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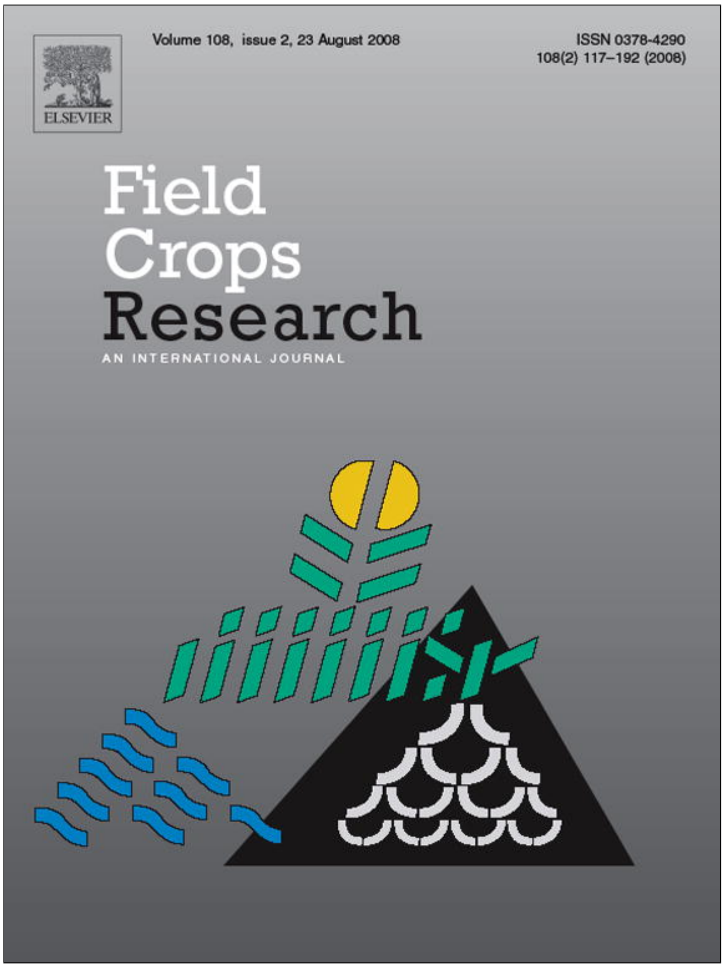

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A sequential approach for determining the cultivar coefficients of peanut lines using end-of-season data of crop performance trials

J. Anothai [a], A. Patanothai [a,*], S. Jogloy [a], K. Pannangpetch [a], K.J. Boote [b], G. Hoogenboom [c]

[a] Department of Plant Science and Agricultural Resources, Faculty of Agriculture, Khon Kean University, Khon Kaen 40002, Thailand
[b] Department of Agronomy, University of Florida, Gainesville, FL 32611-0500, USA
[c] Department of Biological and Agricultural Engineering, the University of Georgia, Griffin, GA 30223-1797, USA

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ABSTRACT

Coefficients of crop cultivars, a required input for the application of crop simulation models, are normally derived from experiments designed specifically for their estimation. This procedure is laborious and time consuming even with a reduced data set. Recent studies have shown that cultivar coefficients for soybean lines can be derived from standard crop performance trials. However, this needs to be confirmed in other crops and be simplified for broader applications. The objective of this study was to determine the feasibility of estimating cultivar coefficients for new peanut lines using data from standard performance trials. Data from performance trials of 17 peanut lines that were conducted in farmers' fields and research stations in the northeastern and northern regions of Thailand during 2002–2004, totaling eight environments, were used in this study. The data that were collected included dates of first flower and harvest maturity, final biomass, pod and seed yield, seed size, pod and seed harvest index, and shelling percentage. These data were used for the calculation of the cultivar coefficients using the Genotype Coefficient Calculator (GENCALC) program, which is part of the Decision Support System for Agrotechnology Transfer (DSSAT). Evaluation of the derived cultivar coefficients was conducted with time series growth data collected in three additional experiments grown during the 2002 rainy, 2003 dry, and 2004 dry seasons. The model calibration with GENCALC resulted in cultivar coefficients that produced simulated values for the development and growth characteristics that were close to their corresponding observed values, with root mean square errors (RMSE) ranging from 1.5 to 4.1 days for development traits and 0.20–1.32 t ha^{-1} for growth traits and coefficient of determinations (r^2) ranging from 0.55 to 0.97 for all traits. The evaluation of the cultivar coefficients that were derived from the performance trials data with independent data worked well for all development traits and fairly well for the plant growth characteristics, as judged by RMSE, r^2, normalized root mean square error (RMSEn) and index of agreement (d). The mean RMSE values for days to first flower and to harvest maturity were 1.6 and 2.4 days; and mean r^2 were 0.72 and 0.91, respectively. The mean RMSEn values calculated from time series growth data were 17.9, 24.6 and 11.5% with the mean d values of 0.88, 0.93 and 0.93 for the 2002 rainy, 2003 dry and 2004 dry seasons, respectively. It is concluded that the cultivar coefficients of peanut lines can be estimated from typical data that are collected in standard performance trials using either GENCALC or similar methodologies.

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1. Introduction

Process-based crop simulation models are increasingly being used in agricultural research, crop management recommendations and policy formulation. Crop growth models, such as the grain cereal model CERES (Jones and Kiniry, 1986; Ritchie et al., 1998) and the grain legume model CROPGRO (Hoogenboom et al., 1994; Boote et al., 1998), simulate crop growth, development and yield for specific cultivars based on the effects of weather, soil characteristics and crop management practices (Jame and Cutforth, 1996; Tsuji et al., 1998; Jones et al., 2003; Miao et al., 2006). These models have been evaluated extensively and applied in agriculture for diverse research areas (Tsuji et al., 1998), Examples are estimating the sensitivity of crop production to climate change (Williams et al., 1988; Alexandrov and Hoogenboom, 2000; Mall et al., 2004), evaluating cultivar performances (Palanisamy et al., 1995; Piper et al., 1998; Boote et al., 2003; Banterng et al., 2006), assessing the adaptation of a new cultivar to a region (Muchow

* Corresponding author. Fax: +66 43 364636.
E-mail address: aran@kku.ac.th (A. Patanothai).

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et al., 1991; Shorter et al., 1991; Hunt, 1993a; Hammer et al., 1996; White, 1998; Chapman et al., 2002), studying the nature of genotype × environment interactions (Aggarwal et al., 1997; White, 1998; Piper et al., 1998; Chapman et al., 2002; Phakamas et al., 2008), forecasting crop yield before harvest (Duchon, 1986; Bannayan et al., 2003; Yun, 2003; Nain et al., 2004; Mercau et al., 2007; Soler et al., 2007) and evaluating improved management options (Ruiz-Nogueira et al., 2001; Nijbroek et al., 2003; Paz et al., 2007).

