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Full Length Research Paper

Application and evaluation of the DSSAT-wheat in the Tiaret region of Algeria

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Crop simulation models are essential tools to design management practices to mitigate such adverse conditions. They can be used to predict crop yield expectancies under limited environmental resources and various management scenarios. However, the application of crop models requires an accurate knowledge of the genotype-related coefficients, which are commonly not available. This paper aimed to evaluate the DSSAT crop model in Algeria for wheat, including the determination of DSSAT-specific genetic coefficients of wheat. Experimental data from three seasons and of nine cultivars were used for model calibration and testing. The results showed that the root mean squared error (RMSE) were 9.5 d and 1.8 d for anthesis and maturity respectively for model calibration ; and was 4.4 d and 3.5 d for anthesis and maturity in testing of the model, respectively. The RMSE of final grain yield was 0.7 t ha^{-1} for calibration and testing. This study showed that DSSAT may be used to predict the growth and yields of wheat genotypes in Algeria. In consequence to compare several crop management strategies in a wheat cropping area.

Key words: Wheat; simulation; DSSAT; genotype.

INTRODUCTION

Wheat (Triticum *durum, aestivum* L.) is the most widely grown crop species in the world. In Algeria, the Tiaret region provides one-third of the national wheat production. However, several climatic and agronomic factors currently prevent the full intrinsic yield potential of wheat cultivars from being realized in this region. These include, by order of importance: limited soil moisture availability, late frosts, nutrients deficiency and diseases. While the latter two factors can be managed by adequate fertilizer and pest control practices, the former two – irrigation is not available in the region – require the development of strategies tailored to the particular climate of Tiaret. In recent years, the inter-annual fluctuations of climate have been characterized by a higher frequency of drought episodes, enhancing the vulnerability of crop yields to this factor. This shift is expected to increase in the near future due to climate change (Alexandrov and Hoogenboom, 2001). Adaptation to this trend requires a capacity to investigate the relationships between crop management practices (such as cultivar selection and planting date), and the environmental factors (essentially soil properties and weather conditions), which interplay ultimately determine final crop yields.

There are currently three main approaches to estimate crop production, namely statistical, biophysical models and remote sensing of crop yields. Statistical models are primarily based on empirical relationships between a given phenomenon and some external driver, for instance between grain yield and rainfall amounts (Feeds et al., 1978; Van Keulen, 1982). The second approach involves holistic crop simulation models, which integrate knowledge of the biophysical processes governing the plant-

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soil-atmosphere system. According to Hoogenboom (2000), one of the main goals of crop simulation models is to estimate agricultural production as a function of weather and soil conditions as well as crop management. This provides the proper means to analyse the effects of the changes of soil characteristics or weather pattern separately, which is difficult to achieve in field experiments. While the latter are indispensable to develop, parameterize and test crop models, they may only investtigate a limited number of variables and geographical locations. Crop simulation models are therefore useful to extrapolate the results obtained under particular experimenttal conditions over time and space.

Under Mediterranean environments, wheat yields vary greatly across years due to markedly irregular rainfall distribution, and this random pattern makes it difficult to identify optimal farming practices and to make decisions on planting date or cultivar selection. In principle, crop simulation models have the capacity to address these risk issues, and to factor out environmental effects from management effects. They may be used to test what-if scenarios under a range of soil or climate conditions, and help to find answers to questions such as: what is the best planting date? What cultivar to use? How much fertilizer to apply? They also provide a realistic approach to the study of genotype and environment interactions over the entire life of the crop (Jagtap et al., 1999; Ghaffari et al., 2001).

In this study, the crop simulation model DSSAT (Decision Support System for Agrotechnology) was chosen because it has been successfully used worldwide in a broad range of conditions and for a variety of purposes: as an aid to crop management (Hunkár, 1994; Ruiz-Nogueria et al., 2001); fertilizer N management (Gabrielle and Kengni, 1996; Gabrielle et al., 1998; Zalud et al., 2001); irrigation management (Ben nouna et al., 2000; Castrignano et al., 1998); precision farming (Booltink and Verhagen, 1997; Booltink et al., 2001); climate change (Iglesias et al., 2000; Semenov et al., 1996); yield forecasting (Landau et al.,1998; Saarikko, 2000); and sustainability (Hoffmann and Ritchie, 1993). Pecetti and Hollington (1997) indicated that the CERES-Wheat model was applicable with sufficient reliability under Mediterranean conditions. Nevertheless, none of these regions reflect the actual pedoclimatic or agronomic conditions of Algeria. However, DSSAT has not been applied in Algeria or in any other neighbouring country.The objective of this work was to evaluate the capacity of DSSAT to predict the phenology and yield of wheat crops in the Tiaret region of Algeria.

MATERIALS AND METHODS

Experimental data

Nine wheat cultivars (T. *aestivum* and *durum*) were sown during the winter of 2001, 2002 and 2003. The three experiments were located at the farm experiment center at Tiaret (35°22' N; 1°22' E; 900 m altitude) in Algeria; on a sandy clay loam (USDA-taxonomy). The sowing dates were 15 Dec. 2001, 23 Dec. 2002 and 6 Dec. 2003, respectively. A complete block design with three blocks was used in each year. Seeding rate was 300 seeds m^{-2}. Diseases, weeds and pest infestations were controlled to achieve full expression of the water and N constraints on yield. The experiment conducted during the 2003-2004 growing season was used to find genetic coefficients for the DSSAT model, and the experiments conducted during the 2001-2002 and 2002-2003 growing seasons were used for model testing.

Daily weather data were obtained from the meteorological station of the experiment site. They included maximum and minimum air temperature (°C), rainfall (mm), and solar radiation ($MJ.m^{-2}$). The latter was estimated using daily sunshine hours and the Angstrom formula (Sys et al., 1991).

