Asian Journal of Plant Sciences

ISSN 1682-3974

Asian Journal of Plant Sciences 5 (6): 913-922, 2006
ISSN 1682-3974

Evaluation of the CSM-CROPGRO-Peanut Model in Simulating Responses of Two Peanut Cultivars to Different Moisture Regimes

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Abstract: Drought is a major yield limiting factor in peanut production. Characterization of drought stress patterns of major production areas and information on crop responses to different levels of drought stresses are needed for the development of appropriate management strategies for individual locations. The CSM-CROPGRO-Peanut model could help in obtaining the required information, but its capability in predicting crop responses to different levels of drought stress needs to be firstly established. The objective of this study was to evaluate the capability of the CSM-CROPGRO-Peanut model in simulating the responses of two peanut cultivars to three levels of soil moisture regimes. The experiments were conducted under field conditions in the dry seasons of 2004 and 2005 at the Field Crop Research Station of Khon Kaen University in northeast Thailand. A split-plot in a randomized complete block design with 4 replications was used. Three levels of soil moisture (field capacity, 2/3 available water and 1/3 available water) were assigned to main-plots and two peanut cultivars (KK60-3 and Tainan 9) were arranged in sub-plots. Data collected on growth and development of the two peanut cultivars under the three soil moisture regimes were compared with the corresponding simulated data from model simulation using the CSM-CROPGRO-Peanut model. The results showed that the model performed fairly in simulating phonological development and patterns of dry matter accumulation but performed reasonably well in predicting the final biomass and pod yields of the two peanut cultivars under the three soil moisture regimes. The model, however, could predict the relative yield reductions from drought stress of the individual peanut cultivars quite accurately and could provide information on the time of occurrence and severity of water stress during the cropping period. These results indicate that the CSM-CROPGRO-Peanut model is sufficiently capable to be used in generating the required information for determining appropriate managements of drought stress.

Key words: *Arachis hypogaea* L., crop simulation, responses to drought stress, peanut modeling

INTRODUCTION

Peanut (*Arachis hypogaea* L.) is an important legume crop of the world, occupying some 26 million ha of planted area with an annual production of about 35 million tons. Developing countries account for 97% of the world peanut area and about 94% of total production (FAO, 2002). In developing countries, peanut is mostly grown under rainfed conditions and drought has been identified as a major limit to its productivity (Nigam *et al*., 2001). In Thailand, peanut is also an important economic crop planted by small farmers in all parts of the country. Like in other developing countries, the crop is mostly grown under rainfed conditions, but it is also grown under irrigation with irrigated area occupying about one-third of the peanut acreage of the country. Drought stress is common under rainfed growing conditions, but even under irrigation water deficit also often occurs during the growing season, resulting in some to substantial reduction in crop yield (Patanothai *et al*., 1987). A number of management options could be used to alleviate the drought stress problem, e.g., choosing a suitable planting date, increasing available soil water to crop through appropriate agronomic management practices, employing an effective irrigation management and using an early maturing or a drought resistant/tolerant cultivar. Normally, a combination of these is needed to be able to cope with the problem of drought stress for a particular production area. As the time of occurrence and severity of drought stress varies in different locations, characterization of

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drought stress patterns of major production areas and information on crop responses to various levels of drought stresses are needed for the development of appropriate management strategies for individual locations. Such information is either lacking or incomplete and will require extensive data collection and experimentation to be able to obtain.

Currently, dynamic crop simulation models have been developed as a tool to support strategic decision making in research, production, land use and policy (Penning de Vries *et al*., 1993). These models can be used to evaluate agricultural production risk as a function of climatic variability, to assess regional yield potential across a wide range of environmental conditions and to determine suitable planting dates and other management factors for increasing crop yield (Egli and Bruening, 1992; Meinke *et al*., 1993; Aggarwal and Kalra, 1994; Meinke and Hammer, 1995; Kaur and Handal, 1999). In peanut, the Cropping System Model (CSM) CROPGRO-Peanut has been developed to simulate vegetative and reproductive development, growth and yield as a function of crop characteristics, climatic factors, soil characteristics and crop management scenarios. This model has been evaluated across a wide range of soil and climate conditions and for various applications in temperate regions (Boote *et al*., 1998; Jones *et al*., 2003) and is included as a part of a suite of crop growth models that encompass the Decision Support System for Agrotechnology Transfer (DSSAT) (Hoogenboom *et al*., 2004). The ability of the CSM-CROPGRO-Peanut model to simulate growth and yield as influenced by growing environment, agronomic practices and cultivar traits offers an opportunity for utilizing the model in characterizing drought stress patterns, choosing suitable planting dates and determining effective irrigation managements for different production areas and in identifying drought avoidant and drought resistant cultivars. However, the applicability of the model for such applications depends very much on the ability of the model to correctly predict growth and development of peanut under different water regimes. Singh *et al*. (1994) reported that the CSM-CROPGRO-Peanut model could be used to simulate peanut growth and development under different soil moisture regimes. Their finding, however, was based on model evaluation using data from uncontrolled experiments with only two soil moisture regime treatments, i.e., rainfed and irrigated. There is a need to evaluate the model with the data from controlled experiment with different moisture regimes to firmly establish the credibility of the model in predicting the responses to drought stress of peanut cultivars. The objective of this study was to evaluate the capability of the CSM-CROPGRO-Peanut model in simulating the responses of two peanut cultivars to three levels of water regimes under controlled experimentation.

