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Research Article
Estimating Cultivar Coefficients of a Spring Wheat Using GenCalc and GLUE in DSSAT

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Abstract

Background and Objective: Crop simulation models are used for simulating crop growth as affected by management and climate. Simulating the growth of a certain variety in a certain soil, climate and management needs specific parameters of that variety due to the genetic variations among varieties, which are called genetic coefficients. **Methodology:** Decision Support System for Agrotechnology Transfer (DSSAT) cropping system model has two programs for estimating specific parameters of a variety. Genotype coefficient calculator (GenCalc) and Generalized Likelihood Uncertainty Estimation (GLUE). An experiment was conducted during winter seasons of 2012/2013 and 2013/2014 to simulate the effect of three rates of nitrogen fertilizer (75, 100 and 125 kg N/feddan) on grain yield and its components of wheat cultivar Sakha 93 and to make a comparison between GenCalc and GLUE in their ability to assess the genetic coefficient of the cultivar. **Results:** Results showed that GenCalc program performed better than GLUE. The results of model validation revealed that the average of the difference between the simulated and observed parameters when using GenCalc were 4.02, 3.96 and 4.14% for biological yield, grain yield and straw yield, respectively, while they were 5.47, 8.32 and 6.12% for the same aforementioned parameters when using GLUE. The GLUE has three disadvantages, first it does not provide estimation for PHINT (Interval between subsequent leaf tip appearances), 2nd it does not provide options for keeping some coefficients fixed, while others are being calibrated like GenCalc, for example in wheat crop there are spring wheats and winter wheats, in GenCalc it can set P1V (required days for vernalization) at 0 meaning that this variety is spring, while in the same time GenCalc are calibrating the other coefficients, 3rd GLUE takes a lot of time for calibration. **Conclusion:** However, GLUE is more easily to use than GenCalc.

Key words: Cultivar coefficients estimation, genetic coefficients, GenCalc, GLUE, DSSAT, spring wheat

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Crop modeling is used in many areas of agricultural researches. Crop growth models, such as grain cereal model simulate crop growth and grain yield in response to weather, soil conditions and management practices[1]. Crop models have been validated and applied in agriculture in many study fields[2], such as assessing the effect of climate change on crop production[3], assessing cultivar performance[4], evaluating the adaptation of a new cultivar to a certain location[5], exploring the interaction between genotype and environment[6], prediction of crop yield[7] and optimizing management[8]. Specific field experiments are designed to estimate cultivar coefficients[9], which requires sampling of growth data at intervals during the growing season. Anothai *et al.*[10] found that the minimum data needed for the estimation of cultivar coefficients in crop simulation model may be lowered to two developmental stages along with plant growth analysis data on three dates, with no need to measure Leaf Area Index (LAI). However, this reduced sampling method for growth data is still time consuming and requires many labor work. Another approach for estimation of cultivar coefficients without conducting a specific field experiments containing intensive data collection is to estimate the cultivar coefficients by using end-of-season data. Genotype coefficient calculator (GenCalc) is used for the optimization of cultivar genetic coefficients. The GenCalc software had been developed to facilitate the calculation of cultivar coefficients from cultivar trial data[11]. Another program for estimating cultivar coefficients is Generalized Likelihood Uncertainty Estimation (GLUE). The GLUE cultivar specific parameters estimation method was integrated into DSSAT using the R language.