Soil surface parameters namely soil pH, organic carbon, nitrogen, cation exchange capacity and bulk density were determined (Ryan et al., 1996; Ogoshi et al., 1999). Surface soil evaporation limit, runoff curve number (Soil conservation service, 1972) and albedo were determined according to Jones et al., (1986) and the drainage rate following Suleiman and Ritchie (2004). Soil physical properties, namely the permanent wilting point (or lower limit of soil water content, LL), the water content at drained-upper limit (DUL), the saturation water content (SAT), and the saturated hydraulic conductivity, were estimated using the pedo-transfer functions developed by Ritchie et al. (1999; see also Suleiman and Ritchie, 2001; Gabrielle et al., 2002).

The DSSAT model

DSSAT v. 4.0 (Jones et al., 2003) was applied in this study. In v. 4.0, all crop models were combined into the Cropping System Model (CSM), which is based on a modular modelling approach. CSM uses one set of code for simulating soil water, nitrogen and carbon dynamics, while crop growth and development are simulated with the CERES, CROPGRO, CROPSIM, or SUBSTOR module (Hoogenboom et al., 2003). The model simulates the impact of the main environmental factors such as weather, soil type, and crop management on wheat growth, development and yield.

Input requirements for DSSAT include weather and soil condition, plant characteristics, and crop management. The minimum weather input requirements of the model are daily solar radiation ($MJ\ m^{-2}d^{-1}$), maximum and minimum temperature (°C) and precipitation (mm). Soil inputs include albedo, evaporation limit, mineralization and photosynthesis factors, pH, drainage and runoff coefficients. The model also requires water holding characteristics, saturated hydraulic conductivity, bulk density and organic carbon for each individual soil layer. Required crop genetic inputs are PHINT (thermal time between the appearance of leaf tips), G3 (tiller death coefficient), G2 (potential kernel growth rate), G1(kernel number per unit weight of stem + spike at anthesis), P5 (thermal time from the onset of linear fill to maturity), P1D (Photoperiod sensitivity coefficient), P1V (vernalization sensitivity coefficient). Management input information includes plant population, planting depth, and date of planting. Latitude is required for calculating day length. The model simulates phenological development, biomass accumulation and partitioning, leaf area index, root-, stem-, and leaf-growth and the water- and N-balance from planting until harvest at daily time steps.

Model calibration and evaluation

Model calibration is the adjustment of parameters so that simulated values compare well with observed data. The so-called 'genetic coefficients' that influence the occurrence of developmental stages in the DSSAT can be derived iteratively by manipulating the relevant coefficients to achieve the exactly match between the simulated and observed number of days to phenological events.

Table 1. Genetic coefficients fitted for the 9 wheat cultivars.

Cultivar	Coefficients						
	P1V	P1D	P5	G1	G2	G3	PHINT
SEMITO (T *d*)	58	43	320	19	37	2.99	95
MEXICALI (T *d*)	60	45	322	17	36	2.99	95
OFANTO (T *d*)	60	45	340	20	45	2.98	95
VITRON (T *d*)	60	55	221	21	46	2.99	95
BIDI17 (T *d*)	58	55	320	19	49	2.99	95
MBB (T *d*)	60	56	328	17	34	2.99	95
MEXICANO (T *a*)	60	58	293	23	33	2.99	95
HD1220 (T *a*)	60	58	300	20	35	2.99	95
MAHONDEMIAS (T *a*)	60	56	305	20	37	2.99	95

T *d* : Triticum durum ; T *a* : Triticum *aestivum*

P1V Days at optimum vernalizing temperature required to complete vernalization.

P1D Percentage reduction in development rate in a photoperiod 10 hour shorter than the optimum relative to that at the optimum

P5 Grain filling (excluding lag) period duration (GDD_0)

G1 Kernel number per unit canopy weight at anthesis (g^{-1}).

G2 Standard kernel size under optimum conditions (mg).

G3 Standard, non-stressed dry weight (total,including grain) of a single tiller at maturity (g).

PHINT Phyllochron interval (GDD_0).

The GENCALC software (Hunt and Pararajasingham, 1994) does this type of adjustment automatically and therefore uses the observations of phenological events from one or several experiments from a range of environments. We chose the manual approach because there were relatively few experimental data percultivar, impeding the identification of optimal parameter values by such a mathematical algorithm. Godwin et al. (1989) suggested that such a manual, iterative approach usually reaches reasonable estimates of the genetic coefficients.

The DSSAT model was calibrated using the data from the 2003 field trial, and tested with the data of the remaining two years (2001 and 2002).

In the testing phase, model performance was evaluated with standard statistical indicators. According to Willmott (1982) the correlation coefficient and the coefficient of determination are of little practical value in evaluating the predictive capabilities of models because their magnitudes are not consistently related to the accuracy of the prediction. More appropriate criteria include mean bias error (MBE), root mean square error (RMSE) and mean absolute percentage error (MAPE). These measures are defined as follows:

$$\text{MAPE} = \frac{1}{n}\left[\sum_{i=1}^{n}\left(\left|\frac{data_i - \text{model}_i}{data_i}\right|\right)100\right]$$

$$\text{RMSE} = \left[\left(\sum_{i=1}^{n}(\text{model}_i - data_i)^2\right)/n\right]^{0.5}$$

$$\text{MBE} = \frac{1}{n}\left[\sum_{i=1}^{n}(\text{model}_i - data_i)\right]$$

Where $model_i$ is the i^{th} forecast value, $data_i$ is the i^{th} mean measured value and n is the number of observations.

RESULTS

Cultivar calibration

Table 1 shows the values of the seven DSSAT genetic coefficients for the nine wheat genotypes obtained by fitting the model against the data from the experimental trials. Parameter values obtained with a previous release of DSSAT (v3.5) were converted into the DSSAT v4.0 format using the relationships supplied by Hunt (2006).

