model showed 13.88, 15.80 and 11 % errors in planting date May sown, N rate of 50 kg ha^{-1} and cultivar CIM-496; however, the % error for rest of the treatments ranged from 2.62 to 6.09. Similarly MPD in this year was higher (7.80) compared to 2009 (1.61). RMSE during 2010 ranged from 0.57 to 1.28 for different treatments. Relationship between

Table 4. Comparison between simulated and observed leaf area index at different nitrogen levels, sowing dates and cotton cultivars during year 2009 and 2010

Treatment	Calibration (2009)				Validation (2010)			
	Obs.	Sim.	Error (%)	RMSE	Obs.	Sim.	Error (%)	RMSE
May Sown	3.81	3.82	0.17	1.22	3.41	3.88	13.88	0.57
June Sown	3.17	3.31	4.63	0.95	3.03	3.18	4.96	1.20
N 50 kg ha^{-1}	3.09	3.18	2.91	1.26	2.68	3.10	15.80	0.93
N 200 kg ha^{-1}	4.34	4.42	1.69	1.13	4.07	4.18	2.62	1.10
CIM-496	3.45	3.47	0.68	1.49	2.88	3.20	11.00	0.91
CIM-506	3.45	3.43	-0.68	1.18	3.09	3.25	4.96	0.68
NIAB-111	3.52	3.54	0.66	1.50	3.23	3.43	6.09	1.05
SLH-284	3.56	3.66	2.81	0.83	3.31	3.41	3.12	1.28
MPD			1.61				7.80	

Table 3. Com ... sowing dates and

Treatment	...	RMSE
May Sown		1.31
June Sown		1.33
N 50 kg ha^{-1}		1.42
N 200 kg ha^{-1}		1.34
CIM-496		1.17
CIM-506		1.09
NIAB-111		1.19
SLH-284		1.24
MPD		

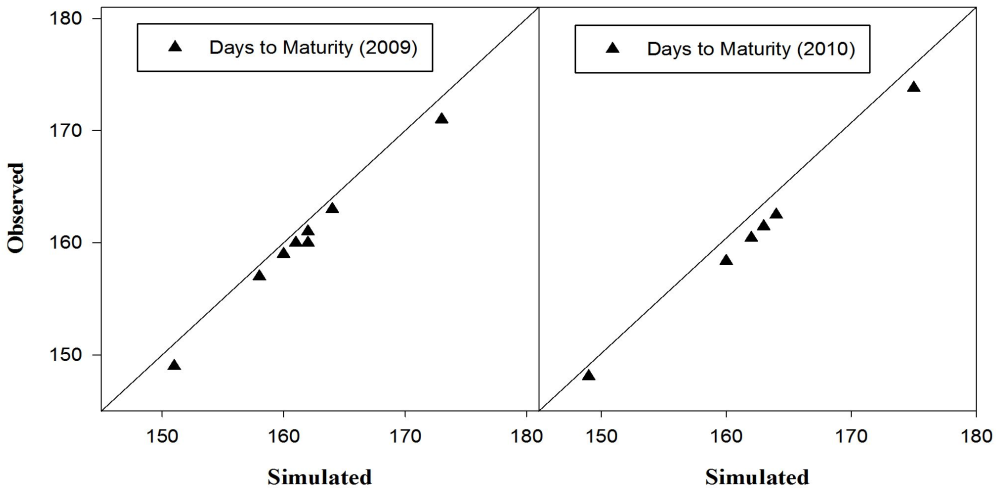


Figure 2. Relationship between simulated and observed days to maturity for cotton cultivars during growing season of 2009 and 2010

