Calibration and Validation of the DSSAT Model with Experimental Data for Three Varieties of Wheat on Different Planting Dates

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Abstract

The Crop Simulation Model (CERES-wheat module) of the Decision Support System for Agrotechnolgy Transfer (DSSAT) was used in this study to simulate the effect of planting date (D) on growth, development and yield of three varieties of durum wheat (*Triticum turgidum L subsp. durum*). The studied varieties were Cham1 (V1), Deir Alla6 (V2) and Haurani (V3). Data were obtained from a field experiment conducted for this purpose on the growing season 2015/2016 at Mushagger Agricultural Research Station Southwest Amman (31° 46' 24.7" N, 35° 47' 47.3" E, 800 m above sea level). First planting date (D1) was used for model calibration and the GenCalc software was applied to achieve acceptable genetic coefficient values. Calibration results showed an excellent estimation for days to anthesis, number of grains m^{-2}, grain yield and days to physiological maturity with normalized root mean square error (nRMSE) ranged from 0 to 5.79%. Tops weight, harvest index, unit grain weight (except for V3) and number of tillers m^{-2} were poorly simulated. Validation of the CERES-Wheat model of the DSSAT using means of observed results of D2 and D3 showed excellent simulation (nRMSE < 10%) for anthesis and maturity dates for the three examined varieties. Good prediction ($10 \leq$ nRMSE $<$ 20%) were attained for grain yield (for V2 and V3) and for grain nitrogen percent (except for V3 which was excellent). Fair predictions ($20 \leq$ nRMSE < 30%) were recorded for grain unit weight of (V1 and V2) and tops weight of V1. Conversely, grain unit weight was poorly simulated for V3. From these results, it can be concluded that the DSSAT model can be considered as an effective tool for predicting wheat growth and yield.

Key words: DSSAT – Simulation models – CERES-Wheat – planting date – Cham1 – Deir Alla6 – Haurani

INTRODUCTION

Traditional agronomic experiments are conducted at particular points in time and space, making results site- and season-specific, time consuming and expensive (Jones *et al.*, 2003). Therefore, using crop simulation models for predicting crop performance in different environments can be a helpful tool to attend the aims of those conventional researches in shorter time and less expenses.

Environmental modeling, particularly, the Crop Simulating Models (CSMs) can be considered as one of the modern techniques that can contribute in improving the agricultural production.

Model, in general, is a descriptive or representational imitation of a real system to improve the understanding of the behavior of that system components and how they react to changing conditions. Crop simulating models are mathematical, computer-based representations of crop growth and interaction with the environment. They play an important role in scientific research and resource management (Graves *et al.*, 2002). They have evolved into practical tools for scientists, engineers, planners, managers, and growers, who are responsible for improving management and control of such systems (Hoogenboom *et al.*, 1992). The Decision Support System for Agrotechnology Transfer (DSSAT) is one of those decision support models, which consist of 42 crops (Jones *et al.*, 2010). The DSSAT depends on understanding the interactions between plants, soil, weather and management. It was originally developed by an international network of scientists, cooperating in the International Benchmark Sites Network for Agrotechnology Transfer project (IBSNAT) to facilitate the application of crop models in agronomic research (IBSNAT, 1993). Its initial development was motivated by a need to integrate knowledge about soil, climate, crops, and management for making better decisions about transferring production technology from one location to others where soils and climate are different. The DSSAT (CERES-Wheat) has been extensively evaluated and validated for use in many different countries, having unique soil and climate conditions, and plant varieties. Its successful performance has been well documented making it a reliable and trusted crop model (Jones, *et al.,* 2003). However, it should be evaluated and validated before use under arid and semi-arid conditions.