Godwin et al. (1989) suggest using a default value of 95 growing degree days for PHINT for winter genotypes in Europe and the North plains of America (Table 2). In the present work, this default value provided the best-fit for all cultivars, and that was in agreement with Ghaffari et al. (2001), Bannayan et al. (2003) and Moreno-Sotomayor and Weiss (2004) in the United Kingdom and Mid West of USA., respectively. In a Mediterranean climate (Southern Italy), Rinaldi (2004) used 100 GDDs for durum wheat. Under semiarid climate, Saseendran et al. (2004) estimated PHINT at 76 GDDs for the winter wheat cultivar TAM 107 in Colorado, USA, while Yang et al. (2006) and Nakayama et al. (2006) set it at 90 GDD_s for some cultivars in the Northern China plain. The range of values reported in the above references for PHINT suggests that values specific to the particular genotypes and geographical region at stake should be sought when applying DSSAT.

The vernalization coefficient (P1V) was set to 60 d for all cultivars, with the exception of cultivars Simito and Bidi17 for which the best-fit value was 58**.** The prediction of anthesis by the model was very sensitive to P1V: change this parameter by 1 d resulted in a 3 d difference delay in the simulated anthesis date. Ritchie (1991)

Table 2. Genetic coefficient for winter wheat from various studies.

Cultivar	Latitude	Location	Climate	Coefficients							SOURCE
				PIV	PID	P5	G1	G2	G3	PHINT	
Mercia (*Ta*)	51°04 to 51°24N 00°40 to 01°27E	United Kingdom	Temperate climate	30	92	548	25	49	2.3	95	Ghaffari et al., 2007
Mercia (*Ta*)	52°50 to 53°13N 00°02 to 02°39E	United Kingdom	Temperate Climate	30	93	553	29	38	2.2	95	Bannayan et al., 2003
Simeto (*Td*)	41°27N to 3°04E	Southern Italy	Mediterranean climate	20	30	570	15	47	1.9	100	Rinaldi, 2004
Arapahoe	40.85°N 96.6°W	Nebraska,USA	Sub-humid Climate	60	54	512	3125	36	1.8	95	Moreno-Sotomayor and Weiss 2004
Karl 92 (*Ta*)	41.13°N 96 5°W			60	58	480		41	2.0	95	
TAM107 (*Ta*)	40°9N 40°9W	Eastern Colorado	Semiarid Climate	65	60	610	50	62	1.7	76	Saseendran et al., 2004
No. 4185 (*Ta*)	37° to 40°N 114° to 117°E	North China plain	Semiarid Climate	15	48	330	24	50	2.9	90	Yang et al., 2006
Jimai28 (*Ta*)	37°90N 114°46E	North China plain	Semiarid Climate	10	100	332	32	75	2.9	60	Nakayama et al., 2006
Ww	-	America/ N. plains	-	6.0 (60)	2.5 (50)	2.0 (490)	4.0 (25)	2.0 (40)	1.5	95.0	Godwin et al., 1989
Ww	-	West Europe	-	6.0 (60)	3.5 (70)	4.0 (530)	4.0 (25)	3.0 (50)	2.0	95.0	Godwin et al., 1989
Ww	-	East Europe	-	6.0 (60)	3.0 (60)	5.0 (550)	4.5 (27)	3.0 (50)	2.0	95.0	Godwin et al., 1989

T d : *Triticum durum* ; Ta : *Triticum aestivum* ; Ww : Winter wheat indicated that spring wheat, which virtually does not require any vernalization should obtain a P1V values lower than 5 d. Godwin et al. (1989) suggest to use a default value of 60 d for winter genotypes in Europe and the North plains of America (Table 2). In practice, P1V was reported to vary within a wide range, from 10 to 65 d, independent of climate type or continent (Table 2). Under Mediterranean climates (Southern Italy), Rinaldi (2004) used a value of 20 d for durum wheat.

The photoperiod coefficient (P1D) varied between 43 and 58%, evidencing differences in sensitivity to photoperiod across the cultivars. The P1D values obtained for cultivars Mexicano and HD1220 were similar to the value found by Moreno-Sotomayor and Weiss (2004) for cultivar Karl92. For winter wheat, Godwin et al. (1989) suggest to use a default value of 50% in the Northern plains of America, of 60 in Eastern Europe, and of 70 in Western Europe. Under Mediterranean climate, albeit for durum wheat, Rinaldi (2004) reported a value of 30%, lower than the range we obtained. In Northern China, Yang et al. (2006) estimated a P1D of 48%, which falls within our range. Similarly to parameter P1D, the prediction of maturity by DSSAT was highly sensitive to P1V: a relative change of 2% in P1V affected the maturity date by 3 d.

The grain filling duration (P5) ranged from 221 to 340 GDDs, depending on cultivar. This range was thus outside that originally suggested by Godwin et al. (1989), and from the various literature studies. Godwin et al. (1989) give a default value of 490 GDD_0 for winter wheat in the Northern Plains of America, and of 530 and 550 GDD_0 for Western and Eastern Europe, respectively. However, there was only a slight difference between our values and that used by Yang et al. (2006) and Nakayama et al. (2006) in Northern China. Literature values for P5 ranged from 332 to 610 GDD_0 (Table 2).

The kernel number coefficient (G1) varied between 17 and 23 k g^{-1}, which is 60 to 90% lower than the default values of Godwin et al. (1989), and in the lower half of the worldwide range. Under a similar climate, Rinaldi (2004) reported a value of G1 of 15 k g^{-1}, which is close to this study values. Godwin et al. (1989) suggest a default value of 25 k g^{-1} for winter wheat genotypes in the Northern Plains of America, and of 27.5 k g^{-1} for Europe. In later studies, G1 was found to vary between 15 and 50 k g^{-1}, worldwide.

The kernel weight coefficient (G2) varied between 33 and 49 mg across the nine cultivars, which falls in the lower half of the 36 to 76 mg range reported by other authors (Table 2). Godwin et al. (1989) suggest a default value of 40 mg for winter wheat genotypes in the Northern Plains of America and Eastern Europe, and of 50 mg for Western Europe. The highest G2 values were given by Saseendran et al. (2004) and Yang et al. (2006), in Colorado, USA and Northern China, respectively. Our result indicates that there is cultivar variability in final grain weight and grain numbers (Ritchie et al., 1998).