Many crop models, including the Cropping System Model (CSM) CROPGRO–Peanut (Boote et al., 1998; Jones et al., 2003), use the concept of cultivar coefficients to characterize genotypes or cultivars (Hunt et al., 1993b; Ritchie, 1993; Jame and Cutforth, 1996; Boote et al., 1998, 2003). The cultivar coefficients or cultivar-specific traits are crop characters that define the development, vegetative growth and reproductive growth of individual genotypes (Hunt et al., 1993a; Boote et al., 2003). They summarize quantitatively how a particular genotype responds to environmental factors. However, if the genotypes used are new breeding lines or local cultivars that have not been used previously with the crop simulation model, one first has to determine the cultivar coefficients and then evaluate/re-confirm them with independent data.

The cultivar coefficients are normally derived from field experiments designed specifically for their estimation (Banterng et al., 2004; Suriharn et al., 2007). This procedure requires the sampling of growth and development data for each cultivar at regular intervals throughout the plant's life cycle in detailed field experiments. Anothai et al. (2008) found that the minimum data required for the determination of cultivar coefficients of the CSM–CROPGRO–Peanut model could be reduced to dates of two critical developmental stages along with plant growth analysis data on three dates, with no need to measure leaf area index (LAI) and specific leaf area (SLA). Nevertheless, this "reduced sampling" methodology for in-season growth data is still laborious and time-consuming, and is impractical for several situations.

Another approach for deriving the coefficients without conducting a specific experiment with intensive data collection is to estimate the coefficients with typical "end-of-season" data collected in yield trials. Mavromatis et al. (2001, 2002) showed that it is possible to derive the cultivar coefficients of soybean lines using routinely collected data from crop performance trials. However, these findings need to be confirmed in other crops such as peanut. Furthermore, the procedures for the optimization that was needed for the estimation of the cultivar coefficients in those studies were difficult because the data were restricted to the maturity date and grain yield, causing the authors to take a more complex, less documented approach. Therefore, a new procedure for the optimization using the Genotype Coefficient Calculator (GENCALC) is proposed here. The GENCALC software had previously been developed to facilitate the calculation of cultivar coefficients from cultivar trial data (Hunt et al., 1993b; Hunt and Pararajasingham, 1994) and a new version of this software is currently under development for incorporation into the Decision Support System for Agrotechnology Transfer (DSSAT) (Hoogenboom et al., 2004).

Yield testing before releasing a new peanut cultivar is a routine in peanut breeding. Such tests often record dates of first flower and harvest maturity, final pod yield, final seed yield, final biomass, seed size, pod harvest index, seed harvest index and shelling percentage. Furthermore, the trials are generally conducted over several seasons and multiple locations. Using the data collected during yield testing, the program GENCALC might help with the determination of the cultivar coefficients. The objective of this study was to determine the feasibility of estimating the cultivar coefficients for new peanut lines using typical data from yield performance trials with the optimization procedures of GENCALC.

2. Materials and methods

2.1. Field experiments

The data used in the present study were obtained from previous studies (Suriharn et al., 2007, in press). The entries included 13 peanut lines and four check cultivars (Table 1). Two types of data were available; the first set included data from performance trials obtained from Suriharn et al. (in press) and those data were used to estimate the cultivar coefficients; the second set included data from the growth analysis experiments obtained from Suriharn et al. (2007) and was used for model evaluation. The performance trials were conducted in farmers' fields and research stations in northeast and northern regions of Thailand during 2002–2004, both during the rainy and dry seasons, totaling eight environments (Table 2). The dry season trials were grown in paddy fields with irrigation, while the rainy season trials were grown in upland areas, some with supplementary irrigation and the others without irrigation. Each trial was arranged in four randomized complete blocks. Each plot consisted of 6 rows, each 5 m long, with a spacing of 20 cm between plants and 50 cm between rows.

The growth analysis experiments that were used for model evaluation were conducted during the 2002 rainy, 2003 dry and

Table 1
Peanut breeding lines and cultivars used in this study

Entry no.	Line/cultivar	Seed type	Duration
1	(Luhua 11 × KK60-3) F6-15	Large-seeded	Short
2	(Luhua 11 × KK60-3) F6-22	Large-seeded	Short
3	KK 5 (check)	Small-seeded	Short
4	KKU 1 (check)	Small-seeded	Short
5	((Nc.17090 × B_1)-25 × Luhua 11) F5-14-2	Large-seeded	Medium
6	((Nc.17090 × B_1)-25 × China 97-2) F5-10-5	Large-seeded	Medium
7	((Nc.17090 × B_1)-25 × China 97-2) F5-14-8	Small-seeded	Medium
8	(Luhua 11 × China 97-2) F6-11-3	Large-seeded	Medium
9	((Nc.17090 × B_1)-25 × China 97-2) F6-7-1	Small-seeded	Medium
10	((Nc.17090 × B_1)-25 × China 97-2) F6-2-2	Large-seeded	Medium
11	(China 97-2 × Singburi) F6-13-1	Large-seeded	Medium
12	((Nc.17090 × B_1)-25 × China 97-2) F5-11-2	Large-seeded	Long
13	((Nc.17090 × B_1)-91 × China 97-2) F6-9-2	Large-seeded	Long
14	((Nc.17090 × B_1)-25 × KK60-3) F6-2-2	Large-seeded	Long
15	((Nc.17090 × B_1)-25 × China 97-2) F6-6-6	Large-seeded	Long
16	KKU 72-1 (check)	Large-seeded	Long
17	KK 60-3 (check, derived from NC7)	Large-seeded	Long

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Table 2
The location, planting date, land use and soil type of the performance trials that were used for model calibration and the growth analysis experiments that were used for model evaluation

Location	Planting date	Land use	Soil type
Data for model calibration			
1. Khon Kaen University (KKU1)	14 December 2002	Upland	Yasothorn sandy loam
2. Farmer field's in Udon Thani (UD1)	25 December 2002	Paddy field	San Pa Tong loamy sand
3. Farmer field's in Lamphun (LP)	17 January 2003	Paddy field	Loamy sand
4. Farmer field's in Chiang Mai (CM1)	31 May 2003	Paddy field	Loamy sand
5. Khon Kaen University (KKU2)	14 December 2003	Upland	Yasothorn sandy loam
6. Farmer field's in Khon Kaen (KK)	14 December 2003	Upland	Yasothorn loamy sand
7. Farmer field's in Udon Thani (UD2)	20 December 2003	Paddy field	San Pa Tong loamy sand
8. Farmer field's in Chiang Mai (CM2)	23 December 2003	Paddy field	Sandy
Data for model evaluation			
2002 rainy season			
1. Khon Kaen University (KKU1)	8 June 2002	Upland	Yasothorn sandy loam
2003 dry season			
2. Khon Kaen University (KKU2)	19 December 2002	Upland	Yasothorn sandy loam
2004 dry season			
3. Khon Kaen University (KKU3)	14 December 2003	Upland	Yasothorn sandy loam