MATERIALS AND METHODS

An experiment was conducted at Soil Salinity and Alkalinity Laboratory, Alexandria, Egypt during 2012/2013 and 2013/2014 winter seasons to simulate the effect of three levels of nitrogen fertilizer 75, 100 and 125 kg N/feddan (1 feddan = 0.42 ha) on grain yield and its components of wheat cultivar Sakha 93 using DSSAT. The design of nitrogen fertilizer levels was RCBD with four replications, where the nitrogen fertilizer levels were the first factor of an experiment including another factor (salicylic acid), only the data of nitrogen fertilizer levels under the control level of salicylic acid was used since DSSAT does not simulate the effect of salicylic acid, each experimental plot area was 1.125 m^2 containing sandy loam soil, with organic matter content (0.63%) and calcium carbonate content (2.3%). It was classified as non-saline soil Ece = 1.82 dS m^{-1} and soil pH (1:2.5) = 7.53. Cation Exchange Capacity (CEC) was 20 cmolc kg^{-1}, every plot contains four rows, the grains were sown in late-November in each year, before sowing all plots were fertilized by adding superphosphate 15.5% P_2O_5 at a rate of 100 kg/feddan, potassium sulphate 48% K_2O at a rate of 100 kg/feddan and the nitrogen fertilizer rates were added at the rates of control, 100 and 125 kg N/feddan of ammonium sulphate 20.5% N in three doses, at sowing, at the first irrigation and at the 2nd irrigation. At the end of the experiment, number of grain per spike, number of spikes per meter square, 1000 grain weight (g), grain yield gram per plot, biological yield gram per plot, straw yield gram per plot, harvest index as the ratio between grain yield and biological yield were measured. The GenCalc program of (DSSAT version 4.5) was used to estimate the cultivar coefficients of the wheat cultivar. The GenCalc is a software used for the calculation of cultivar coefficients for use in many crop models[12] including the CERES wheat model, which has 7 cultivar coefficients that describe growth and development of a wheat cultivar (Table 1).

Because Sakha 93 variety is a spring wheat, P1V (required days for vernalization) was set to 0. The GenCalc starts with the initial values of the cultivar coefficient. The algorithm searches in the output of the crop model file and based on the difference between simulated and observed target variables, it tends whether to increase or decrease the value of the coefficient that is being optimized. The sequences for the optimization procedures followed with GenCalc are summarized in Fig. 1.

The first step was to set P1V to 0. Then, the coefficient of days to anthesis (ADAP) was adjusted to produce the lowest RMSE between the simulated and observed values of days to anthesis. The next step was adjusting the days from anthesis to maturity (MDAP) to obtain the lowest RMSE between the simulated and observed days to maturity. Then interval between subsequent leaf tip appearances (PHINT) was adjusted based on the target of leaf number on main stem. Next, standard, non-stressed mature tiller weight including grain (G3) was adjusted based on grain yield components then the standard kernel size under optimum conditions (G2) was adjusted until the simulated and observed values for final grain size provide the lowest RMSE. Then, the coefficient of kernel number per unit canopy weight at anthesis (G1) was calibrated based on grain yield components. Finally, readjust G1, G2 and G3 at the same time. The GLUE is simple to use program, just select a crop, then a cultivar from a list of cultivars included in the database for the crop in DSSAT and the treatments from experiments, in which that cultivar was grown, define at least 6000 runs for phonological parameters and another 6000 runs for growth parameters. The first step

Table 1: Cultivar coefficients and growth parameters of wheat CERES model

Cultivar coefficients	Description
P1V	Days required for vernalization under optimum vernalizing temperature
P1D	Percentage reduction in rate/10 h drop in photoperiod relative to that at threshold, which is 20 h
P5	Grain filling phase duration (°C day)
G1	Kernel number per unit canopy weight at anthesis (# g^{-1})
G2	Standard kernel size under optimum conditions (mg)
G3	Standard and non-stressed mature tiller weight (including grain) (gram dry weight)
PHINT	Interval between subsequent leaf tip appearances (°C day)
Growth parameters	Definitions
ADAP	Time between emergence and anthesis
MDAP	Time between anthesis and maturity
L#SM	Leaf number on main stem
HWUM	Weight of single grain
H#AM	Number of grain per unit weight
T#AM	Tiller number per square meter

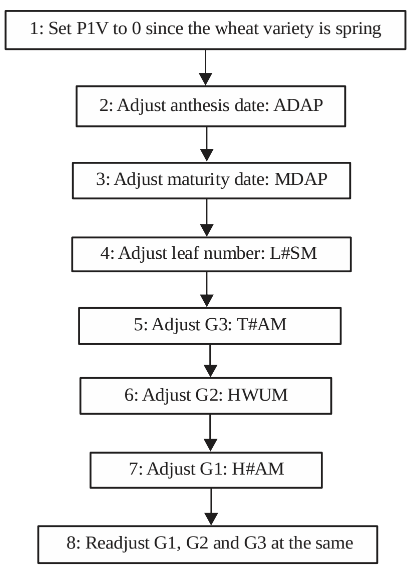

Fig. 1: Sequence for calibrating the cultivar coefficients using GenCalc

was to choose a cultivar to calibrate then choose treatments to be used in estimating the cultivar coefficients then run the program for phonological parameters first then update the cultivar file with phonological parameters produced by GLUE then rerun the program again for growth parameters and finally update the cultivar file with the growth parameters produced from the second run.