The optimal value for the spike number coefficient (G3) was 2.9 g for all cultivars**.** This value is outside the 1.5-2.0 g range proposed by Godwin et al. (1989), but at the top of the 1.5-2.9 g range reported in later studies. Only Yang et al. (2006) reported a similar G3 value in Northern China.

DISCUSSION

The performance of the DSSAT model after calibration was evaluated. The variables tested included the key phenological dates (anthesis and harvest maturity), the final yield and the yield components, as recommended by Hunt et al. (1993). In general, the model gave good predictions of crop development and final grain yields, and for all cultivars (Table 3).

The model predicted the anthesis and maturity dates, with an overall root mean squared error (RMSE) value of 6.6 and 3.0 d, respectively. The mean absolute percenttage errors (MAPE) were of 3.4 and 1.2%, respectively. Overall, the differences between the simulated and observed anthesis and maturity dates for all cultivars and for three years were less than 2 weeks.

This goodness of fit statistics compare favorably to those reported by Bannayan et al. (2003) for the simulation of winter wheat with DSSAT: the model achieved root mean squared errors (RMSEs) of 7.1 and 10.0 d, and the mean percentage errors (MPEs) of 2 and 2.4% for the anthesis and maturity dates, respectively. For three winter wheat cultivars (Arapahoe, Karl 92, NE92458), Xue et al. (2004) found a RMSE of 4.7d using CERES-Wheat (within DSSAT v3.0). However, Timsina and Humphreys (2006) found when they combined a wide range of data sets, the fit of DSSAT to phenology data tended to improve, with an RMSE of 4.49 and 5.08 d for anthesis and maturity, respectively. Humphreys et al. (2005) cited by Timsina and Humphreys (2006) reported similarly good results with DSSAT v3.5 predicted anthesis and maturity quite well in 2 cases out of 3 without giving quantitative goodness of fit figures. Overall, the simulation of grain yield was quite acceptable with a RMSE of 0.76 t ha^{-1}. The model tended to underestimated grain yield, with a mean bias error (MBE) of -0.50 t ha^{-1}. These values are similar to those mentioned in previous tests of DSSAT: Bannayan et al. (2003) reported a slight underestimation of grain yield with a MBE of -0.03 t ha^{-1}, while Timsina and Humphreys (2006) calculated an RMSE of 0.48 t ha^{-1} by compiling a large number of data sets. Jamieson et al. (1998) compared 5 different wheat models in Australia, including CERES-Wheat, and found a MBE of 0.13 t ha^{-1} and an RMSE of 0.9 t ha^{-1}. Staggenborg and Vanderlip (2005) reported CERES-Wheat overestimated wheat yields by 16% with a MBE of – 0.3 t ha^{-1}, while Ntiamoah (2001) reported an underestimation of grain yield. The latter two authors suggested that the model does not perform as well under dry land conditions as under more humid conditions. This was supported by

Table 3. Statistical comparison between observed and simulated values for days to anthesis, maturity, grain yield and components yield for model DSSAT evaluation.

Harvest year	Cultivars	Anthesis		Maturity		Grain yield		Thousand grain weight		Number of ears m^2	
		DAP		DAP		t ha^{-1}		g			
		Sim	Obs	Sim	Obs	Sim	Obs	Sim	Obs	Sim	Obs
2002	Vitron	153	150	176	172	1.383	1.433	36	39	119	194
2002	Bidi17	152	155	180	184	1.271	1.357	44	47	130	147
2002	Mexicali	151	153	179	174	0.690	1.257	36	43	121	152
2002	Semito	150	155	178	171	0.583	1.032	37	45	174	187
2002	Ofanto	151	158	180	182	0.974	1.425	43	44	200	186
2002	MohamedBenBachir	153	155	182	182	1.051	0.850	34	40	146	150
2002	Mexicano	153	154	180	175	1.290	1.129	33	36	223	199
2002	HD1220	153	155	180	182	1.458	1.650	35	34	150	131
2002	Mahondemias	153	150	180	176	1.346	1.388	37	40	186	107
2003	Vitron	147	148	166	170	2.162	2.416	40	39	173	267
2003	Bidi17	144	153	180	180	1.508	2.208	49	47	136	277
2003	Mexicali	145	150	169	171	1.677	2.916	36	43	112	204
2003	Semito	142	150	166	173	1.434	2.290	37	46	133	274
2003	Ofanto	147	148	169	169	1.666	2.790	45	45	212	272
2003	MohamedBenBachir	145	153	181	180	1.553	1.875	34	43	145	202
2003	Mexicano	147	147	169	170	1.002	2.937	33	36	157	252
2003	HD1220	147	147	170	170	1.853	3.290	35	35	119	201
2003	Mahondemias	147	147	170	171	1.688	2.458	37	42	278	207
2004	Vitron	168	157	192	192	4.268	4.650	37	48	387	477
2004	Bidi17	167	163	197	197	3.182	2.290	44	42	280	363
2004	Mexicali	166	155	196	192	2.837	3.442	36	45	553	478
2004	Semito	164	153	194	192	3.747	4.306	37	44	412	470
2004	Ofanto	166	159	197	194	3.223	4.782	42	48	457	481
2004	MohamedBenBachir	169	163	198	197	2.081	1.962	34	44	378	472
2004	Mexicano	169	158	197	197	3.319	3.532	33	48	389	481
2004	HD1220	169	158	197	197	2.887	3.630	35	38	394	472
2004	Mahondemias	169	158	197	197	3.267	3.550	37	39	576	470
	All years										
	MBE	1.29		0.48		-0.50		-4.59		-38.25	
	RMSE	6.60		3.08		0.76		6.28		76.57	
	MAPE	3.40		1.23		24.22		11.52		25.43	
	Calibration										
	MBE	9.22		1.11		-0.37		-6.77		-37.55	
	RMSE	9.58		1.82		0.72		8.35		81.08	
	MAPE	5.85		0.57		16.76		15.89		16.98	
	Testing										
	MBE	-2.66		0.16		-0.56		-3.50		-38.61	
	RMSE	4.40		3.55		0.79		4.92		74.21	
	MAPE	2.18		1.56		27.94		9.33		29.66	

Obs : observed; Sim: simulated; DAP: days after planting; MBE: mean bias error; RMSE: root mean square error; MAPE: mean absolute percentage error.