2004 dry seasons at Khon Kaen University in Northeast Thailand (latitude 16°28′N, longitude 102°48′E, and 203 m above sea level) (Table 2). Each trial was arranged in four randomized complete blocks. Each plot consisted of 12 rows, 7 m long, with a spacing of 20 cm between plants and 50 cm between rows. The trials were well managed to obtain optimum conditions for plant growth, avoiding drought, nutrient and other stresses as much as possible. Land preparation was done as per the normal procedure for yield trials. Fertilizer was applied at flowering at a rate of 23.4 kg N ha^{-1}, 10.2 kg P ha^{-1} and 19.4 kg K ha^{-1}. Gypsum ($CaSO_4$) was applied at pegging at a rate of 313 kg ha^{-1}. Weeds were controlled by an application of a pre-emergence herbicide and hand weeding. Fungicides and pesticides were applied as recommended for a full protection of the crop from the prevalent pests and diseases in Thailand. The plots received supplementary irrigation during dry periods in the rainy season and full irrigation at weekly intervals in the dry season with overhead sprinklers.

2.2. Plant measurement

At each of the performance trials, crop development was recorded for the dates of planting, emergence (VE), plants with first flower (R1) and harvest maturity (R8). Final pod yield, final seed yield, final biomass, final seed size, pod harvest index, seed harvest index and shelling percentage were measured at maturity. The four center-rows of each plot were harvested by hand, except for the two end-hills of each row. Plants were then depodded, and fresh weights of pods and stover were recorded. A sub-sample of five plants was also taken from each plot, and fresh weights of pods and stover (excluding roots) were measured. The sub-sample was oven-dried at 80 °C, and dry weights of pods and stover were obtained. The dry matter concentration of the sub-samples was then used to calculate dry pod yield, stover and total biomass for each plot.

For the growth analysis experiments, the observed development data for the rainy season of 2002 and the dry season of 2003 included emergence (VE), plants with four nodes present on the main stem including the unifoliate node (V4), plants with first flower (R1), plants with first peg (R2), plants with the first pod beginning to swell (R3), plants with a fully expanded pod (R4), plants with the first seed beginning to develop (R5), plants with one pod having full-sized seeds (R6), physiological maturity (R7; plants with one matured pod) and harvest maturity (R8; plants with 70–80% matured pods) (Boote, 1982). However, only R1 and R8 were observed for the dry season of 2004. Each stage was defined to have occurred if at least 50% of the plants in a plot reached that stage. Growth analysis data were collected at V4, R4, R6, R7 and R8 developmental stages for the 2002 rainy and the 2003 dry seasons, but at 25, 67, 81, 95, 106 days after planting and at harvest maturity for the 2004 dry season. Five plants were harvested from a 0.5 m^2 area in each plot. The samples were oven dried at 80 °C for 48 h and weighed to determine dry matter.

2.3. Soil and weather data

To measure soil characteristics, soil samples were taken at two locations in each field prior to planting at depths of 0–15, 15–30, 30–45, 45–60, 60–75, 75–90 and 90–105 cm. The soil samples were analyzed for texture, bulk density, soil moisture, as well as pH, organic matter, exchangeable potassium (K) and phosphorus (P), nitrate (NO_3^-) and ammonium (NH_4^+) concentrations. Daily maximum and minimum air temperature, rainfall and solar radiation data were obtained from the nearest meteorological station to the variety trial site.

2.4. Calculation of the cultivar coefficients

The GENCALC program of the Decision Support System for Agrotechnology Transfer (DSSAT Version 4.5) was used to calibrate the cultivar coefficients of the peanut lines/cultivars. GENCALC is a software package that facilitates the calculation of cultivar coefficients for use in existing crop models (Hunt et al., 1993b), including the CSM–CROPGRO–Peanut model. The CSM–CROPGRO–Peanut model has 15 cultivar coefficients that define growth and development characteristics or traits of a peanut cultivar (Table 3). Seven coefficients define the life cycle development characteristics and eight coefficients define the growth characteristics (Boote et al., 2003). Because all lines in this study are insensitive to photoperiod, the critical short day length (CSDL) was set at 11.84 h, and the photoperiod sensitivity (PPSEN) was set at 0.00, i.e., allowing for no photoperiod response. In this study, only seven candidate coefficients were selected and calculated by running GENCALC, i.e., the photothermal days (PD) from emergence to first flower (EMFL), and from first seed to physiological maturity (SDPM), maximum leaf photosynthetic rate (LFMAX), the coefficient of maximum partitioning intensity to pods and seeds (XFRT), seed size (WTPSD), seed-filling duration for an individual pod

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Table 3
Cultivar coefficients of the CSM–CROPGRO–Peanut model

Abbreviation	Definition	Unit
CSDL	Critical short day length below which reproductive development progresses with no day length effect	h
PPSEN	Relative response of development to photoperiod with time	h^{-1}
Development parameters		
EMFL	Time between plant emergence and flower appearance (R1)	Photothermal day
FLSH	Time between first flower and first pod (R3)	Photothermal day
FLSD	Time between first flower and first seed (R5)	Photothermal day
SDPM	Time between first seed (R5) and physiological maturity (R7)	Photothermal day
FLLF	Time between first flower (R1) and end of leaf expansion	Photothermal day
PODUR	Time required for cultivar to reach final pod load under optimal conditions	Photothermal day
Growth parameters		
LFMAX	Maximum leaf photosynthesis rate at 30 °C, 350 vpm CO_2, and high light	mg CO_2 m^{-2} s^{-1}
SLAVR	Specific leaf area of cultivar under standard growth conditions	cm^2 g^{-1}
SIZLF	Maximum size of full leaf (four leaflets)	cm^2
XFRT	Maximum fraction of daily growth that is partitioned to seed and shell	Fraction
WTPSD	Maximum weight per seed	g
SDPDV	Average seed per pod under standard growing conditions	No. pod^{-1}
SFDUR	Seed-filling duration for pod cohort at standard growth conditions	Photothermal day

cohort (SFDUR) and the photothermal time required for a cultivar to reach final pod load (PODUR). For other coefficients, i.e., the photothermal days from first flower to first pod (FLSH), from first flower to first seed (FLSD), and from first flower to end of leaf expansion (FLLF), specific leaf area (SLAVR) and the number of seeds per pod (SDPDV), the default values of each cultivar in the respective seeded type were used, since the experimental data for calculating their coefficients were not measured. The value of maximum size of a full leaf (SIZLF) was obtained from Suriharn et al. (2007). The default values of the cultivars NC 7 and TMV 2 were used as initial coefficients for the large-seeded type and the small-seeded type, respectively.