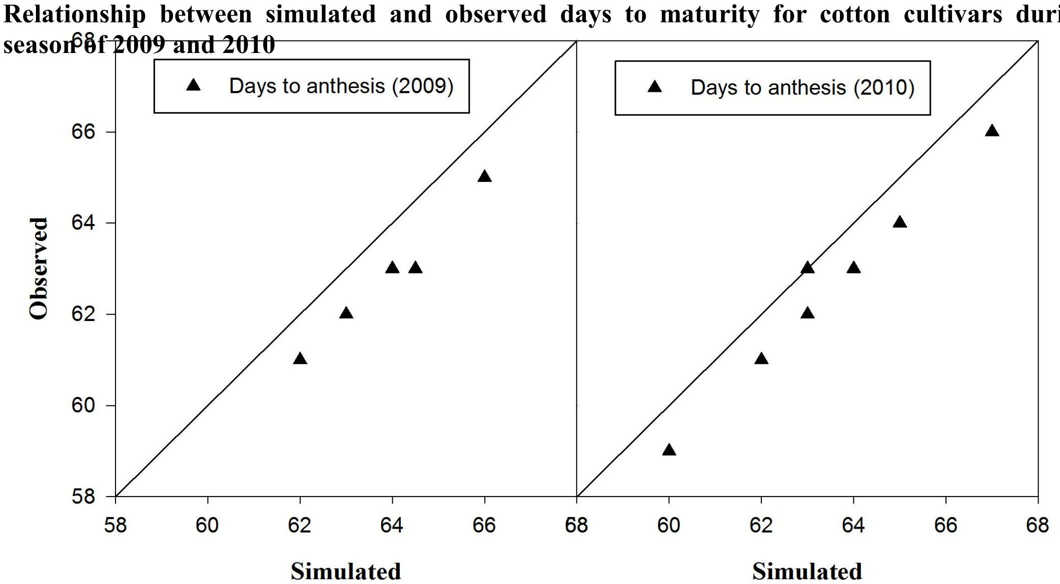


Figure 1. Relationship between simulated and observed days to anthesis for cotton cultivars during growing season of 2009 and 2010

Table 5. Comparison between simulated and observed total dry matter (kg ha^{-1}) at different nitrogen levels, sowing dates and cotton cultivars during year 2009 and 2010

Treatment	Calibration (2009)				Validation (2010)			
	Obs.	Sim.	Error (%)	RMSE	Obs.	Sim.	Error (%)	RMSE
May Sown	11650	11675	0.21	496.67	10871	11594	6.65	449.00
June Sown	9871	10206	3.39	391.00	9451	9873	4.47	405.33
N 50 kg ha^{-1}	8957	9149	2.14	393.00	8855	9000	1.64	367.33
N 200 kg ha^{-1}	11858	12684	6.97	479.67	11757	11895	1.17	411.67
CIM-496	10168	10710	5.33	417.00	10085	10332	2.45	398.67
CIM-506	9833	10145	3.17	377.33	9816	10558	7.56	398.33
NIAB-111	10535	10843	2.92	405.67	10555	10995	4.17	396.67
SLH-284	10647	10864	2.04	407.00	10620	11002	3.60	401.33
MPD			3.27				3.96	

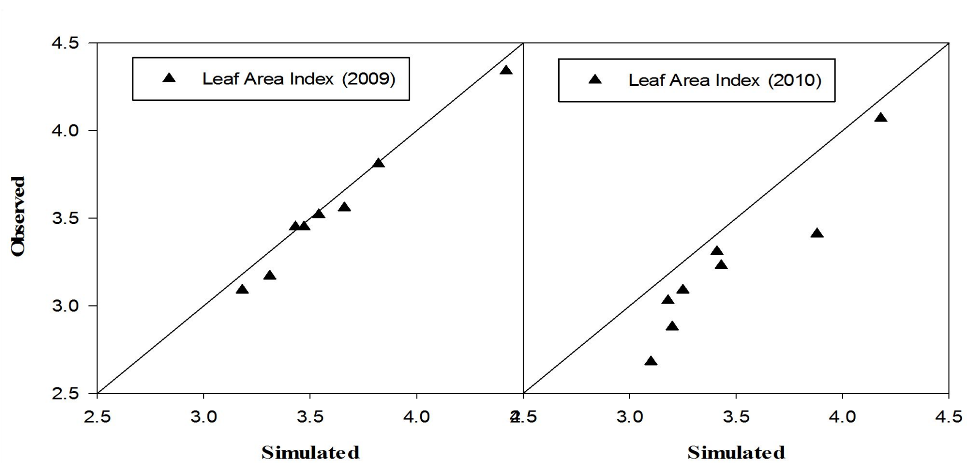
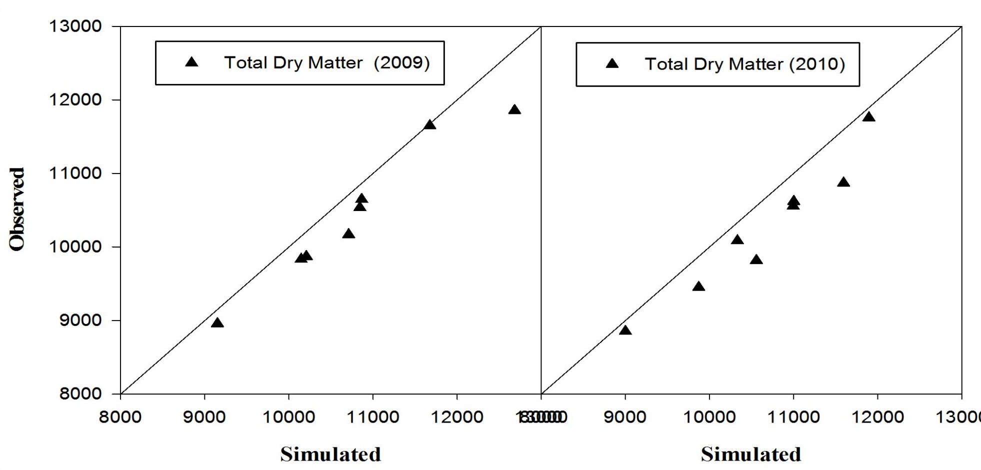