RESULTS AND DISCUSSION

Model calibration (estimating cultivar coefficients): Table 2 shows both the initial and final values of cultivar coefficients used and generated by GenCalc and GLUE. The data used for estimating cultivar coefficients was end-of-season data. The results demonstrated that GenCalc has the capability to let the user set the value of P1V to 0, since the variety under study is spring wheat and has no requirements for vernalization, while GLUE has not this capability, where it deals with the cultivar as winter wheat. There is a contradiction with Maldonado-Ibarra *et al.*[13] who stated that spring wheats have small values of vernalization, however, a partial agreement with Lobell and Ortiz-Monasterio[14] was found who stated that vernalization days of spring wheat was set to 0.5. On the other hand, GenCalc was able to adjust PHINT, while GLUE was not able to adjust this coefficient resulting in inaccurate results for that coefficient and consequently negatively affected the accuracy of the model. However, both GenCalc and GLUE were similar in their efficiency in estimating G1 and G2. The GenCalc gave reasonable estimation of G3, while GLUE underestimated that coefficients. This results for coefficient PHINT of cultivar Sakha 93 is agreed with those obtained by Fayed *et al.*[15] who stated that PHINT for Sakha 93 was 120 and partially agreed in P1V coefficient, where they stated that P1V was 0.5 for Sakha 93. However, P1D, P5, G1 and G2 were not agreed with this results, this may be due to the difference in locations of the experiments. However, a contradiction with Liu and Tao[16] was found, where they stated that GLUE was accurately assessed P5 and PHINT for Maize.

Data in Table 3 and 4 show the comparisons between the simulated values and the observed values and indicated that the cultivar coefficients that were estimated from model calibration using GenCalc were more efficient than those estimated from model calibration using GLUE. The calculated average absolute relative error value between mean values of simulated and observed grain yield (tons/feddan) was 1.44 and 1.64%, for number of spikes per meter square was 12.39 and 140.81%, for number of grains per spike was 18.65 and 60.78% when using GenCalc and GLUE, respectively, which revealed that GenCalc performed better than GLUE in estimating cultivar coefficients more efficient in predicting the previous agronomic parameters. However, the calculated average absolute relative error value between mean values of

Table 2: Initial and final values of genetic coefficients used in the study for cultivar Sakha 93

	P1V	P1D	P5	G1	G2	G3	PHINT
Initial values (before calibration)	5	75	450	30	35	1.0	95
Final values (after calibration by GenCalc)	0	60	600	18	45	3.2	112
Final values (after calibration by GLUE)	5	4	577	19	43	1.8	95

Table 3: Simulated and observed values of the agronomic parameters (model calibration) using GenCalc and GLUE

	75 kg N/feddan			100 kg N/feddan			125 kg N/feddan		
		Simulated			Simulated			Simulated	
	Observed	GenCalc	GLUE	Observed	GenCalc	GLUE	Observed	GenCalc	GLUE
Grain yield (tons/feddan)	1.78	1.78	1.81	1.86	1.88	1.88	1.85	1.91	1.89
Thousand grain weight (g)	41	44	43	41	44	43	43	44	43
Number of grain per meter square	9891	9519	10052	11299	10059	10410	11098	10238	10482
Number of grain per spike	47	39	19	49	40	19	52	41	20
Harvest index	0.35	0.38	0.37	0.36	0.35	0.35	0.36	0.33	0.34
Number of spikes per meter square	213	246	526	234	249	533	216	249	535
Biological yield (tons/feddan)	5.05	4.73	4.96	5.15	5.37	5.39	5.15	5.71	5.55
Straw yield (tons/feddan)	3.28	2.95	3.15	3.29	3.49	3.51	3.29	3.80	3.66