MATERIALS AND METHODS

Field experiment and data collection: A field experiment was conducted at the Field Crops Research Station of Khon Kaen University in Khon Kaen province of northeast Thailand (16°28'N, 102°48'E, 200 m above mean sea level) in the dry season of 2004 and repeated in the dry season of 2005. The treatments included factorial combinations of three levels of water regime, i.e., Field Capacity (FC), 2/3 available water (2/3 AW) and 1/3 available water (1/3 AW) and two peanut cultivars which are commonly grown in Thailand, i.e., Tainan 9 (small-seeded Spanish type) and KK 60-3 (large-seeded Virginia type). A split-plot in a randomized complete block design with four replications was used. The three moisture regimes were assigned to main-plots and the two peanut cultivars were sub-plot treatments. Plot size was 5×6 m for a sub-plot and spacing was 50 cm between rows and 20 cm between plants. The 2004 dry season experiment was planted on 23 November 2003 and the 2005 dry season experiment was planted on 18 October 2004.

Land preparation was done as per the normal procedure for peanut experiment. Lime was applied at a rate of 625 kg ha^{-1} prior to planting. Seeds were treated with iprodione [3-(3,5-dichloro-phenyl)-*N*-isopropyl-2-4-dioxoimidazolidine-1-carboxamide 50% Wettable Powder (WP)] at a rate of 5 g per 1 kg of seed prior to sowing. Four seeds were planted per hill and the seedlings were thinned to one plant per hill at seven days after emergence. P_2O_5 and K_2O fertilizers were applied as basal at a rate of 37.5 and 56.25 kg ha^{-1}, respectively. Gypsum ($CaSO_4$) was applied at pegging at a rate of 313 kg ha^{-1}. Weeds were controlled by an application of alachlor (2-chloro-2',6'-diethly-*N*-methoxymethylacetanilide 48% W/V emulsifiable concentrate) at a rate of 3.75 L ha^{-1} at planting and hand weeding during the remainder of the season. Pests and diseases were controlled by weekly applications of monocrotophos [dimethyl (*E*)-1-methyl-2-(methylcarbamoyl) vinyl phosphate 60% W/V water soluble concentrate] at 2.5 L ha^{-1}, metomyl [*S*-methyl-*N*-((methylcarbamyl)oxy) thaioatimidate 40% soluble powder] at 1.0 kg ha^{-1} and benomyl [methyl-1-(butylcarbamoyl)-2-benzimidazole-2-ylcabamate 50% wettable powder] at 1.68 kg ha^{-1}. Carbofuran (2,3-dihydio-2,2-dimethylbenzofuran-7-ylmethyl-carbamate 3% granular) at a rate of 31.3 kg ha^{-1} was also applied during the early pod forming stage. After planting, the moisture level at 0-30 cm depth of all experimental plots was uniformly controlled at field capacity by drip irrigation. Controlled valves were used to maintain water pressure in pipes at 0.6 barrs loading and 1.1 L h^{-1} of water flow through each nozzle. A meter was also installed in each main-plot to measure the volume of applied water. The three water-regime treatments were imposed to the individual main-plots by applying different amounts of irrigation water to the plots corresponding to the designated water regimes, starting at 14 days after emergence. The moisture level of each main-plot was then constantly maintained at the designated level throughout the growing season. The amount of water applied to a plot to maintain a specified level was determined from water requirement of the peanut crop, calculated following the procedure of Doorenbos and Pruitt (1992) and surface evaporation, calculated using the procedure of Singh and Russel (1980). Soil moisture of each moisture-regime treatment was also monitored by neutron probes.

Data were collected on plant development and growth, soil characteristics, weather and management as required for model evaluation (Hoogenboom *et al.*, 1999). Plant development data included the dates on which 50% of the plants reached flowering (first flowering) and maturity (plant with 2/3 to 3/4 of all developed pods having testa or pericarp coloration) stages. The flowering date for a sub-plot was determined by daily inspection of all plants in the sub-plot. For the determination of maturity stage, four plants in each sub-plot were harvested for inspection every three days, starting from 15 days before the generally recommended harvesting date for each peanut cultivar.

Total biomass and pod dry weights were measured seven times at 15 days intervals, from 15 days after emergence until maturity. For each measurement, six bordered plants in each sub-plot were harvested and pods were detached from the plants. The two parts were oven-dried separately at 70°C for 48 h and dry weights of pods and stover were obtained. Final total biomass and pod dry weight were also recorded at maturity from the harvested area of 8 m^2 of each plot. Plants were depodded and fresh weights of pods and stover were recorded. A sample of six plants was also taken from each plot and fresh weights of pods and stover were determined. The sample was oven-dried at 70°C and dry weights of pods and stover were obtained. Dry matter contents of pods and of stover were determined and used in calculating dry weight of pod and total biomass.