DAISY and DSSAT, out of eight tested models showed the best yield estimation with lowest root mean square error (RMSE) values and the indices of agreement were the highest (Palosuo *et al* 2011). The performance of the DSSAT in simulating the impact of different seeding dates and seeding rates on wheat yield based on three-year field experiments, were good with overall model efficiencies of 0.95 for growth stages, 0.85 for LAI and 0.92 for yield (Wu *et al.* 2013). Simulated data using the DSSAT model showed a reasonable agreement and were well matched with the reported yields with acceptable correlation coefficients and RMSE (Huffman *et al.* 2014), (Al-Bakri, *et al.* 2010) and (Al-Qerem, 2010)

The findings of Rezzoug *et al.* (2008) confirmed the potential use of DSSAT to predict the yield of various winter wheat cultivars, provided that the genetic coefficients are calibrated based on local field trials.

Rezzoug and Benoit (2009) assessed various wheat management strategies with DSSAT and they concluded that climate variability accounted for 95% of the overall variance of simulated yields. Sowing date recorded the most affected agronomic factor, followed by cultivar and N fertilizer rate, while no significant effect of plant density (Rezzoug and Benoit 2009).

Agricultural Production System Simulator (APSIM) predicted wheat crop growth and yield with more accuracy than DSSAT, thus it can be parameterized to simulate crop growth under changing climatic scenarios to select suitable genotypes, sowing time, cropping pattern, fertilizer and weed control (Ahmed and Ul-Hassan 2011),.

Using CERES-Wheat model with temperature change scenarios for future prediction attested that wheat grain yield will be reduced in average by 12 and 31% when air temperature increased by 1.5 and 3.5 °C respectively (Hassanein, *et al.* 2012).

Hussien, (2009) reported that the DSSAT-CSM can be considered as a useful tool for predicting crop growth and production under ordinary conditions, however the model need to be modified and developed to consider the impact of salinity and different cropping systems

Al-Bakri, *et al.* (2010) indicated that barley would be more negatively affected by the climate change scenarios compared to wheat.

The main objective of this study is to assess the performance of the DSSAT model under semiarid conditions with experimental data for different crop management practices (three varieties of durum wheat and three planting dates).

Material and methods

Data used for the model run were obtained from a field experiment conducted to study the effect of three planting dates on growth, development and yield of three varieties of durum wheat (*Triticum turgidum L subsp. durum*). The first planting date (D1) was on November 25th 2015, the second (D2) was on December 21st 2015 and the last (D3) was on January 19th 2016, while the examined varieties were Cham1 (V1), Deir Alla6 (V2) and Haurani (V3). The field experiment was pursued at Mushagger Agricultural Research Station Southwest Amman (31° 46' 24.7" N, 35° 47' 47.3" E, 800 m above sea level). Field experiment and data collection were performed to obtain the information needed to run the DSSAT model, thus enabling comparison between observed and simulated data (IBSNAT, 1990).

The Crop Simulation Model (CERES-wheat module) of the DSSAT version 4.6.1 was used to simulate wheat crop growth, development and yield (Hoogenboom *et al.* 2015). The simulation was based on soil analysis, daily weather and crop management data that was collected from the field experiment. These data were entered into specific database management programs. The files in the crop models of the DSSAT are structured into input, output and experiment data files (Hoogenboom *et al.* 2010).

1. Input files

Some of the input files are dealing with the experiment, weather and soil and the others are approaching the genotypes characteristics (crop and cultivar) (Hoogenboom, *et al.*, 2010). The standard applications of the DSSAT exist in the “Tools”, “Accessories” and “Utilities” section that are presented on the left side of the main screen (Wilkens, *et al.*, 2004).

2. Model calibration

In many crop simulations models, certain coefficients are considered as inputs data to differentiate between the performance of assorted crop varieties under different environmental and management conditions (Hunt *et al.,* 1993). These coefficients are referred to as genetic or genotype coefficients. The Genetic Coefficient Calculator v2 (GENCALC2) of the DSSAT was used to determine a best fit set of genetic coefficients for the examined varieties. The GENCALC2 is a software used for the calculation of cultivar coefficient that related to phenology phase durations, leaf development, canopy, tillers production and death, root growth and nitrogen content in plant tissues (Table 1). Cultivar calibration was done to adjust some development and growth parameters to ensure minimum differences between observed and simulated data. Thus, number of existing files such as ecotype and cultivar files were modified and others such as (A) and (T) files were created to enter all needed data. Since the studied varieties are classified as spring cultivars and they may not have vernalization requirements, P1V coefficient was set to zero in the cultivar file to launch the calibration (Ibrahim *et al.*, 2016). As the first planting date treatment (D1) is a common sowing time of wheat in the region, it was used for model calibration to combat any possible effect of delayed planting on results.