Table 4: Average of the difference (%) between simulated and observed values of the agronomic parameters (model calibration) using GenCalc and GLUE

	GenCalc				GLUE				
	75 (kg N/feddan)	100 (kg N/feddan)	125 (kg N/feddan)	Average (%)	75 (kg N/feddan)	100 (kg N/feddan)	125 (kg N/feddan)	Average (%)	Significance
Grain yield (tons/feddan)	0.00	1.08	3.24	1.44	1.69	1.08	2.16	1.64	ns
Thousand grain weight (g)	7.32	7.32	2.33	5.66	4.88	4.88	0.00	3.25	ns
Number of grain per meter square	3.76	10.97	7.75	7.49	1.63	7.87	5.55	5.02	ns
Number of grain per spike	17.02	18.37	21.15	18.85	59.57	61.22	61.54	60.78	**
Harvest index	8.57	2.78	8.33	6.56	5.71	2.78	5.56	4.68	ns
Number of spikes per meter square	15.49	6.41	15.28	12.39	146.95	127.78	147.69	140.81	**
Biological yield (tons/feddan)	6.34	4.27	10.87	7.16	1.78	4.66	7.77	4.74	ns
Straw yield (tons/feddan)	10.06	6.08	15.50	10.55	3.96	6.69	11.25	7.30	ns

Ns: Non significant, **Significant

Table 5: Simulated and observed values of the agronomic parameters (model validation) using GenCalc and GLUE

	75 kg N/feddan			100 kg N/feddan			125 kg N/feddan		
		Simulated			Simulated			Simulated	
	Observed	GenCalc	GLUE	Observed	GenCalc	GLUE	Observed	GenCalc	GLUE
Grain yield (tons/feddan)	1.97	1.87	2.08	1.92	1.92	2.18	2.06	1.92	2.18
Thousand grain weight (g)	44	45	43	45	45	43	44	45	43
Number of grain per meter square	9672	9884	11527	10474	10193	12054	13689	10193	12054
Number of grain per spike	45	44	21	46	45	21	55	45	21
Harvest index	0.37	0.38	0.41	0.37	0.36	0.38	0.37	0.36	0.38
Number of spikes per meter square	215	224	550	228	224	561	251	224	561
Biological yield (tons/feddan)	5.33	4.89	5.08	5.27	5.29	5.68	5.57	5.38	5.79
Straw yield (tons/feddan)	3.36	3.02	3.00	3.34	3.36	3.50	3.51	3.45	3.61

simulated and observed 1000 grain weight was 5.66 and 3.25%, for biological yield (tons/feddan) was 7.16 and 4.74%, for straw yield (tons/feddan) was 10.55 and 7.3% when using GenCalc and GLUE, respectively. An agreement was found with He *et al.*[17] who found that there was a relative error between 0.23 and 11.05% between simulated and observed values of grain yield in winter wheat. There were a significant difference between GenCalc and GLUE in calibration of number of spikes per meter square and number of grains per spike, while there were no significant differences in calibrating the other agronomic parameters. The results from the present study are in general agreement with those obtained by Pal *et al.*[18] who stated that GenCalc was efficient in estimating cultivar coefficients to predict grain yield, biological yield and straw yield of wheat.

Model validation: The results of model validation in Table 5 and 6 reveal that the difference between the simulated values and the observed values indicated that the cultivar coefficients that were estimated from model