Soil data collected included bulk density, percentages of sand, silt and clay, soil moisture, organic matter, pH, nitrate (NO_3^-) and (NH_4^+) concentrations and exchangeable P and K. These data were obtained from soil samples taken at two spots in the experimental field at each depth of 0-15, 15-30, 30-45, 45-60, 60-75, 75-90 and 90-105 and analyzed separately for physical properties. Composite samples of individual depths were used for chemical property analysis. Weather data, e.g., daily maximum and minimum temperatures (°C), rainfall (mm) and solar radiation (MJ m^{-2}), were obtained from the Khon Kaen University Field Crops Research Station where the experiment was conducted. Management data recorded were row spacing, plant density, date of sowing and dates and rates of fertilizer, irrigation, herbicide and pesticide applications.

Model simulation and evaluation: The CSM-CROPGRO-Peanut model requires data on crop characters, soils surface and profile characteristics, local weather conditions and management practices as the inputs for model simulation. The weather conditions required are daily maximum and minimum air temperature, solar radiation and precipitation and the management practices required include planting date, spacing, plant population and applications of fertilizers and irrigation. The CSM-CROPGRO-Peanut model uses 15 crop characters or genetic coefficients to define development and growth characteristics of a peanut cultivar (Hoogenboom *et al.*, 1999). In this study, the genetic coefficients of Tainan 9 and KK 60-3 cultivars were obtained from Banterng *et al.* (2004) and Suriharn *et al.* (2006), respectively. They were derived from the experiments designed specifically for their determination. The experiments were conducted in the rainy season of 1999 and 2002 and the dry season of 2000 and 2003 at Khon Kaen University (KKU) in northeast Thailand. In these experiments, data were collected on plant development and growth, soil parameters, weather and management as required for calibrating the genetic coefficients of a new peanut cultivar. These are described in Volume 4 of DSSAT v3 (Hoogenboom *et al.*, 1999) and are referred to as the minimum data set. Data collection also followed the procedures described in IBSNAT (1988) and Hoogenboom *et al.* (1999). To determine genetic coefficients of the these two peanut cultivars, the minimum data set was used as inputs in the standard format of DSSAT v3.5. Model calibrations were done following the procedure described by Boote (1999). Details of the experiment, data collection and model calibration are described in Banterng *et al.* (2004) and Suriharn *et al.* (2006).

Data on soil parameters, weather conditions and management practices collected from the experimental site and genetic coefficients of the two peanut cultivars were used to simulated growth and development of the two peanut cultivars grown under the three soil moisture regimes in the dry seasons of 2004 and 2005. Optimization for the soil fertility factor was also done to account for some uncertainties in soil properties that were not included as the input in the model simulation.

Model evaluation was done by comparing the simulated values of development and growth characters with their corresponding observed values and by the values for Root Mean Square Error (RMSE) and the index of agreement (d) which indicate the degree of agreement between the simulated values with their corresponding observed values. A low RMSE value and a d value approaching unity are desirable. The RMSE was computed using the following equation:

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

where n is the number of observations, P_i is the predicted value for the ith measurement and O_i is the observed value for the ith measurement. The index of agreement was computed using the following equation:

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

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

Final biomass and pod yields of each peanut cultivar at individual soil moisture regimes were also calculated as percentages of their corresponding biomass or pod yield at FC for both observed and simulated data. Percentages of reduction in biomass and pod yield at each level of water stress were determined and the average over the two stress levels was calculated for each peanut cultivar. The ability of the model to predict the relative responses to water stress of a peanut cultivar was evaluated by comparing the average reductions in the observed biomass and pod yield of the water stress treatments, expressed as the percentage of the respective biomass or pod yield of the FC treatment, with the corresponding reductions in the simulated biomass and pod yield of that particular peanut cultivar.

RESULTS AND DISCUSSION

Climatic conditions during the cropping periods in the two years in which the experiment was conducted differed to some extent because of the differences in time of planting and time of occurrence of cool weather in the individual years. The experiment was planted on 23 November 2003 for the dry season of 2004 and on 18 October 2004 for the dry season of 2005, while cool weather came in during December and January in both years. Thus, the crop in the 2004 dry season experienced cool weather at an earlier developmental stage than the crop in the 2005 dry season. Solar radiation was lower during the early growth stages for the 2004 dry season crop, but higher during the latter part of crop duration as it approached the hot summer earlier than the 2005 dry season crop. In the dry season of 2004, there was also a heavy rain (50 mm) on February 4 (78 days after planting) resulting from a cold wave from China, making the levels of soil moisture in the two water stress treatments higher than the intended levels (i.e., 2/3 and 1/3 AW) for a period afterward. There was no rainfall throughout the cropping period in the dry season of 2005 and the soil moisture levels in the different treatments were maintained as intended.