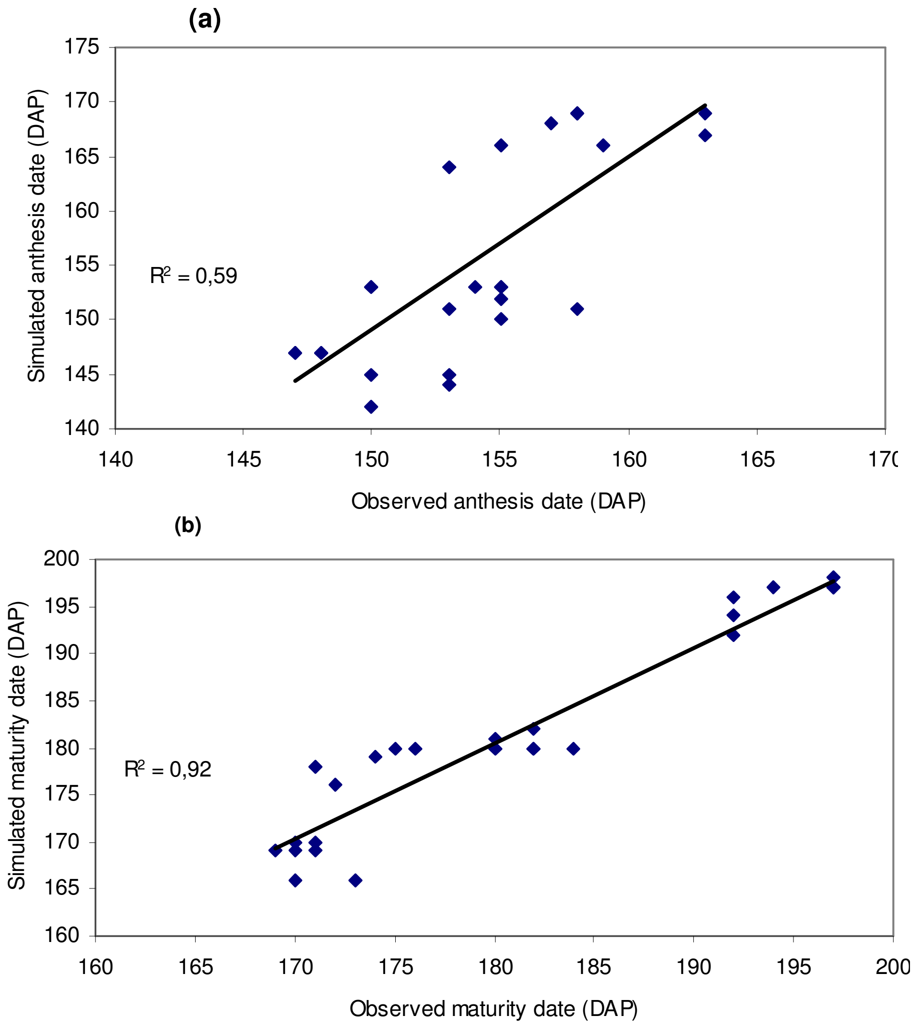


Figure 1. Regression analysis of simulated and observed values for a) anthesis, b) maturity, c) kernel weight, d) ear number and e) grain yield.

our results: model our results: model errors were higher in the drier years than in the wetter ones.

Regarding the yield components, the thousand grain weight was underestimated by the model, with a MBE of -4.5 g and an RMSE of 6.2 g (Table 3). Also, the number of ears per m^2 was underestimated, with a MBE of -38.2 ears m^{-2} and a RMSE of 76.5 ears m^{-2}. This is probably due to the fact that genetic coefficients were obtained from a limited set of field observations. Because some of the genetic coefficients are probably correlated (for instance, the kernel weight G1 and kernel number G2), different compensations of may explain this behavior though compensation between these components lead to simulated grain yields that were in good agreement with the observed values.

Regression analysis gave an r^2 of 0.59 and 0.92 for anthesis and maturity dates, respectively (Figures 1a, b), and with r^2 of 0.71 and 0.77 for grain yields and number of ears m^{-2} respectively (Figures 1e, d). Only the regression of measured and simulated kernel weights the other variables, the good coefficients of determination achieved by the model could be partially explained by the ample variation range of the explanatory varia-bles (the observed data), as a result of contras-contrast-ed climatic years during the wheat trials.

There were little differences in model performance between the calibration and independent testing phases, as may be seen on Figure 2. The differences between simulated and observed dates of maturity ranged between 0 and 4 d in the calibration and between 0 and 7 d for testing. The prediction of anthesis was slightly less successful, with a mean model error ranging from 4 and 11 d for the calibration and between 0 and 9 d in the testing phase. The differences between simulated and observed thousand-grain weights ranged between 1 and 15 g for the calibration and between 0 and 9 g for the testing. The differences between simulated and observed