Figure 3. Relationship between simulated and observed leaf area index (LAI) for cotton cultivars during growing season of 2009 and 2010



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simulated and observed LAI for all studied treatments demonstrated in Fig.3, indicating strong association.

Table 5. Comparison between simulated and observed total dry matter (kg ha^{-1}) at different nitrogen levels, sowing dates and cotton cultivars during year 2009 and 2010

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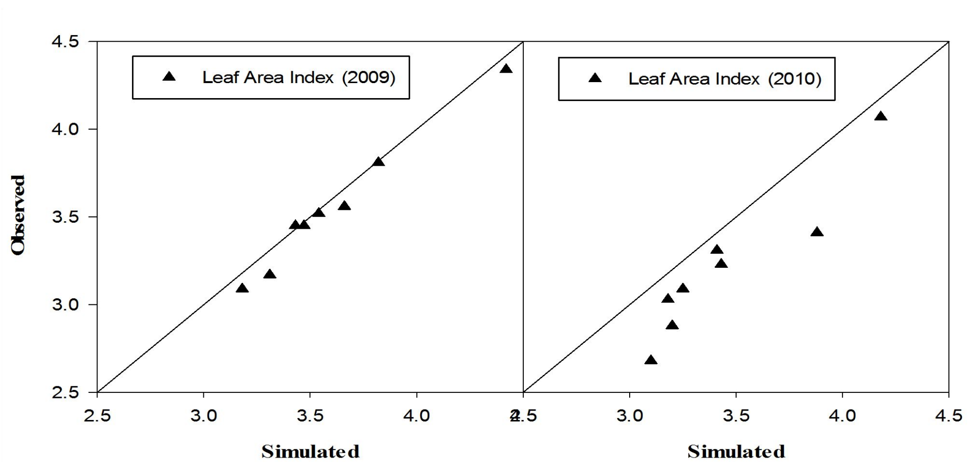

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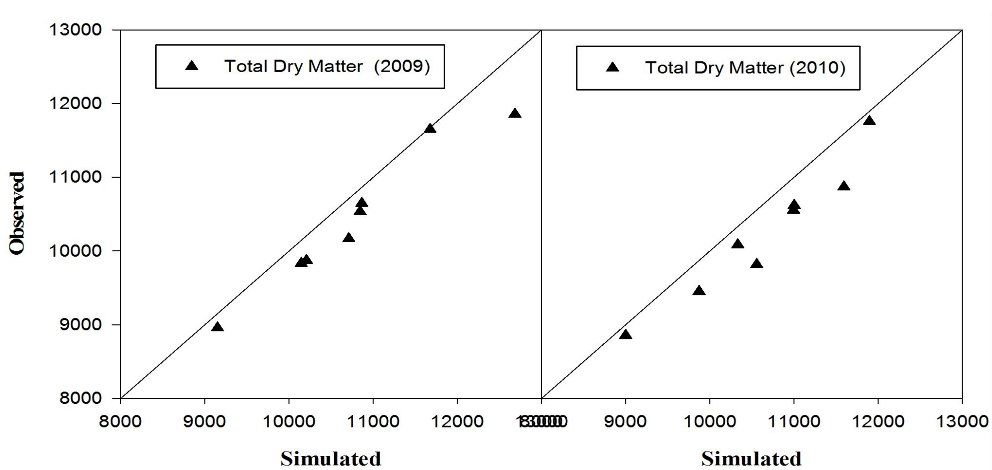