3. Model evaluation

Evaluation of a model usually proceeded to compare model simulations with observed data and to determine its suitability for certain purposes (Jones *et al.*, 2003). The model was run for the three studied wheat varieties individually under both planting dates (D2 and D3). Simulation was proceeded using CSM-CERES-Wheat model (Ritchie and Otter, 1985) by selecting the desired crop (wheat) from the crop directory tree on the main DSSAT screen. In order to evaluate the output data and for the comparison between measured and predicted results, the normalized root mean square error (nRMSE) expressed in percent was used Equations (1) and (2) (Loague and Green 1991). The predicted values are considered excellent when the nRMSE <10 %, good when 10 ≤ nRMSE < 20, fair if 20 ≤ nRMSE < 30 % and poor when nRMSE > 30 % (Jamieson *et al.*, 1991).

$$\text{RMSE} = \sqrt{\sum_{i=1}^{n} \frac{(Pi - Oi)^2}{n}} \qquad (1)$$

$$\text{nRMSE} = \text{RMSE} * \frac{100}{M} \qquad (2)$$

Where:

RMSE is the absolute root mean square error.

nRMSE is normalized root mean square error expressed in percent of the relative difference between simulated and observed values.

P_i and O_i indicate predicted and observed values for the studied variable, respectively, n is number of used observations and M is the mean of the observed variable.

Table (1) Genetic coefficient definitions

Coefficient	Definition
ECO#	Ecotype code for the specified cultivar to be used in ECO file
P1V	Days, optimum vernalizing temperature required for vernalization
P1D	Photoperiod response (% reduction in rate/10 h drop in pp)
P5	Grain filling (excluding lag) phase duration (°C.d)
G1	Kernel number per unit canopy weight at anthesis (#/g)
G2	Standard kernel size under optimum conditions (mg)
G3	Standard non-stressed mature tiller wt (including grain) (g dry wt)
PHINT	Interval between successive leaf tip appearances (°C.d)

Source: (Hoogenboom et al., 2010).

Results

1. Model calibration for cultivar genetic coefficients estimation

A set of genetic coefficients were obtained from the GenCalc for the studied cultivars according to the lowest values of nRMSE (%). Table (2) shows values of both, original coefficients with which the calibration were initiated and the generated values that resulted from the software.

Table (2) Original and calculated values of genetic coefficients as resulted by GenCalc calculator

	VAR. Name	**ECO code**	**P1V** (V day)	**P1D** (%/10h)	**P5** (°C.d)	**G1** (#/g)	**G2** (mg)	**G3** (g)	**PHINT** (°C.d)
Original	NEWTON	USWH01	0	75	500	25	30	2	95
Calculated	CHAM1	USWH01	0.9	78.75	556.7	11.51	25.62	6.421	119
	DEIR ALLA6	USWH01	0.6	90.75	517.9	11.16	32.9	5.04	119
	HAURANI	USWH01	0.15	88.36	495.2	10.67	31.16	2.571	104.6

Table (3) shows model calibration resulted from GenCalC2 software with first planting date treatment. Excellent predictions were achieved by the software for the three studied cultivars for the traits: days to anthesis, days to maturity, grain number m^{-2} and grain yield. Values of nRMSE for these traits ranged from 0 to 6.67%, indicated that the different between observed and simulated values were negligible. Additionally, similar values were resulted for grain nitrogen content and grain unit weight for the cultivar Haurani (nRMSE = 0 for both traits).