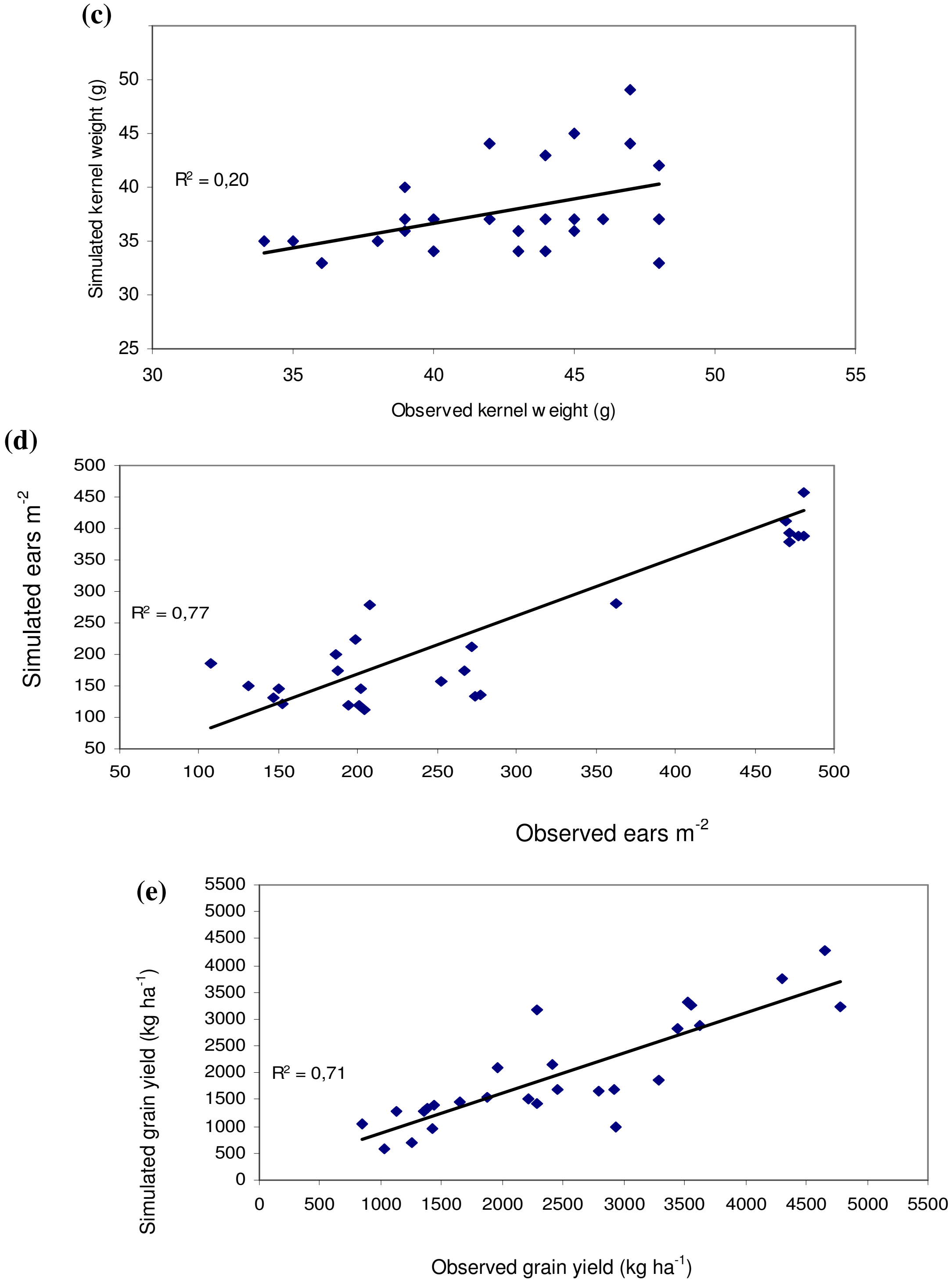


Figure 1 (continuation). Regression analysis of simulated and observed values for a) anthesis, b) maturity, c) kernel weight, d) ear number and e) grain yield. Simulated ears m^{-2}, Observed ears m^{-2}Simulated grain yield (kg ha^{-1}) , Observed grain yield (kg ha^{-1})

grain yields ranged between 0.11 tha^{-1} and 1.55 t ha^{-1} in the calibration and between 0.04 t ha^{-1} and 1.93 t ha^{-1} in the testing phase. Godwin et al. (1989) advocated the use of a common set of genetic coefficients for all winter wheat cultivars. Pecetti and hollington (1997) and Chippanshi et al. (1997) used a standard vernalization