To assess how well the CSM-CROPGRO-Peanut model could simulate the phenological development of peanut cultivars under different soil moisture regimes, comparisons were made between the observed and the simulated days to first flowering and days to maturity of the two test peanut cultivars under the three levels of soil moisture in the two test seasons. The results showed reasonably good agreements between the observed and the corresponding simulated values for days to first flowering in most cases, with the differences being within 4 days (Table 1). Considerable disparities, however, were observed between the observed and the simulated days to first flowering of the peanut cultivar KK 60-3 at FC and at 1/3 AW in which the simulated values differed from the observed values for 5 and 6 days, respectively. In many cases, the simulated values were slightly longer than the observed values, indicating somewhat over predictions of the model. There was no indication that prediction of flowering date of the crop at FC would be better or worse than when the crop was under drought stress.

Predictions of the maturity dates were reasonably accurate for the peanut cultivar Tainan 9 at all three moisture regimes in 2004 and at FC in 2005, with the differences between the observed and the simulated values ranging from 0-4 days. However, predictions of the maturity dates of this cultivar under the two moisture stress levels in 2005 were rather poor, with the differences being 6-7 days (Table 1). For the cultivar KK 60-3, prediction of the maturity date at FC in 2004 was rather poor (8 days difference) while predictions of the maturity dates at the two moisture stress levels were reasonably

Table 1: Simulated (S) and observed (O) days after planting to first flowering and to maturity of two peanut cultivars grown under three soil moisture regimes in the dry seasons of 2004 and 2005

		Days to first flowering						Days to maturity					
		2004			2005			2004			2005		
Water regime[a]	Cultivar	S	O	S-O	S	O	S-O	S	O	S-O	S	O	S-O
FC	Tainan 9	33	29±4	4	29	27±3	2	115	112±4	3	114	114±0	0
2/3 AW	Tainan 9	33	31±3	2	29	27±2	2	113	114±3	-1	111	117±3	-6
1/3 AW	Tainan 9	33	29±3	4	29	26±2	3	113	117±3	-4	110	117±3	-7
FC	KK60-3	33	31±3	2	37	32±2	5	128	120±3	8	129	128±4	1
2/3 AW	KK60-3	33	33±3	0	37	35±1	2	123	121±3	2	127	133±3	-6
1/3 AW	KK60-3	33	32±2	1	37	31±1	6	120	124±2	-4	125	136±3	-11

[a]FC = Field Capacity, AW = Available Water

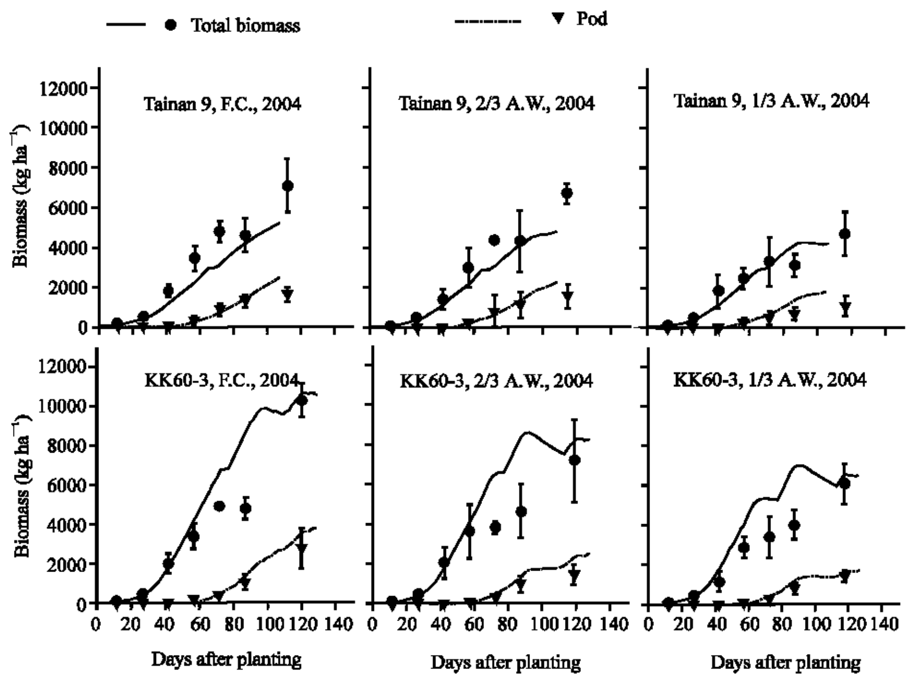

Fig. 1: Simulated (lines) and observed (symbols) values for total biomass and pod dry weights of the peanut cultivars Tainan 9 and KK 60-3 grown under three soil moisture regimes in the dry season of 2004

good (2-4 days differences). However, the opposite was observed in 2005 where prediction was quite accurate for the maturity date at FC (1 day difference) but were rather poor for the maturity dates at the two levels of drought stress (6-11 days differences). It was also noted that, the simulated days to maturity under drought stress conditions were less than the corresponding observed values in most of the cases. The variable results and considerable disparities between the simulated and observed values for days to maturity could be explained by the inaccuracy in the determination of the observed maturity dates, as the plants had to be uprooted for pod inspection. With 3 day intervals of inspection, each examining four plants, considerable variations could occur for observed values due to large plant to plant variations of the peanut crop. Determining whether a plant has reached the maturity stage was also difficult, particularly for the cultivar KK 60-3 that has the indeterminate growth habit and for the plants under water-deficit treatments in which many of the pods in a plant were not developed fully as a result of drought stress.