Good simulation was attained only for grain nitrogen content for the cultivar Cham 1 (nRMSE = 15%). Harvest index, grain nitrogen content and grain unit weight were fairly predicted for the cultivar Deir Alla 6, nRMSE values were 26.67, 21.05 and 25.0 %, respectively. Conversely, the calibration showed poor predictions (nRMSE > 30%) for tops weight (for all tested cultivars), harvest index (for Cham 1 and Haurani) and for grain unit weight (for Cham 1).

Table (3) Simulated and observed data and calibration results as calculated using GenCalc2

Parameter	Cultivar								
	CHAM 1			DEIR ALLA 6			HAURANI		
	SIMU	OBSE	nRMSE (%)	SIMU	OBSE	nRMSE (%)	SIMU	OBS	nRMSE (%)
Days to anthesis	138	138	0.0 (E)	147	147	0.0 (E)	144	144	0.0 (E)
Tops wt. (kg/ha)	15053	7992	88.35 (P)	14228	10293	38.23 (P)	14209	9791	45.12 (P)
Grain no. m^{-2}	10473	11021	4.97 (E)	9527	9944	4.19 (E)	8822	8535	3.36 (E)
Harvest index	0.166	0.31	46.45 (P)	0.22	0.3	26.67 (F)	0.189	0.27	30.00 (P)
Grain N (%)	2.3	2	15.00 (G)	2.3	1.9	21.05 (F)	2.3	2.3	0.0 (E)
Grain Yield (kg/ha)	2503	2501	0.08 (E)	3134	3131	0.10 (E)	2691	2691	0.0 (E)
Grain wt. (g/grain)	0.024	0.036	33.33 (P)	0.033	0.044	25.00 (F)	0.031	0.031	0.0 (E)
Maturity day	179	190	5.79 (E)	182	193	5.70 (E)	179	192	6.77 (E)
Tiller no #/m2	499	303	64.69 (P)	527	286	84.27 (P)	553	325	70.15 (P)

(E) means excellent, (G) good, (F) fair and (P) poor

2. Model validation

Validation was conducted to assess the performance of the model under certain environmental and management conditions. Variable results were obtained from the model run among cultivars for the same parameter. Figures (1, 2 and 3) and Table (4) illustrate differences between simulated data resulted from DSSAT and that observed from field experiment (average of D2 and D3) for the following traits:

2.1. Grain yield

Good simulation values of grain yield was predicted by the model for V2 and for V3 when compared to observed yield that recorded nRMSE values of 16.42 and 16.97 %, respectively. However, poor grain yield prediction was underestimated for V1 versus field measurements with a value of nRMSE of 42.25% Figure (1).

2.2. Anthesis day

Simulation results for the number of days from planting to anthesis showed excellent prediction for the three examined varieties compared to observed values obtained from field experiment, The model predicted this trait for V1, V2 and V3 having nRMSE of 3.9, 1.36 and 2.16 %, respectively Figure (2).

2.3. Physiological maturity day

CERES-Wheat model had excellently simulated the days from planting to physiological maturity for all examined varieties V1, V2 and V3 with nRMSE values 5.57, 4.18 and 5.47 %, respectively Figure (2).

2.4. Tops weight

Simulation of Tops weight at maturity (above ground biomass) was fair for V1 when compared with measured data that recorded 26.78 % nRMSE, while it was poorly overestimated for the other two varieties V2 and V3 with nRMSE 33.08 and 57.29 %, respectively Figure (3).

2.5. Number of grains per square meter

Results of this trait revealed poorly underestimated prediction for V1 with nRMSE 40.61%. However, the simulation was good for V2 and excellent for V3 with nRMSE values of 12.96 % and 7.55 %, respectively Table (4)

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2.6. Harvest index

As shown in (Table 4), this trait was underestimated poorly for V1 (0.175) and V2 (0.223) compared to their observed values (0.365) and (0.33), respectively while it was fairly predicted for V3 (0.197) compared to measured index of 0.275. Mainwhile, the values of nRMSE between simulated and observed harvest index for V1, V2 and V3 were 52.3, 33.0 and 29.1, respectively.