Figure 4. Relationship between simulated and observed total dry matter (Kg ha^{-1}) for cotton cultivars during growing season of 2009 and 2010

***Total dry matter (TDM kg ha^{-1})*:** The data in Table 5 indicated a significant and positive correlation among simulated and observed TDM during both the season at all

Table 5. Comparison between simulated and observed total dry matter (kg ha^{-1}) at different nitrogen levels, sowing dates and cotton cultivars during year 2009 and 2010

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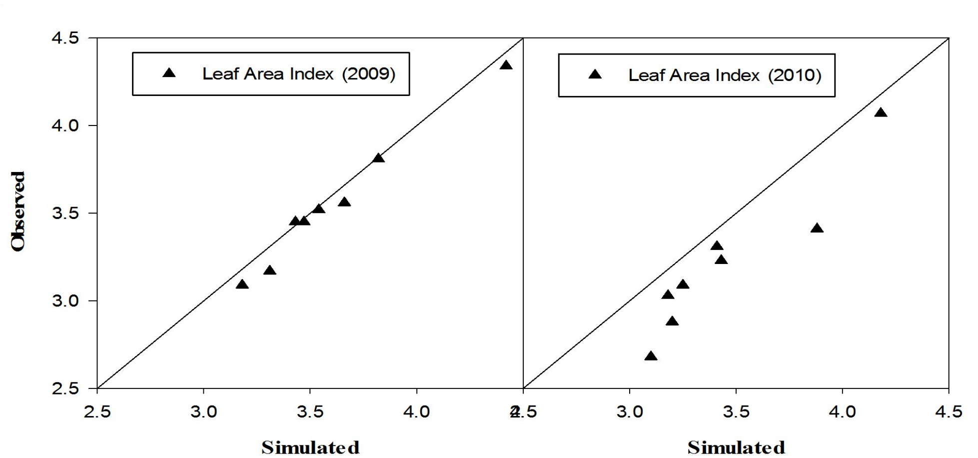

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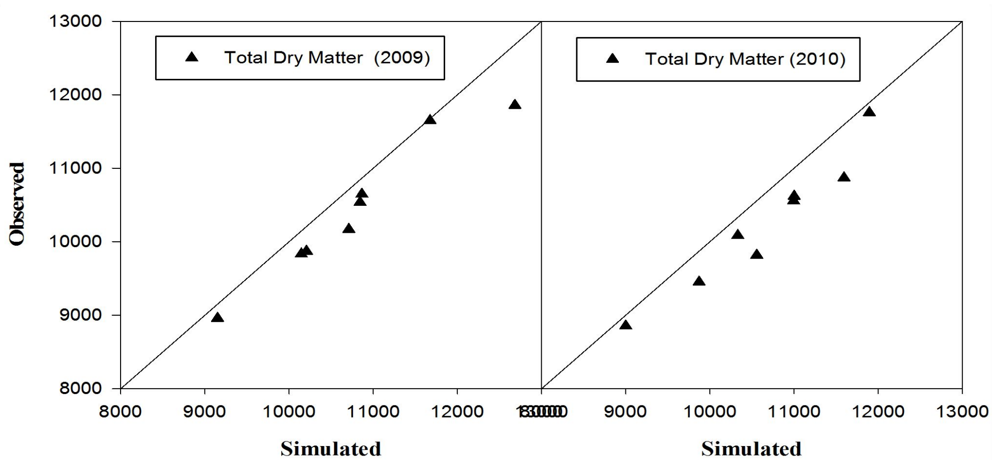