Figure 1 and 2 compare the observed cumulative values for biomass and pod weight at different growth stages of the two peanut cultivars grown under the three soil moisture regimes in 2004 and 2005 with their corresponding simulated values. Both biomass and pod yields at FC of the two peanut cultivars in 2005 were higher than in 2004. This could be accounted for by the differences in climatic conditions during the cropping periods of the two years, presumably because of different time of planting relative to the onset of the cool season and the period of hot weather in the summer. However,

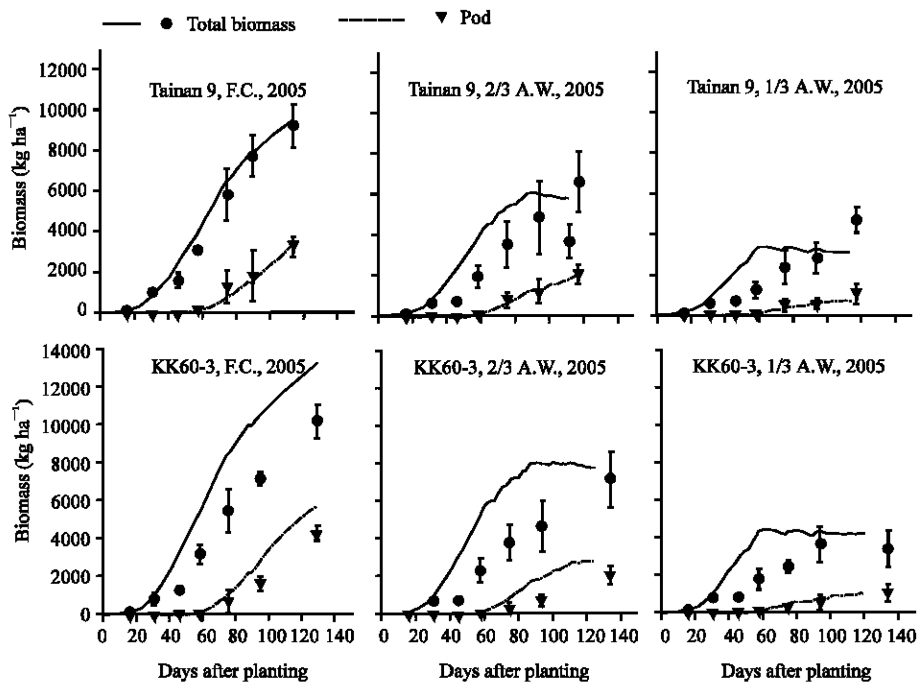

Fig. 2: Simulated (lines) and observed (symbols) values for total biomass and pod dry weights of the peanut cultivars Tainan 9 and KK 60-3 grown under three soil moisture regimes in the dry season of 2005

Table 2: Root mean square error (RMSE) and d-Stat values for total biomass and pod dry weight of two peanut cultivars grown under three soil moisture regimes in the dry seasons of 2004 and 2005

		Total biomass dry weight				Pod dry weight			
		2004		2005		2004		2005	
Water regime[a]	Cultivar	RMSE (kg ha^{-1})	d-stat	RMSE (kg ha^{-1})	d-stat	RMSE (kg ha^{-1})	d-stat	RMSE (kg ha^{-1})	d-stat
FC	Tainan 9	1115.9	0.96	1265.3	0.94	315.2	0.96	265.8	0.95
2/3 AW	Tainan 9	1688.5	0.83	1200.1	0.91	169.2	0.97	145.5	0.96
1/3 AW	Tainan 9	1257.8	0.72	1214.2	0.86	92.4	0.95	182.0	0.87
FC	KK60-3	2287.7	0.90	2826.5	0.83	689.5	0.91	1128.4	0.72
2/3 AW	KK60-3	2104.6	0.86	2854.6	0.71	683.8	0.80	1011.1	0.59
1/3 AW	KK60-3	1961.2	0.75	1457.4	0.69	450.9	0.76	258.4	0.77

[a]FC = Field Capacity, AW = Available Water

yield reductions in the two water stress treatments appeared to be lower in the year 2004 and this could be due to less level of drought stress in this year as a consequence of a rainfall during the cropping period.