2.7. Grain nitrogen content

The prediction of grain nitrogen percent resulted from the model (Table 4), exhibited good simulation for V1 and V2 (2.2 % N for the both) compared to 1.9 % measured values having nRMSE of 16.63 and 15.79 %, respectively, however the simulation was excellent for V3, which recorded nRMSE value of 3.23 % containing 2.2 % nitrogen in both, simulated and observed records.

2.8. Single grain weight

Simulation of grain weight was fair for V1 and V2 when compared to measured weight having nRMSE of 29.73 and 25 %, respectively. However, for V3 the simulated grain weight was good that recorded 0.037 g per grain versus observed weight of 0.033 g and nRMSE was 18.92 % Table (4).

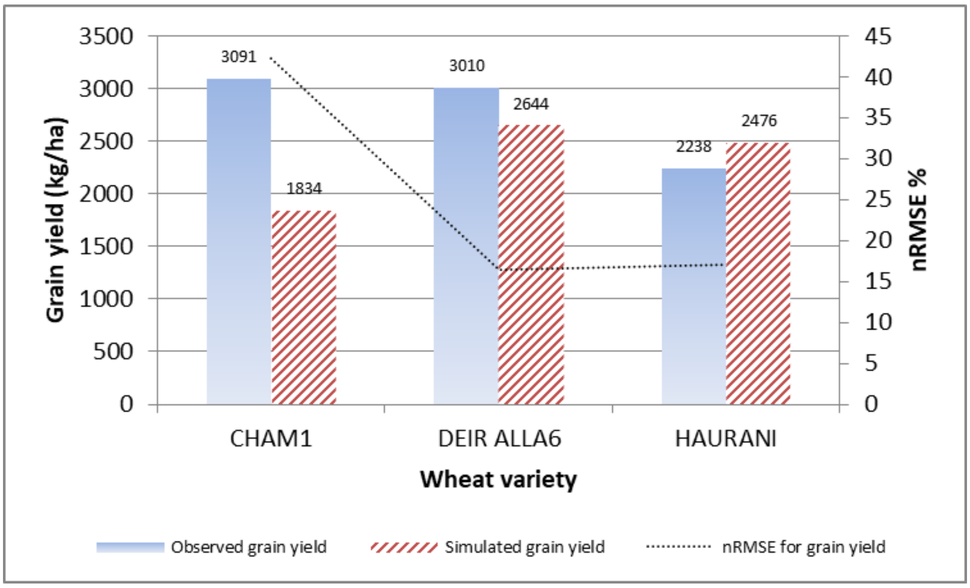

Figure. (1) Observed and simulated grain yield and the nRMSE for the studied varieties

Table (4) Observed data from field experiment and predicted values resulted from CERES-Wheat model for some variables and some statistical indices.

Variable Name	Crop variety	Observed	Simulated	RMSE	nRMSE %	Simulation level
No. of Grain m^{-2}	V1	11567	7164	4697.1 (-)	40.61	Poor
	V2	9118	8035	1181.2 (-)	12.96	Good
	V3	8058	7936	608.6 (-)	7.55	Excellent
Harvest index	V1	0.365	0.175	0.191 (-)	52.33	Poor
	V2	0.33	0.223	0.109 (-)	33.03	Poor

	V3	0.275	0.197	0.080 (-)	29.09	Fair
Grain N %	V1	1.9	2.2	0.316 (+)	16.63	Good
	V2	1.9	2.2	0.300 (+)	15.79	Good
	V3	2.2	2.2	0.071	3.23	Excellent
Grain Weight (g/grain)	V1	0.037	0.026	0.011 (-)	29.73	Fair
	V2	0.044	0.033	0.011 (-)	25.00	Fair
	V3	0.037	0.031	0.007 (-)	18.92	Good