In the estimation method, GENCALC starts with the initial “default” values for each cultivar coefficient. The value for a given cultivar coefficient is varied, relative to one or more simulated and observed crop measurements. The algorithm searches the crop model output file and, based on the difference between simulated and actual target variables, decides whether to increase or decrease the value of the coefficient that is being optimized. The order, increment of the cultivar coefficient and the selected target crop variable are set in an external file which can be changed by the user. When GENCALC finds a good fit to each observation, it averages the coefficients and calculates the root mean square error (RMSE) (Wallach and Goffinet, 1987) averaged over all trials included in the optimization. Based on the new candidate parameters, the user repeats the process. GENCALC uses an interactive procedure in which the user changes the cultivar coefficient step to minimize the error. The search finishes when the user accepts the parameters providing the lowest RMSE for a single target trait or the lowest average normalized root mean square error (RMSEn) (Loague and Green, 1991) for multiple target traits. We used RMSEn for multiple targets because it is difficult to use RMSE alone for determining the goodness of fit because RMSE defines the deviation between the simulated and experimental values and the targets differ in the absolute value. The RMSEn, which is RMSE divided by observed mean, gives a normalized value that allows averaging over multiple characteristic targets providing a single index for their goodness of fit.

The approach, order and target traits for the optimization procedures followed with GENCALC are summarized in Fig. 1. The first step was to select the general Maturity Group of the cultivar in the genotype file (e.g. Spanish, runner or Virginia). Then, the coefficient for duration to first flower (EMFL) was adjusted to produce the lowest RMSE for the simulated and observed values of days to first flower. The next step was adjusting the values of SDPM to obtain the lowest RMSE for the simulated and observed days to harvest maturity. Then LFMAX was adjusted based on the target of final biomass. Next, the WTPSD was adjusted until the simulated and observed values for final seed size provide the lowest RMSE. Then, the coefficient of maximum partitioning intensity to pods–seeds (XFRT) was calibrated based on the values of final pod yield, final seed yield and pod harvest index, which were multiple targets in the calibration process. In the next step, the duration of pod addition (PODUR) was optimized for multiple targets of final pod yield, final seed yield, pod harvest index and seed harvest index. Then seed-filling duration (SFDUR) was adjusted until a good fit for shelling percentage was attained. Next, the WTPSD was re-calibrated to final seed size. Also, the SFDUR was re-adjusted based on the simulated and observed values for shelling percentage as well as final pod yield, final seed yield, pod harvest index and seed harvest index. Next, the WTPSD was again re-calibrated. After that, the PODUR and XFRT were re-calculated until obtained the lowest average RMSEn for final pod yield, final seed yield, pod harvest index and seed harvest index. Finally, LFMAX was re-adjusted to attain the lowest average RMSEn of final biomass, final pod yield and final seed yield. If the fit was good, it was determined that the calibration was finished. The iterations in this process are needed, because intermediate adjustment of some cultivar coefficients has an impact on the performance of other cultivar coefficients.

The accuracy of the procedure used to estimate the cultivar coefficients was determined by comparing the simulated mean values with the corresponding observed mean values for the dates of first flower and harvest maturity as well as final biomass and final pod and seed yields, and by the values of the coefficient of determination (r^2) and the RMSE. A high value of r^2 and a low value of RMSE indicate goodness of fit between the simulated and observed values. The RMSE was computed using the following equation:

$$\mathrm{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}(P_i - O_i)^2}{n}} \quad (1)$$

where n: number of observations, P_i: predicted value for the ith measurement and O_i: observed value for the ith measurement.

The RMSEn was computed using the following equation:

$$\mathrm{RMSEn} = \frac{\mathrm{RMSE} \times 100}{\bar{O}} \quad (2)$$

where RMSE: root mean square error and $\bar{O}$: the overall mean of observed values.

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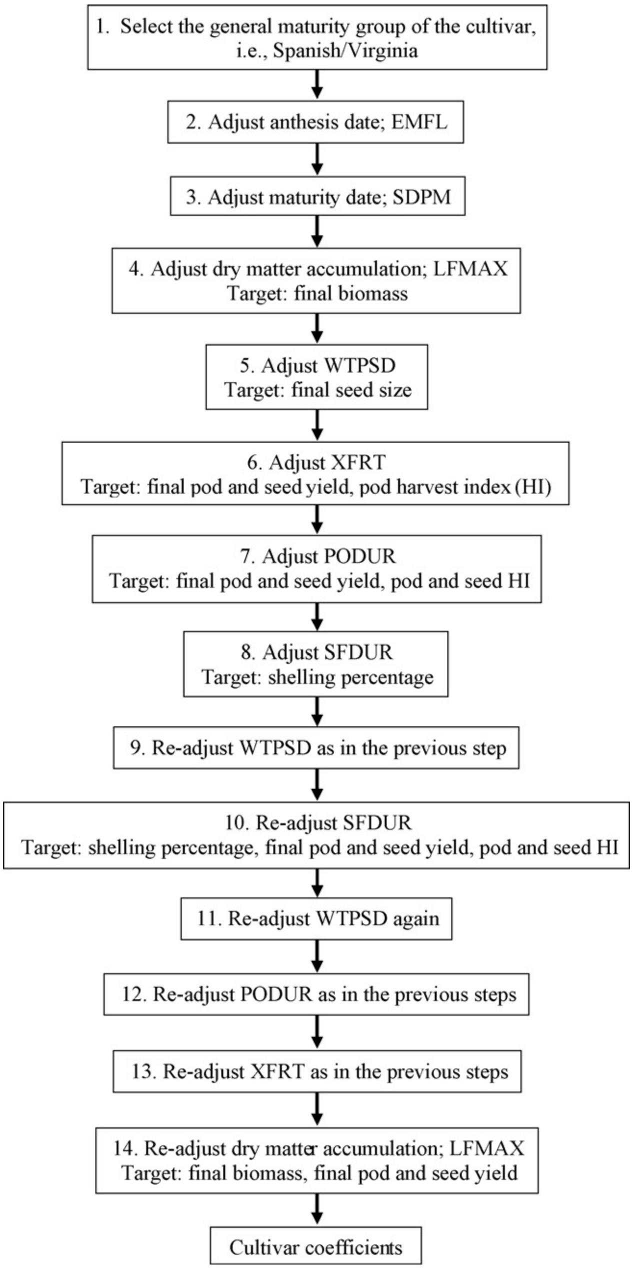

Fig. 1. The sequence of optimizations for calibrating the cultivar coefficients using GENCALC (see description of the cultivar coefficients in Table 3).