The agreements between the observed cumulative values and the corresponding simulated values for biomass and pod weight at different growth stages of the different treatments could be visually observed from the graphs in Fig. 1 and 2 and evaluated statistically by the values of root mean square error (RMSE) and d-statistic shown in Table 2. Visual inspection of Fig. 1 and 2 revealed that the model could capture the responses to drought stress of the two peanut cultivar quite well for both biomass and pod yield, i.e., both simulated biomass and simulated pod yield decreased at the 2/3 AW soil moisture level and further decreased at the 1/3 AW soil moisture level. However, the agreements between the observed and the simulated values were rather variable, some are reasonably good but some are rather poor. Predictions of the cultivar Tainan 9 were reasonably good for both biomass and pod dry weight in 2004 at almost all levels of soil moisture regimes (Fig. 1), with the value of RMSE ranging from 1115.9 to 1688.5 kg ha^{-1} for biomass and from 92.4 to 315.2 kg ha^{-1} for pod dry weight and the d-statistic values ranging from 0.72 to 0.96 and from 0.95 to 0.97 for biomass and pod dry weight, respectively. In 2005, predictions of Tainan 9 were good for pod weight at all three moisture regimes, with the d-statistic ranging from 0.87 to 0.96 and relatively low RMSE values and for biomass at the FC moisture level, with the

Table 3: Observed and simulated dry weights of the peanut cultivars Tainan 9 and KK 60-3 grown under three soil moisture regimes and the average reduction expressed as percentages of the corresponding dry weights at Field Capacity (FC)

		Tainan 9			KK 60-3		
Year	Dry weight	FC	2/3 AW	1/3 AW	FC	2/3 AW	1/3 AW
2004	Observed total biomass (kg ha^{-1})	7,068	6,687	4,687	10,300	7,895	6,117
	Simulated total biomass (kg ha^{-1})	9,078	6,822	5,443	10,610	8,269	6,543
	Average reduction, Observed (%)		16.8			20.3	
	Average reduction, Simulated (%)		20.0			19.2	
	Observed pod yield (kg ha^{-1})	1,585	1,576	1,069	2,778	1,486	1,470
	Simulated pod yield (kg ha^{-1})	2,622	1,579	1,162	3,811	2,554	1,713
	Average reduction, Observed (%)		16.3			23.5	
	Average reduction, Simulated (%)		27.3			27.5	
2005	Observed total biomass (kg ha^{-1})	9,219	6,654	3,386	10,142	7,186	3,776
	Simulated total biomass (kg ha^{-1})	11,208	6,832	3,549	13,292	7,798	4,220
	Average reduction, Observed (%)		31.6			31.4	
	Average reduction, Simulated (%)		34.2			34.1	
	Observed pod yield (kg ha^{-1})	3,312	2,123	1,073	4,423	2,029	1,035
	Simulated pod yield (kg ha^{-1})	3,875	2,208	797	5,739	2,838	1,017
	Average reduction, Observed (%)		33.8			36.0	
	Average reduction, Simulated (%)		39.7			41.1	

d-statistic of 0.94 and the RMSE value of 1265.3. Predictions of biomass of this cultivar at the two moisture stress treatments were somewhat poorer, being over estimated at the early growth stages but turning to be underestimated toward maturity (Fig. 2). The d-statistic for these two treatments, however, still showed good agreement, with the values being 0.91 and 0.86 and their RMSE values (1200.1 and 1214.2) were also comparable to the FC treatment.

For the cultivar KK 60-3, predictions of biomass showed overestimations at all three moisture levels in both years, while predictions of pod weight were overestimated in 2005 but agreed well with the observed values in 2004 at all three moisture levels (Fig. 1 and 2). The d-statistic for biomass ranged from 0.75 to 0.90 in 2004 and from 0.69 to 0.83 in 2005, while those for pod weight ranged from 0.76 to 0.91 and from 0.59 to 0.77 in 2004 and 2005, respectively (Table 2). It was interesting to note that, in the two moisture stress treatments, the simulated biomass of both peanut cultivars continued to increased and were overestimated at the early growth stages, but declined during the later part of crop growth and became underestimated at maturity. The decline in biomass growth also occurred earlier when the moisture stress was more severe, i.e. earlier at 1/3 AW than at 2/3 AW. The corresponding observed values for biomass, however, continued to increase without a decline until maturity (Fig. 1 and 2). This suggested that, although the model could capture the response to drought stress quite well in term of biomass growth, it might not capture the exact pattern of biomass accumulation at different growth stages under moisture stress conditions. Further investigations are needed to verify this speculation.

Simulated values for final biomass and pod yield of the two peanut cultivars at different water regimes are shown in Table 3 in comparison with the corresponding observed values. In most cases, the simulated values were in good agreement with the corresponding observed values for both biomass and pod yield of the two peanut cultivars, particularly those under the water stress treatments. However, the simulated values at FC were mostly higher than the corresponding observed values for both biomass and pod yields, indicating an overestimation of the model, but the differences were not considerably large, being within 20% of observed value for total biomass and 13% of observed value for pod yield. Thus, the model performed reasonably well in predicting the final biomass and pod yield of peanut cultivars under different moisture regimes.