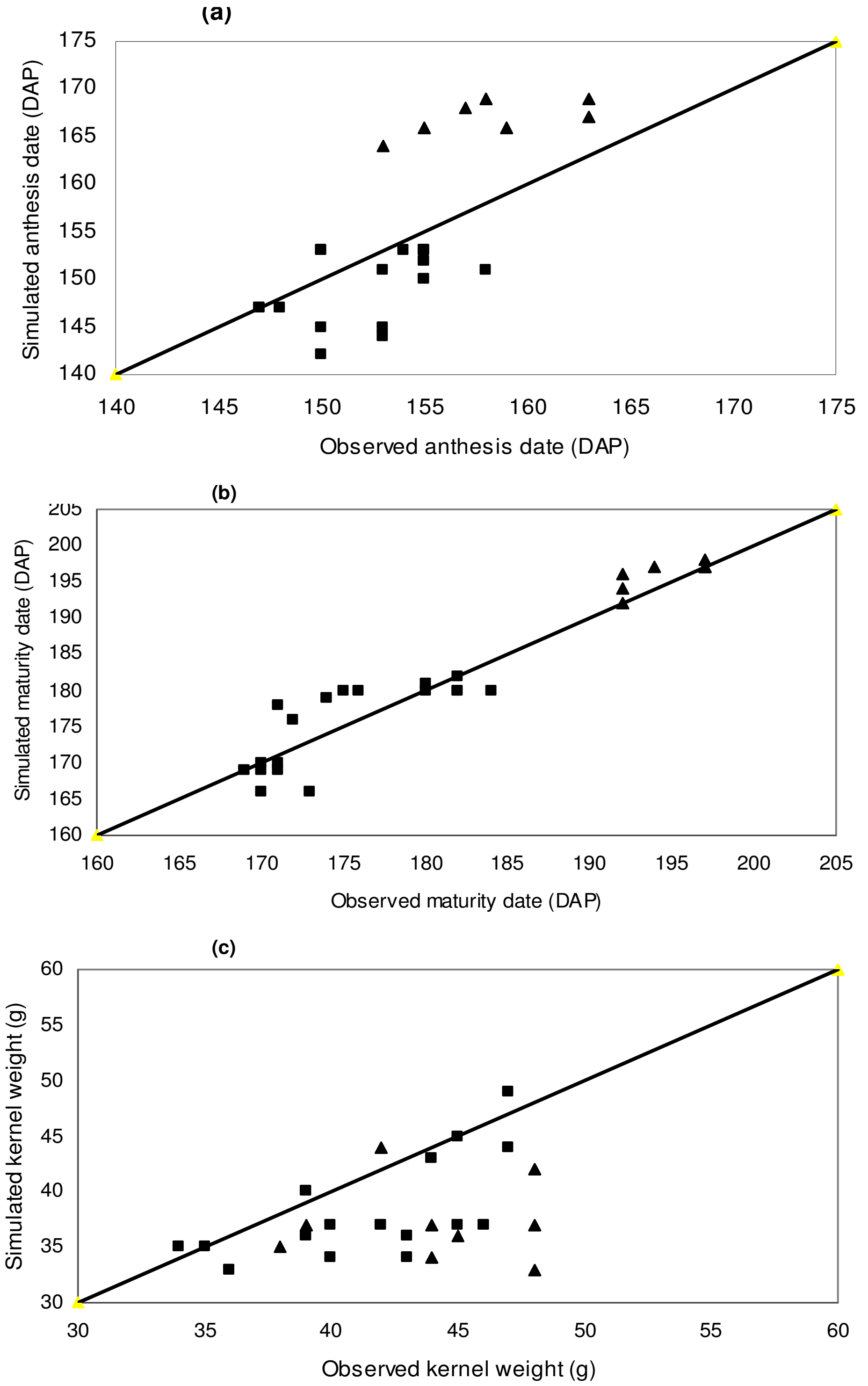
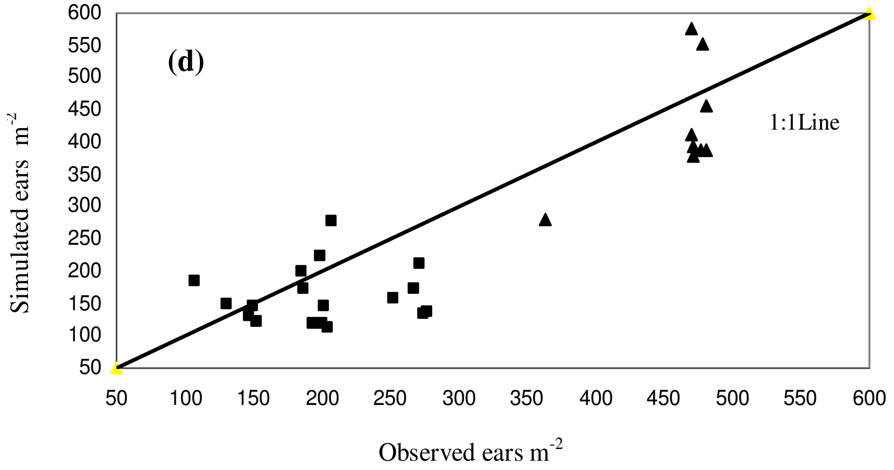


Figure 2. Comparison of simulated and observed data for a) anthesis, b) maturity, c) kernel weight, d) ear number and e) grain yield for the nine cultivars for calibration (▲) and testing years (■).

coefficient value of 0.5 for spring wheat in their studies. In the present study, different winter wheat cultivars produced different values of genetic coefficient, proving the use of default values for all winter wheat cultivars to be inappropriate. The capacity of DSSAT to reproduce the response of nine wheat cultivars to inter-annual climate



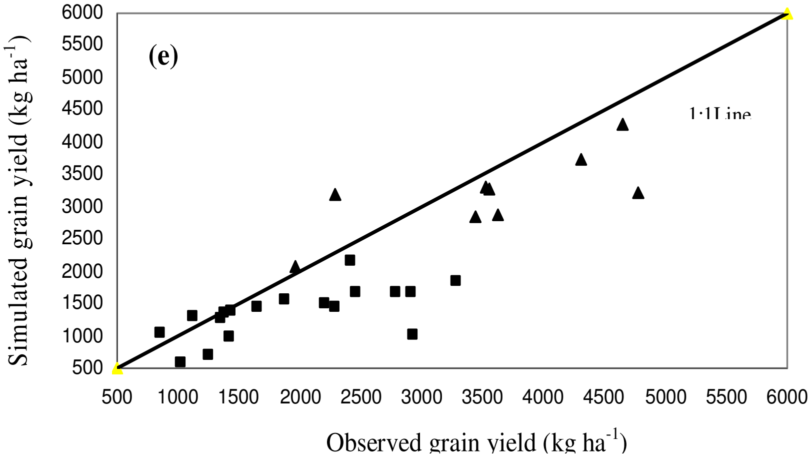


Figure 2 (continuation). Comparison of simulated and observed data for a) anthesis, b) maturity, c) kernel weight, d) ear number and e) grain yield for the nine cultivars for calibration (▲) and testing years (■).

variability was evaluated. Figure 3 shows there were large differences in observed grain yields across the 3 growing seasons. The 2002 season was unfavorable with a seasonal rainfall of only 190 mm, and a severe frost in the weeks following planting. Cultivar HD1220 achieved the highest grain yield (1.65 t grain DM ha^{-1}), while cultivar

Mohamed BenBachir had the lowest one, at 0.85 t grain DM ha^{-1}. The 2003 season was more favorable, with more frequent rainfall events, and a seasonal cumulative value of 354 mm. The highest and lowest grain yields were again achieved by cultivars HD1120 and Mohamed BenBachir*,* with values of 3.29 and 1.87 t grain DM ha^{-1}, respectively. The 2004 season was the best of all, with a cumulative rainfall of 476 mm. Cultivar Ofanto had the highest grain yield (4.78 t grain DM ha^{-1}), while cultivar MohamedBenBachir had the lowest one (1.96 t grain DM ha^{-1}), similarly to the two previous seasons. There were thus significant variations across cultivars for a given year, with final grain yields differing by a factor of 1.5 to 2 between the lowest- and highest-yielding crops. The variations were still ampler between climatic years, evidencing the prominent effect of water availability on wheat growth.