2.5. Evaluation of the cultivar coefficients

The cultivar coefficients of the peanut lines derived from end-of-season data of the performance trials were evaluated against independent data sets obtained from the experiment conducted in the 2002 rainy, 2003 dry and 2004 dry seasons. The derived cultivar coefficients of each line were used to simulate growth and development of the same line for the individual seasons. Model evaluation was conducted by comparing the simulated values of development and growth characteristics of the individual peanut lines with their corresponding observed values, and by calculating statistical parameters of agreement between simulated and observed values. Two types of data were used for model evaluation, i.e., single state data that include days to first flower (R1), days to harvest maturity (R8), final biomass and final pod yield, and time series data that include dry weights of biomass, stem, leaf, pod and seed collected over time. For single state observations, r^2 and RMSE were used to evaluate the agreement between simulated and observed values. However, for the time series data, RMSEn and the index of agreement (d) (Willmott et al., 1985) were used for evaluating the goodness of fit. For time series data, RMSEn is preferred over RMSE because RMSE varies greatly with growth over time as the magnitude of the growth variables increase, while RMSEn does not have this problem as it is normalized. In addition, RMSEn allows a normalized comparison across multiple variables that may have different absolute magnitudes. The d-statistic was used for time series data because it provides a single index of model performance that encompasses bias and variability, and is a better indicator of 1:1 prediction than r^2 which gives no indication of bias. Furthermore, time series data are autocorrelated, thus violating the statistical assumptions for r^2. A low value for RMSEn (expressed in percent) is desired to define a good fit. The d statistic has values between zero and one, with one being the best fit.

The value of d was computed using the following equation:

$$d = 1 - \left[\frac{\sum_{i=1}^{n}(P_i - O_i)^2}{\sum_{i=1}^{n}(|P_i'| + |O_i'|)^2}\right], \quad 0 \le d \le 1 \qquad (3)$$

where n: number of observations, P_i: predicted value for the ith measurement, O_i: observed value for the ith measurement, $\bar{O}$: the overall mean of observed values, $P_i' = P_i - \bar{O}$ and $O_i' = O_i - \bar{O}$.

3. Results

3.1. Calibration of the cultivar coefficients

The comparisons between the simulated values for the durations from planting to first flower (R1) and from planting to harvest maturity (R8) of 17 peanut lines based on the calibration and the corresponding simulated values from the performance trials indicated that the cultivar coefficients that were derived from model calibration with performance trials data simulated R1 and R8 quite well (Table 4). The RMSE values for R1 and R8 were low, ranging from 1.5 to 2.9 days and 1.9 to 4.1 days, respectively, and the r^2 values were high, ranging from 0.75 to 0.94 and 0.79 to 0.97, respectively (Table 4). Similarly, the simulation of final pod yield, final seed yield and final biomass showed good agreement with the observed values. The RMSE for final pod yield had low values, ranging from 0.24 to 0.48 t ha^{-1}; and the values for r^2 were high, ranging from 0.71 to 0.87. Final seed yield had RMSE and r^2 values that ranged from 0.20 to 0.36 t ha^{-1} and 0.70 to 0.87, respectively, while final biomass had RMSE and r^2 values ranging from 0.72 to 1.32 t ha^{-1} and 0.55 to 0.85, respectively (Table 4). The RMSE values obtained for these traits are within the range of standard errors for the respective traits normally observed in normal variety trials. The comparisons between the simulated

Table 4
Mean observed (Obs.), mean and range for the root mean square error (RMSE) and coefficient of determination (r^2) for the different crop characters of the peanut breeding lines based on the calibration of the cultivar coefficients from the performance trials

Physiological trait	Mean Obs. (t ha^{-1})	RMSE (t ha^{-1})		r^2	
		Mean[a]	Range	Mean[a]	Range
First flower (R1)[b]	37	2.13	1.54–2.85	0.79	0.75–0.94
Harvest maturity (R8)[b]	122	3.17	1.87–4.11	0.88	0.79–0.97
Final biomass	7.67	0.94	0.72–1.32	0.65	0.55–0.85
Final pod yield	2.84	0.34	0.24–0.48	0.77	0.71–0.87
Final seed yield	1.86	0.27	0.20–0.36	0.78	0.70–0.87

[a] Averaged over all 17 lines.
[b] Unit: day.

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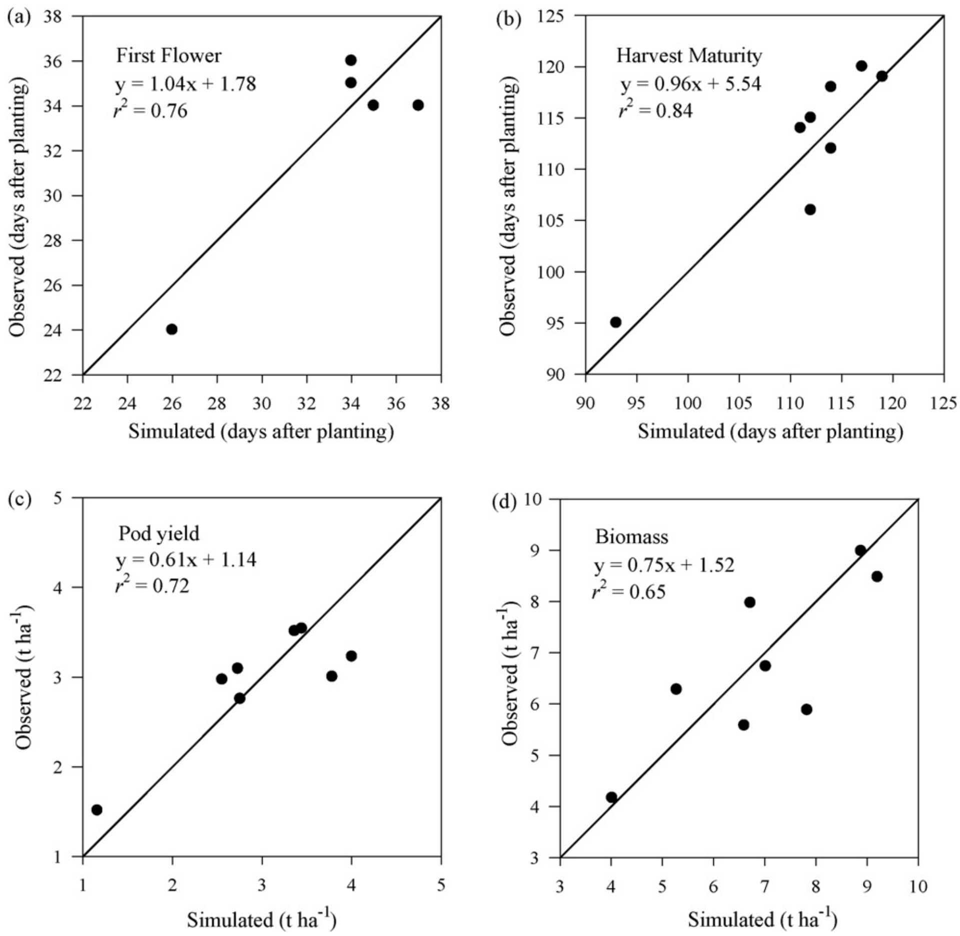