In order to evaluate how well the model can simulates the relative responses of the two peanut cultivars to the three soil moisture regimes, the total biomass and pod yield of each cultivar at 2/3 available water and 1/3 available water were calculated as the percentage of their respective total biomass and pod yield obtained from the FC moisture treatment. This was done for both the observed and simulated values of the individual season and the results are shown graphically in Fig. 3 and 4. Average percentages of reduction in biomass and pod yield over the two levels of moisture stress were also calculated for each cultivar in each year from both observed and simulated values (Table 3). Results from both visual inspections of the graphs and comparisons of the relative yield reduction percentages indicated that the model could predict the relative responses to different soil moisture regimes of the two peanut cultivars quite well. Average relative reduction percentages of the two peanut cultivars obtained from simulated data were close to those obtained from observed data for both biomass and pod yield in all the years. Only for pod yield of Tainan 9 in

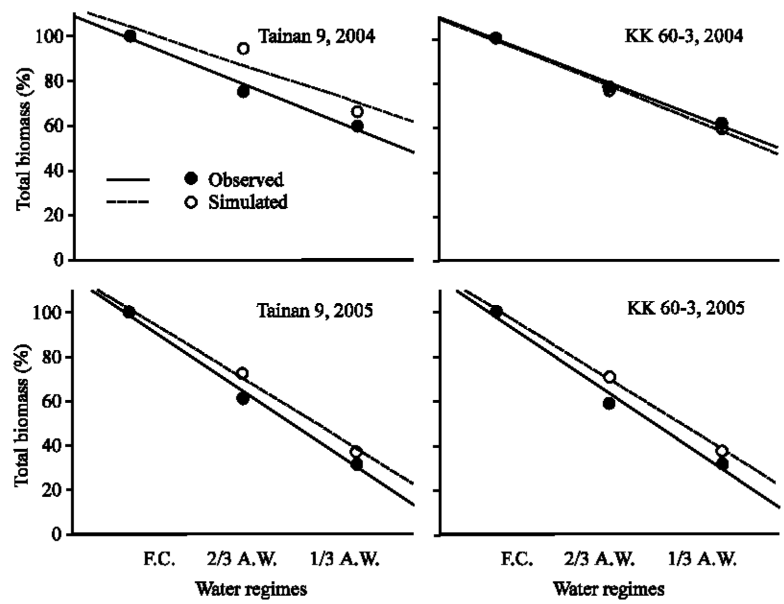

Fig. 3: Observed and simulated total biomass of the peanut cultivars Tainan 9 and KK 60-3 grown under three soil moisture regimes, expressed as percentages of their corresponding total biomass at Field Capacity (FC)

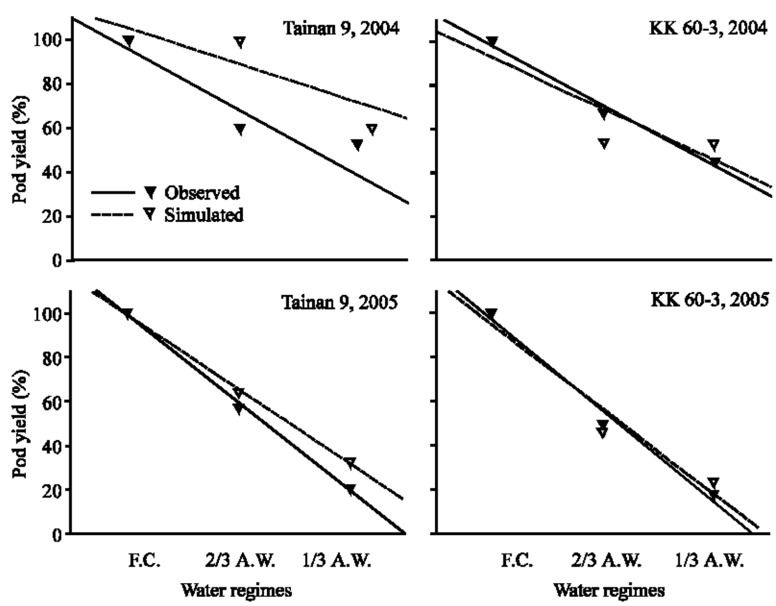

Fig. 4: Observed and simulated pod yields of the peanut cultivars Tainan 9 and KK 60-3 grown under three soil moisture regimes, expressed as percentages of their corresponding pod yields at Field Capacity (FC)

2004 that the relative reduction percentage of the simulated value (27.3%) was somewhat higher than that of the observed value (16.3%) (Fig. 4). In this year, although biomass at FC of this cultivar was higher that at 2/3 AW (7068 vs. 6687 kg ha^{-1}), pod yields at the two moisture levels were about the same (1585 vs. 1576 ha^{-1}) because of poor pod setting for the FC treatment for unknown reason. Overall, it was assessed that the CSM-CROPGRO-Peanut model is quite capable of predicting the relative yield reduction from water stress of peanut cultivars. This capability indicated the potential of using the model in evaluating peanut cultivars/breeding lines for drought tolerance/resistance. However, the two peanut cultivars used in this study did not differ in their