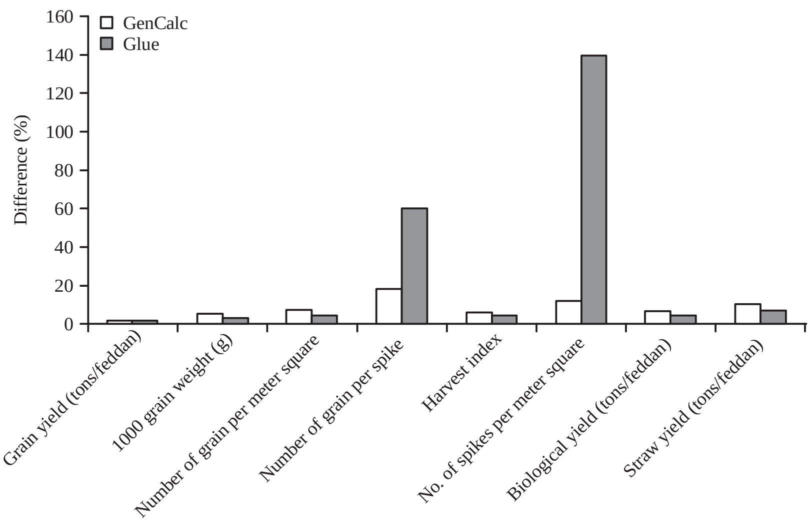

Fig. 2: Comparison between GenCalc and GLUE in predicting crop yield parameters

Table 6: Average of the difference (%) between simulated and observed values (model validation) of the agronomic parameters using GenCalc and GLUE

	GenCalc				GLUE				
	75 (kg N/feddan)	100 (kg N/feddan)	125 (kg N/feddan)	Average (%)	75 (kg N/feddan)	100 (kg N/feddan)	125 (kg N/feddan)	Average (%)	Significance
Grain yield (tons/feddan)	5.08	0.00	6.80	3.96	5.58	13.54	5.83	8.32	ns
Thousand grain weight, g	2.27	0.00	2.27	1.51	2.27	4.44	2.27	2.99	ns
Number of grain per meter square	2.19	2.68	25.54	10.14	19.18	15.08	11.94	15.40	ns
Number of grain per spike	2.22	2.17	18.18	7.52	53.33	54.35	61.82	56.50	**
Harvest Index	2.70	2.70	2.70	2.70	10.81	2.70	2.70	5.40	ns
Number of spikes per meter square	4.19	1.75	10.76	5.57	155.81	146.05	123.51	141.79	**
Biological yield (tons/feddan)	8.26	0.38	3.41	4.02	4.69	7.78	3.95	5.47	ns
Straw yield (tons/feddan)	10.12	0.60	1.71	4.14	10.71	4.79	2.85	6.12	ns

Ns: Non significant, **Significant

calibration using GenCalc and were used for model validation were more efficient than those derived from model calibration using GLUE in predicting crop yield parameters. There were no significant differences between GenCalc and GLUE in predicting all the studied crop yield parameters except for number of grains per spike and number of spike per meter square as shown in Fig. 2. The absolute relative error between simulated and observed grain yield (tons/feddan) was 3.96 and 8.32% and for biological yield (tons/feddan) was 4.02 and 5.47% and for straw yield (tons/feddan) was 4.14 and 6.12%, for number of spikes per meter square was 5.57 and 141.79%, for number of grain/spike was 7.52 and 56.5% when using GenCalc and GLUE, respectively, which means that GenCalc performed better than GLUE in calibrating cultivar coefficients more efficient in predicting the crop yield parameters. A similar grain yield was obtained by Asal *et al.*[19]. The calculated average absolute relative error value between mean values of simulated and observed 1000 grain weight was 1.51 and 2.99%, while it was 2.7 and 5.4% for harvest index and was 10.14 and 15.4% for number of grain per meter square when using GenCalc and GLUE, respectively. The GenCalc accurately predicting number of grains per spike and number of spikes per meter square, while GLUE under estimated number of grains per spike and over estimated number of spikes per meter square. The results from the present study are in partial agreement with those obtained by Fayed *et al.*[15].

CONCLUSION

The DSSAT was able to simulate the effect of different rates of nitrogen fertilizer on wheat grain yield and its components. The two programs (GenCalc and GLUE) included in DSSAT for estimating cultivar coefficients were used to assess the coefficients. The results from the present study revealed that GenCalc was more accurate than GLUE in estimating cultivar coefficients of spring wheat, however, GLUE was more easily to use than GenCalc. There was a significant difference between GenCalc and GLUE in both number of grains per spike and number of spikes per meter square in both model calibration and model validation where GenCalc accurately predicting those parameters, while GLUE under estimated number of grains per spike and over estimated number of spikes per meter square.

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