As noted earlier, the model also underestimated the grain yields across the 3 years. This was probably due to the under-estimations of the number of grains per ear, which could not be corrected in the calibration phase because of strong interactions between genetic parameters. A simple sensitivity analysis showed that grain yield was mostly influenced by the values of coefficients PHINT, G1, G2, and G3. The model was highly sensitive to the latter two: a +1 or -1 change on G1 resulted in a 10% variation in grain yield, while G2 and G3 had a similar influence on the kernel weight and number of ears per m^2, respectively. In practice, only G1 and G2 varied across cultivars and could explain most of the differences between them. Improvement should rather be sought in the way the model handles water stress in moderately dry years, i.e., in the mid-range of the response curves to

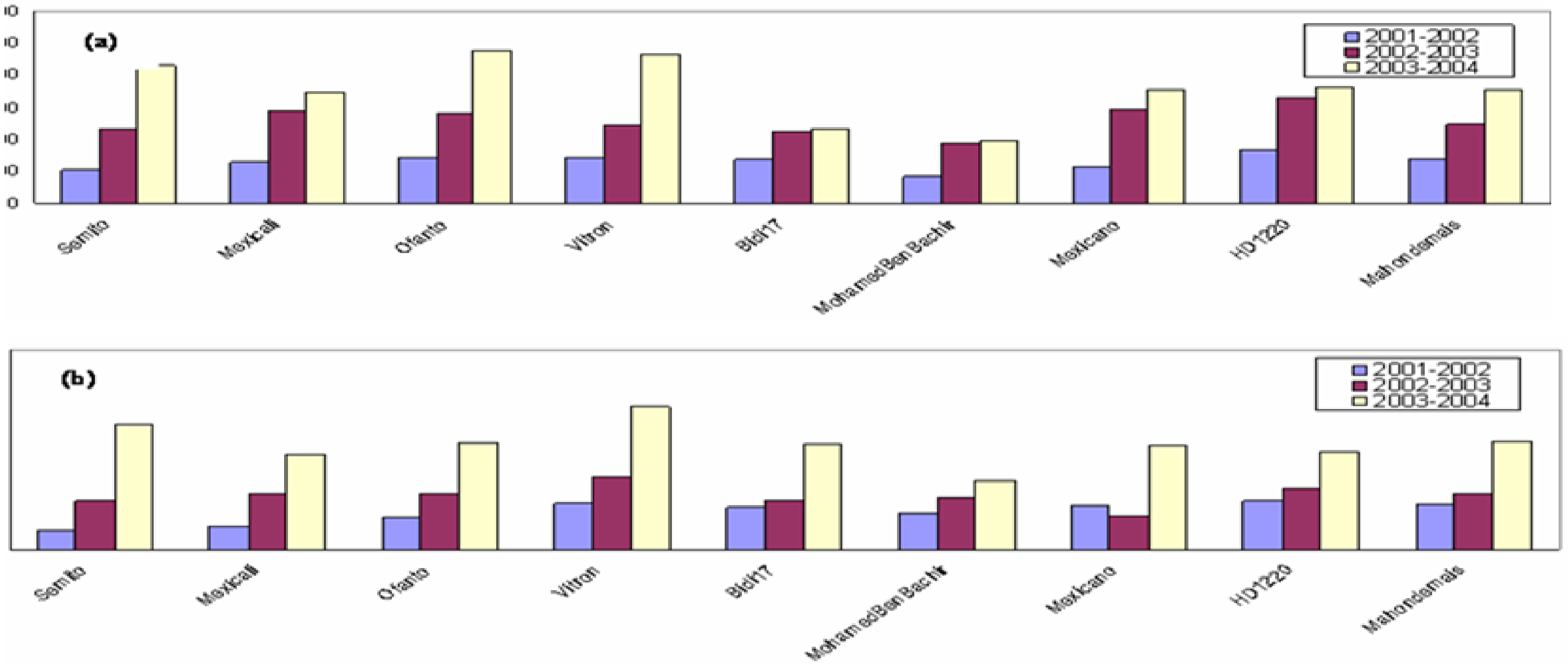


Figure 3. Observed (a) and stimulated (b) final grain yields for the three growing seasons for the nine cultivars.

soil water shortage.

Conclusion

The DSSAT model was calibrated and evaluated for winter wheat under Algerian environmental conditions, for which it had not been evaluated yet. Studies with similar purposes have already been carried out in neighboring countries in the Mediterranean (Pecetti and Hollington, 1997; Rinaldi, 2004; Heng et al., 2007; Ouda et al., 2005). However, none of these regions reflect the actual pedoclimatic or agronomic conditions of Algeria. Thus the results obtained elsewhere in the Mediterranean could not be readily transferred to the Tiaret area. This also provides scope for demonstrating the usefulness of crop models for providing decision-support for agriculture in Algeria, which has not been done yet. Our results confirm the possibility of applying DSSAT to predict the yield of various winter wheat cultivars, provided the genetic coefficients are calibrated based on local field trials. There were little differences in model performance between the calibration and testing years, and the model errors were acceptable. The model correctly predicted the ranking of cultivars in terms of grain yield in two out of the three years of the field trials. In the remaining year, it could only partly render the differences between cultivars, and this limitation could not be overcome by a recalibration of genetic coefficients A more robust determination of these parameters may have been achieved by using several experimental sites rather than only one. In the future, the model may be used as a management tool to determine an optimum planting date or cultivar choice, taking into account the variability of weather and the associated yield loss risks. It may also be used to predict crop performance in regions where the crop has not been grown before, by predicting probabilities of grain yield levels for a given soil type and rainfall distribution. Such analysis may be carried out to evaluate the effect of global climate change on crop production. Assessing such effects is important at the producer as well as at the government level for planning purposes, and models such as DSSAT are expected to play a major role in that area.

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