(-) = under-simulated, (+) = over-simulated

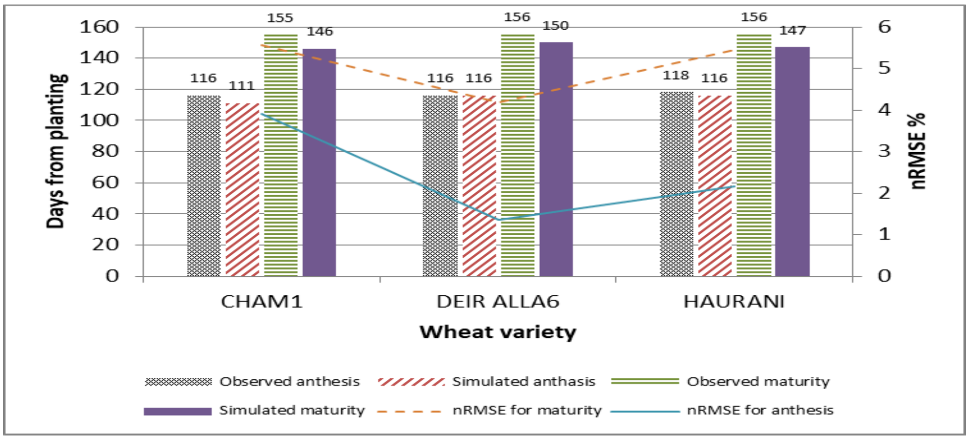

Figure. (2) Observed and simulated results for days to anthesis and days to physiological maturity and the nRMSE for the studied varieties

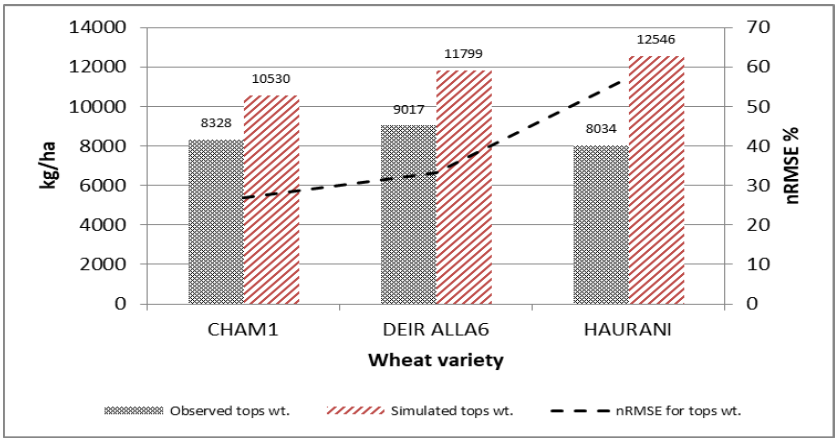

Figure. (3) Results of observed and simulated tops weight for the studied varieties

Discussion

Results obtained from the model calibration showed excellent prediction for many tested traits of the studied cultivars. These results are in line with Maldonado-Ibarra *et al.* (2015) who investigated the genetic coefficients of three spring wheat varieties using the DSSAT model and they reported that nRMSE values for days to anthesis ranged from 3.5 to 9.7% according to the variety. They also indicated that acceptable calibration results can be obtained using the DSSAT model and good predictions of yields for the studied varieties were achieved, which support the findings of this study. The reason of this accuracy could be related to the robust performance of the GenCalc software in calculating the genetic coefficients beside the capability of the CERES-Wheat in estimating these traits (Ibrahim *et al.* 2016). On the other hand, the simulations resulted from the validation of the model were varied from excellent to poor prediction among the simulated traits and within the tested cultivars. The poor simulations, which indicate the high differences between predicted and observed values may be attributed to: (i) errors related to some initial genetic coefficients particularly, those responsible for traits that poorly simulated (Xiong *et al.* 2008), (ii) errors may be due to the low number of experimental treatments, which may affect the reliability of the means in addition to relaying on single season observations as data input (Hoogenboom, *et al.* 2012) and (iii) could be due to the weakness of the model in predicting some traits (Palosuo, *et al.* 2011). The achieved results can be considered as an acceptable indicator to relay on the DSSAT model in predicting phynological stages and yield and yield components of wheat. These results are matched the findings of Bahram, *et al.* (2014) and Pal, *et al.*, (2015) who confirmed the robustness of the CERES-Wheat model in simulating wheat grain yield that they stated very well model simulation results with nRMSE value of 11.8 % between predicted and observed grain yield.