Fig. 2. Simulated versus observed values for model calibration of days from planting to first flower (R1) (a) and to harvest maturity (R8) (b), final pod yield (c), and final biomass (d) of Entry 2 grown in performance trials during 2002–2004.

values for R1, R8, final pod yield and final biomass of peanut Entry 2 that were derived from the calibration of the cultivar coefficients and the corresponding observed values are graphed in Fig. 2 as an example. For this entry, the r^2 for prediction of R1, R8 and the final pod yield were reasonably high, being 0.76, 0.84 and 0.72, respectively, but the r^2 for the final biomass was moderate, being 0.65. The rather low mean values of r^2 for the final biomass obtained for several peanut lines could have been caused by the fact that at several trial sites, the peanut crop was affected by biotic stresses, especially foliar diseases after R6 or R7, as well as abiotic stresses such as water stagnation and micro-environmental variability, while the yield predicted by the simulation model did not account for those stresses. Nevertheless, overall, it was assessed that the calibration of the cultivar coefficients based on data from the performance trials resulted in satisfactory simulations of crop development as well as final pod and seed yields.

3.2. Model evaluation

For the model evaluation with independent data sets, the simulated values for R1 and R8 of the 17 peanut lines were in good agreement with the corresponding observed values for all experiments (2002 rainy, 2003 dry and 2004 dry seasons), with mean RMSE of 1.6 days for R1 and 2.4 days for R8 and moderately high to high mean r^2, i.e., 0.72 for R1 and 0.91 for R8 (Table 5). The simulation of final pod yield and final biomass also showed a reasonably good agreement with the observed values, as indicated by low RMSE, e.g., 0.64 t ha^{-1} for final pod yield and 0.78 t ha^{-1} for

Table 5
Mean observed (Obs.), the coefficient of determination (r^2) and root mean square error (RMSE) for model evaluation of different crop traits of new peanut lines grown during the 2002 rainy, 2003 dry and 2004 dry seasons

Growing season	First flower (R1)			Harvest maturity (R8)			Pod yield			Final biomass		
	Mean Obs. (day)	RMSE[a] (day)	r^{2a}	Mean Obs. (day)	RMSE[a] (day)	r^{2a}	Mean Obs. (t ha^{-1})	RMSE[a] (t ha^{-1})	r^{2a}	Mean Obs. (t ha^{-1})	RMSE[a] (t ha^{-1})	r^{2a}
2002 Rainy season	29	1.03	0.68	109	2.00	0.92	3.80	0.62	0.62	9.33	0.63	0.61
2003 Dry season	38	2.07	0.72	121	2.22	0.94	4.31	0.70	0.76	10.27	1.15	0.46
2004 Dry season	36	1.81	0.75	124	3.03	0.88	2.65	0.60	0.67	6.18	0.55	0.55
Mean	34	1.64	0.72	118	2.42	0.91	3.59	0.64	0.68	9.17	0.78	0.54

[a] Averaged over all 17 lines.

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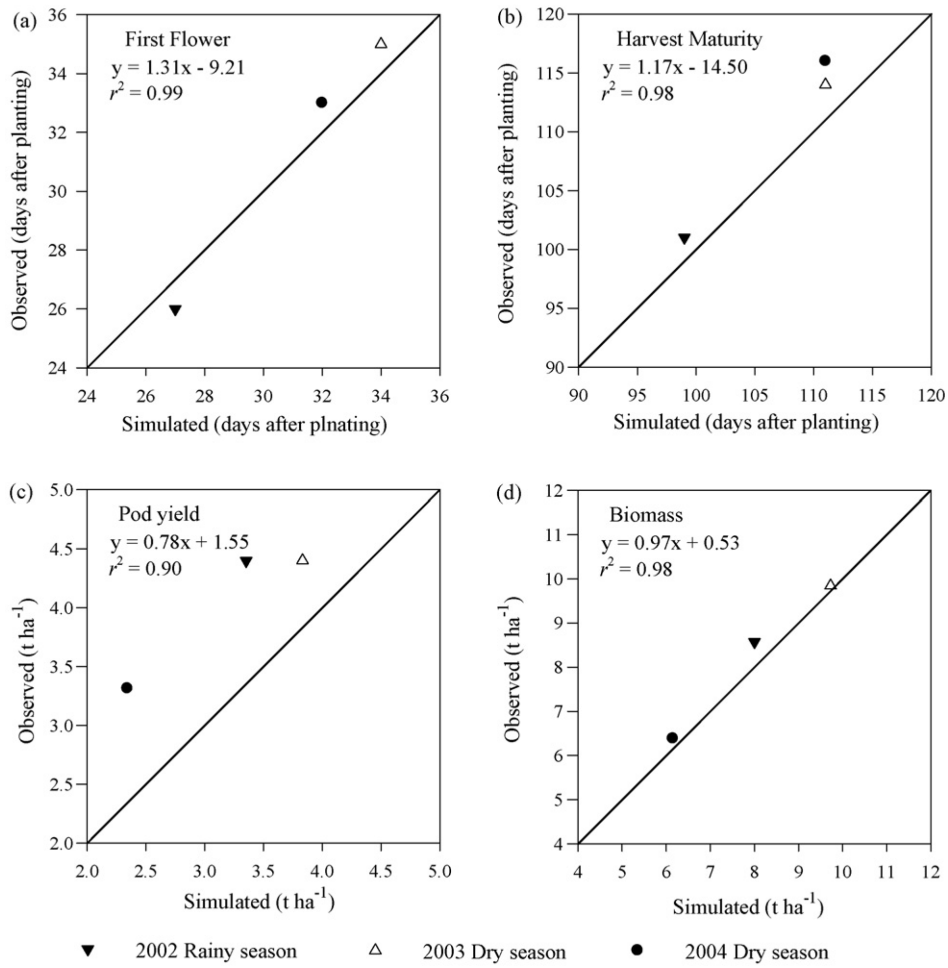