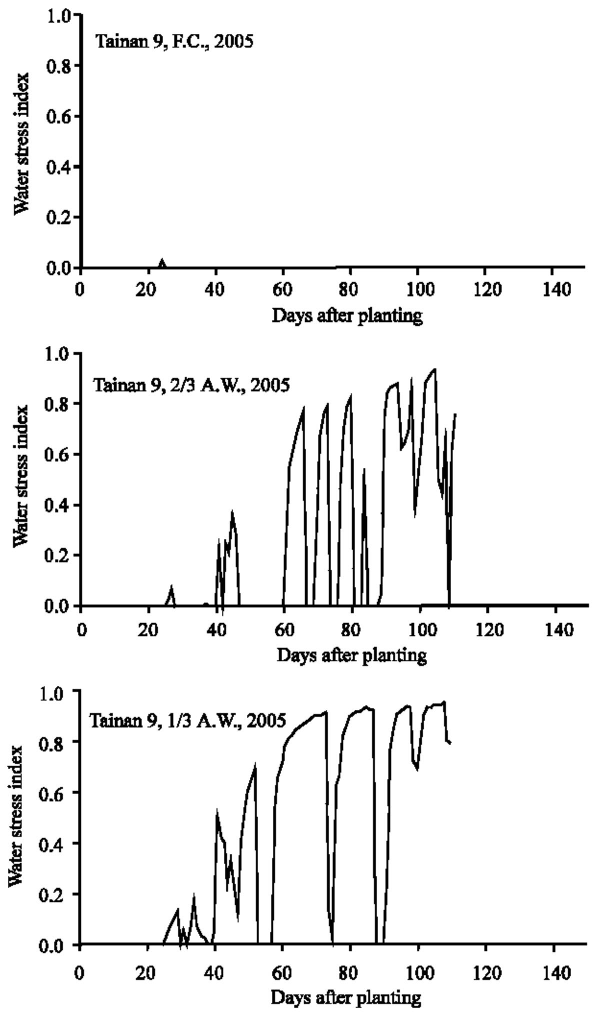

Fig. 5: Water stress index during cropping period of peanut cultivar Tainan 9 at three soil moisture regimes in the dry season of 2005 (0 = no stress, 1 = most severe stress)

tolerance/resistance to drought and did not show much difference in their relative average yield reduction percentages. Further investigations are, thus, needed to evaluate the capability of the model in capturing the differential relative responses to drought stress of peanut cultivars with different degree of drought tolerance/resistance.

Another feature of the CSM-CROPGRO-Peanut model is the provision of the times of occurrence and severity of water stress, expressed as water stress index, during the cropping duration as one of the model outputs. An example of this is shown in Fig. 5 for Tainan 9 grown under the three moisture regimes in the dry season of 2005. It was quite clear that the model captured this attribute quite well, as no stress was shown for the FC treatment and more severe stress was indicated for the 1/3 AW moisture level than the 2/3 AW level. This feature could be used in characterizing the patterns of drought stress of the individual peanut production areas, however, its actual application needs to be further investigated.

This study aimed to evaluate the capability of the CSM-CROPGRO-Peanut model in predicting the responses to drought stress of peanut cultivars. The results indicated that the model performed fairly in simulating phenological development and patterns of dry matter accumulation of peanut cultivars under different soil moisture regimes. However, the model performed reasonably well in simulating the final biomass and pod yields under different moisture levels of peanut cultivars. Most importantly, the model could predict the relative yield reduction from drought stress of individual peanut cultivars quite well. In most of the potential applications of the model for drought stress management, relative values are more important than absolute values. Hence, the ability of the CSM-CROPGRO-Peanut model to capture the response feature and to correctly predict the relative yield reduction percentages from drought stress of individual peanut cultivars would make the model applicable to various applications for drought stress management, such as choosing suitable planting dates, determining effective irrigation managements and identifying drought avoidant and drought resistant cultivars. With the water stress index provision feature, the model could also be used in characterizing drought stress patterns and frequency of occurrence for the different peanut production areas. This study was conducted under continuous, long term water stress conditions, which would not occur in natural conditions and with only two peanut cultivars. Further investigations need to be done under the drought stress patterns normally occur in nature, e.g., early drought, mid-season drought and terminal drought and with more number of peanut cultivars, preferably with different degrees of drought tolerance/resistance, in order to establish the creditability of the model in different aspects and to make crop models a viable tool for drought stress management.

ACKNOWLEDGMENTS

This study was supported by the Thailand Research Fund through the Senior Research Scholar Project of Professor Dr. Aran Patanothai and assistance in carrying out the work was also received from the Peanut Project of the Department of Agronomy, Faculty of Agriculture, Khon Kaen University, Khon Kaen, Thailand.

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