Conclusion and recommendations

Generally, DSSAT model can be considered as an effective tool for predicting crop growth and yield and therefore as decision supporter. The DSSAT model was capable of simulating phenological stages (anthesis and physiological maturity days) perfictly. Satisfactory predictions can be obtained by the model for grain yield, grain nitrogen content and grain unit weight. Cultivar genetic charactarestics can affect the performance of the model. In accordance to this study, The following recommendations could be considered:

- This work should be repeated with different environmental and management scinarios, multi-location and multi-season observations to obtain more applicable data for mor dependable evaluation
- Other croping system models should be compared to the DSSAT model using experimental data from different regions of arid and semiarid zones.

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معايرة وتدقيق النموذج الحاسوبي DSSAT بواسطة بيانات تجريبية لثلاثة أصناف من القمح في مواعيد زراعة مختلفة

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الملخص

تهدف هذه الورقة لمعايرة نظام دعم القرارات لنقل التقنيات الزراعية (DSSAT) في التنبؤ بتأثير مواعيد الزراعة على نمو وتطور وإنتاجية ثلاثة أصناف من محصول القمح الصلب (*Triticum turgidum L. Var. durum*) وهذه الأصناف هي: شام 1, ديرعلا6 و حوراني، البيانات المستخدمة في معايرة وتقييم هذا النموذج تم الحصول عليها من نتائج تجربة حقلية نفذت لهذا الغرض خلال الموسم الزراعي 2016/2015 بمحطة المشقر للأبحاث الزراعية الواقعة جنوب غرب عمان خط عرض "24.7 '46 °31 شمالاً وخط طول '47 °35 "47.3 شرقاً وعلى ارتفاع 800 م عن مستوى سطح البحر.

إن استخدام البرنامج GenCalc (الخاص بحساب الصفات الوراثية) أعطى نتائج مقبولة لقيم العوامل الوراثية للمحصول مما يسر عملية معايرة النموذج التي أظهرت توقعات ممتازة لموعد التزهير, عدد الحبوب/م^2, إنتاجية الحبوب وموعد النضج الفسيولوجي حيث تراوحت قيم nRMSE لهذه الصفات ما بين صفر و5.79 %، بينما كانت التنبؤات ضعيفة لكل من وزن المحصول الكلي, دليل الحصاد ووزن الألف حبة (ما عدا للصنف حوراني التي كانت توقعاته ممتازة), كذلك بالنسبة لعدد الأفرع/م^2 والوزن الخضري (سيقان + أوراق).

أظهرت نتائج تقييم النظام الحاسوبي CERES-Wheat الملحق بال DSSAT عند استخدام البيانات الحقلية لمتوسط معاملتي موعد الزراعة الثاني والثالث وبمقارنة القيم الواقعية مع القيم الناتجة من النموذج فقد كان مستوى التوقعات ممتازاً لموعدي التزهير والنضج في جميع الأصناف المجربة (قيم nRMSE أقل من 10%) وكانت التوقعات جيدة لإنتاجية الحبوب (قيم nRMSE بين 10 و20%) للصنفين ديرعلا6 وحوراني، وكذلك لنسبة النيتروجين في الحبوب (ماعدا للصنف حوراني)، سجلت تقديرات النموذج مستوى مقبول (قيم nRMSE بين 20 و 30%) لوزن الحبة الواحدة للصنفين شام1 و ديرعلا6 وكذلك لصفة الوزن الكلي للمحصول لصنف شام1.

وقد خلصت الدراسة إلى إمكانية اعتبار النموذج الحاسوبي DSSAT أداة جيدة لاستعمالها في التنبؤ بنمو وإنتاجية محصول القمح حال توفر البيانات المطلوبة.