Figure 4. Relationship between simulated and observed total dry matter (Kg ha^{-1}) for cotton cultivars during growing season of 2009 and 2010

three sites. Pooled date for three sites showed that model slightly over estimated (0.21%) TDM in early sown crop than late in which model estimation was 3.39% more than observed data. Percent difference increased to 6.97% at higher fertilizer rates (200 kg N ha^{-1}) than lower 50 kg N ha^{-1} with percent error of 2.14. Root mean square difference for cultivars ranged from 377 to 417 kg ha^{-1} between observed and simulated data of total dry matter accumulation during 2009. Model validation with independent set of data from three sites in second year was also good with MPD of 3.96% only. RMSE values were ranging from 367 kg ha^{-1} to 449 kg ha^{-1} which showed that model was robust in validation under various climatic conditions. Coefficient of regression (R^2) between observed and simulated data for the pooled data at three sites was estimated at 0.87 and 0.89 for 2009 and 2010, respectively (Fig. 4).

Table 5. Comparison between simulated and observed total dry matter (kg ha^{-1}) at different nitrogen levels, sowing dates and cotton cultivars during year 2009 and 2010

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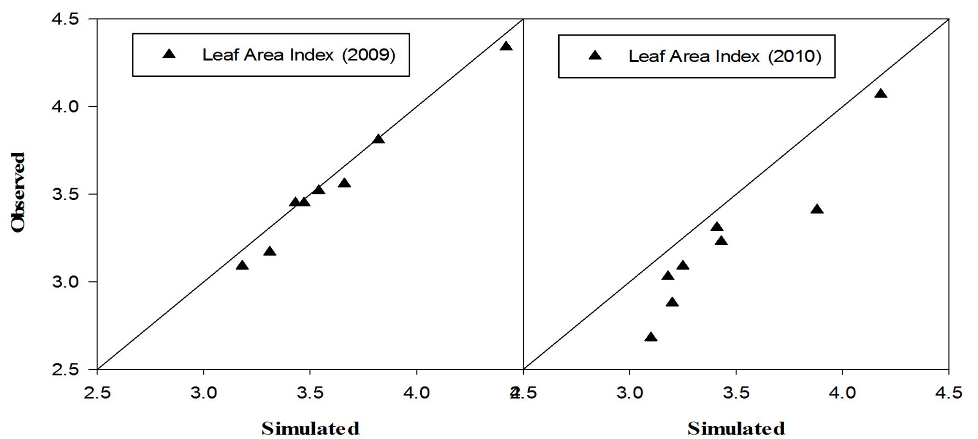

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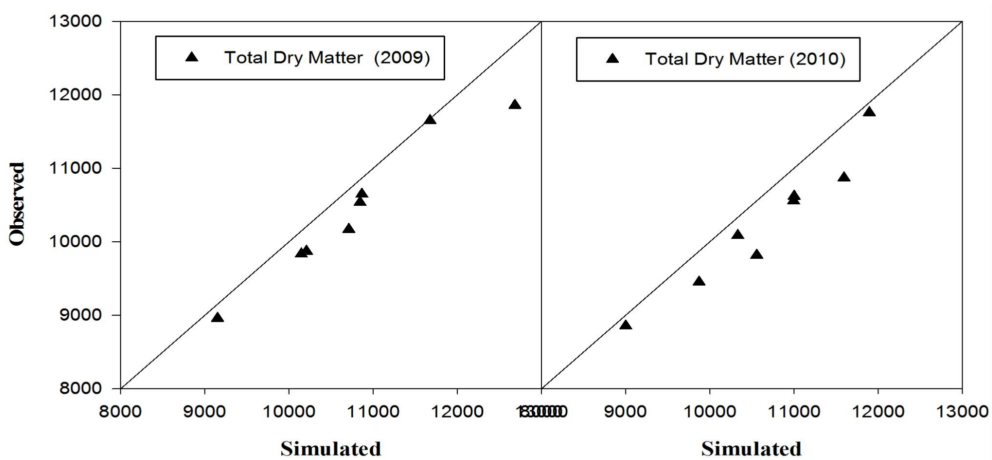

Figure 4. Relationship between simulated and observed total dry matter (Kg ha^{-1}) for cotton cultivars during growing season of 2009 and 2010

Seed cotton yield: The data presented in Table 6 shows that the May sown crop produced seed cotton yield of 2260 kg ha^{-1} whereas June sown produced 1765 kg ha^{-1} according to