Fig. 3. Simulated versus observed values for model evaluation of days from planting to first flower (R1) (a) and to harvest maturity (R8) (b), final pod yield (c), and final biomass (d) of Entry 2 grown in the evaluation experiments during the 2002 rainy, 2003 dry and 2004 dry seasons.

final biomass, and moderate values for mean r^2, e.g., 0.68 for final pod yield and 0.54 for final biomass (Table 5). An example of the comparisons between simulated and observed R1, R8, final pod yield and final biomass of a peanut line from the model evaluation is shown in Fig. 3 for peanut Entry 2. Good agreements between simulated and observed values were obtained for all four traits, with the r^2 being 0.99 for R1, 0.98 for R8, 0.90 for final pod yield, and 0.98 for final biomass. However, the simulated final pod yield of this entry was lower than the corresponding observed pod yield for the four evaluation experiments (Fig. 3c). Such a result was also observed for all peanut lines in the model evaluation, indicating an underestimation of model simulation. This was anticipated because of the quality of the calibration data where the peanut crop was affected by biotic stresses and certain abiotic stresses at several sites of the performance trials. Additionally, the evaluation trials were managed better, especially as all plots received full irrigation throughout the growing season.

The comparisons between the simulated values of time series data using the cultivar coefficients that were derived from performance trials and the corresponding observed values for total biomass, stem, leaf, pod yield and seed yield of the tested peanut lines in model evaluation are shown in Table 6, and an example is illustrated in Fig. 4 for Entries 2 and 5. The corresponding RMSEn and *d* computed over time were used to assess the goodness of fit between simulated and observed values. The 2002 rainy season had RMSEn that ranged from 0.4 to 39.9% with a mean of 17.9% and had *d* values that ranged from 0.55 to 1.00 with a mean of 0.88 for all growth traits. For the 2003 dry season, growth characteristics had RMSEn that ranged from 4.9 to 112.4% with a mean of 24.6%, and had *d* values that ranged from 0.64 to 1.00 with a mean of 0.93. The exceptionally high RMSEn,

Table 6
Mean and range for the normalized root mean square error (RMSEn) and index of agreement (*d*) for model evaluation with time series data for crop characters of new peanut lines grown during the 2002 rainy, 2003 dry and 2004 dry seasons

Crop character	RMSEn (%)		*d*	
	Mean[a]	Range	Mean[a]	Range
2002 rainy season				
Biomass	16.9	10.6–24.3	0.90	0.82–0.96
Stem dry weight	21.6	15.6–28.2	0.87	0.80–0.96
Leaf dry weight	26.8	9.9–39.9	0.93	0.86–0.99
Pod dry weight	12.9	2.2–28.0	0.86	0.68–0.99
Seed dry weight	11.0	0.4–26.2	0.83	0.55–1.00
2003 dry season				
Biomass	12.5	4.9–21.2	0.98	0.95–1.00
Stem dry weight	19.9	5.2–40.9	0.94	0.83–0.99
Leaf dry weight	57.8	11.4–112.4	0.83	0.64–0.99
Pod dry weight	16.4	7.6–24.9	0.94	0.84–0.99
Seed dry weight	16.6	7.5–27.8	0.94	0.86–0.99
2004 dry season				
Biomass	9.7	5.1–16.5	0.98	0.94–1.00
Pod dry weight	12.9	3.8–23.2	0.93	0.76–0.99
Seed dry weight	11.8	1.0–21.4	0.89	0.70–1.00

[a] Averaged over all 17 lines.

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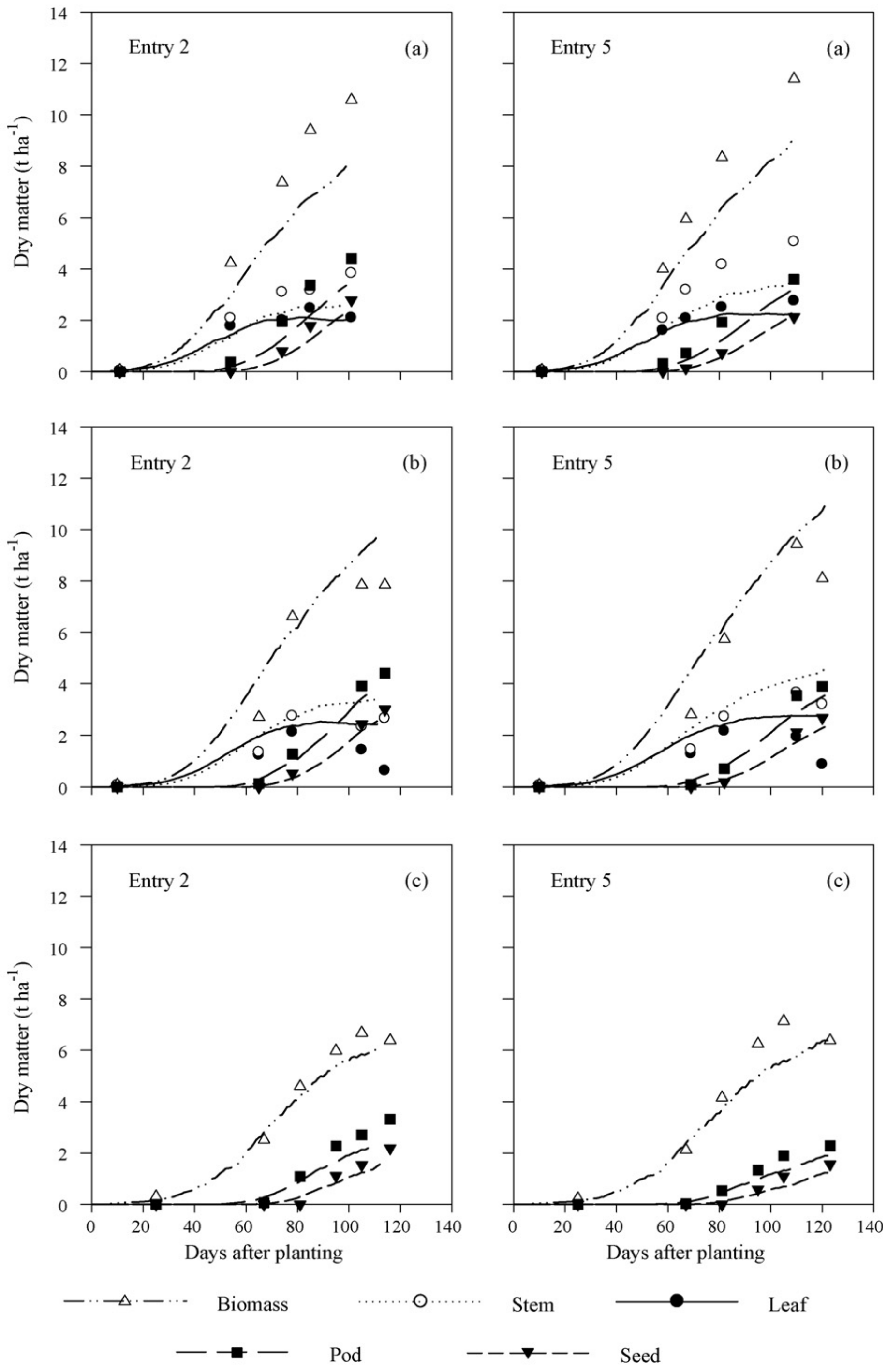

Fig. 4. Simulated (lines) versus observed (symbols) values for biomass, stem, leaf, pod and seed at different growth stages for Entries 2 and 5 (see Table 1 for line descriptions) in the evaluation experiments during the 2002 rainy (a), 2003 dry (b) and 2004 dry seasons (c) where the cultivar coefficients were derived from performance trials.

e.g., 112.4%, and moderate *d*, e.g., 0.64, were those of leaf dry weight of some peanut lines (Table 6). During this season, although the crop was regularly sprayed with fungicides, late leaf spot disease (*Phaeoisariopsis personata* (Berk. & Curt.) V. Arx.) occurred at high incidence causing considerable leaf losses for susceptible entries at R6 and R7 stages. The model, however, assumed that no disease occurred, and hence high disparities between simulated and observed values were obtained for this trait of those entries. For the 2004 dry season, pod yield, seed yield and total biomass had low to moderately low RMSEn, ranging from 1.0 to 23.2% with a mean of 11.5%, and moderately high to high *d*, ranging from 0.70 to 1.00 with a mean of 0.93 (Table 6), indicating good agreements between simulated and observed values for these traits.

Despite some discrepancies, the overall results of model evaluation with independent data indicated that the derived cultivar coefficients could accurately simulate growth and development as well as final pod yield and final biomass of the peanut breeding lines.

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4. Discussion

Crop models are available for most economically important crops, and on many occasions they have been successfully used in research. Nevertheless, before they can be used as decision support tools to assist management of agricultural systems, one should first determine and evaluate the cultivar coefficients of crop varieties/cultivars, especially if they have not been simulated previously. Our results show that the cultivar coefficients of peanut lines can be estimated with routinely collected data from yield trials with the assistance of GENCALC, and using the sequential approach that we outlined. The coefficients derived from the yield trial experiments predicted biomass and pod dry matter accumulation reasonably well in the independent experiments, as shown by low RMSEn that ranged from 4.9 to 24.3% for biomass and from 2.2 to 28.0% for pod dry weight, and high values for *d* that ranged from 0.82 to 1.00 for biomass and from 0.68 to 0.99 for pod dry weight (Table 6). This approach conveniently offers the opportunity to derive the cultivar coefficients of crop cultivars when their data are readily available from multi-environment trials, but prior to cultivar release to producers.

Calculating the cultivar coefficients using GENCALC should involve crop performance trials at least five or six seasons and/or locations. For illustrative purpose, we consider a crop breeding program in Thailand in which a series of yield trials prior to the release of a new cultivar often includes preliminary yield trials (PYT), standard yield trials (SYT), regional yield trials (RYT) and farm trials (FT). Normally, PYTs are evaluated over two to three seasons/locations, while SYTs are tested over four to five seasons/locations. Therefore, the earliest time upon which to derive the cultivar coefficients from this approach is the late period of the SYTs. The derived cultivar coefficients could then be used to simulate yield of the tested lines in the trial over a wider range of environments than actual testing. With these cultivar coefficients, model simulation could also be used to extend the range of the test environments of the more advanced trials, i.e., the regional yield trial and the farm trial, making line selection more accurate and effective (Hunt, 1993a; Aggarwal et al., 1997).

In the routine multi-environment trials of crop breeding lines, the recently released cultivars and the popularly grown cultivars are always included as the check entries. Data collected from the multi-environment trials can be used to derive the cultivar coefficients of these cultivars by the procedures described in the present study. The derived cultivar coefficients can then be use in various model applications, for examples, in evaluating management options for a certain situation, or in assessing yield gaps in certain production areas.

The application of the CSM–CROPGRO–Peanut model to assist in the multi-environment evaluation of peanut breeding lines would be more useful if it could be done during the preliminary yield trial stage because actual yield testing is normally done in only a few environments. However, the approach of deriving the cultivar coefficients from end-of-season data of crop performance trials proposed in the present study will not be able to provide the required cultivar coefficients at this stage of yield testing. The only way to obtain the cultivar coefficients of the peanut lines at the preliminary yield trial stage is to use a reduced data set from a well-managed experiment, as described by Anothai et al. (2008).

The quality of the typical data that are collected in crop performance trials is still of prime importance for estimating the cultivar coefficients. Therefore, care should be taken in managing the trials and in data measurements, since poor quality of the observed data will certainly affect the accuracy of the estimation of the cultivar coefficients.

The suggested approach and order for calibrating the cultivar coefficients using the GENCALC program (Fig. 1) is our recommended method for deriving the cultivar coefficient from typical information provided by routine peanut performance trials. However, further work is recommended to confirm the best sequence of optimizations in GENCALC to calculate the coefficients for new peanut lines. As multi-environment trials of crop breeding lines are normally conducted for all crops, the data required for deriving the cultivar coefficients by this approach are readily available. The approach, thus, could be used for other crops for which crop simulation models are available. Further work, however, is also needed to determine the best sequence of optimizations in GENCALC for other crops as the cultivar coefficients required for model simulation may differ for the different crops.

5. Conclusion

The cultivar coefficients of 17 peanut lines from routine performance trials provided simulated values of development and growth characteristics that were close to their corresponding observed values from which they were derived. Simulations using these cultivar coefficients with independent data resulted in accurate predictions of growth, development and yield for all peanut lines. Thus, it appears feasible to estimate the cultivar coefficients for new peanut lines from typical data of routine performance trials by using GENCALC. The procedures should also be applicable to other crops for which crop simulation models are available.

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