Simulation and assessment of planting date and climatic effects on Soybean (*Glycine Max* L.) yields in Thailand using GLYCIM

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Abstract

The soybean model GLYCIM was used to assess soybean yield potential as a function of planting date, soil type and cultivar for growing conditions in northeastern Thailand. A study was conducted at the Asian Institute of Technology (AIT), Pathumthani, Thailand in 2005 to calibrate and validate GLYCIM for Thailand conditions. The study used three planting dates and three cultivars commonly used in Thailand, CM-2, CM-60 and SJ-5. The model validation results indicated a good agreement between simulated and observed data for phenology, growth and yield of soybean, and demonstrated the potential of the model for assessment purposes. Simulations were carried out to determine yield variations due to seven planting dates, three soil types and three cultivars using 37 years of measured weather data for two locations, Sukhothai and Khonkaen in the northern part of Thailand. Delayed (middle of June to end of June) planting showed a reduction in yield potential ranging from 7% to 35% due to a shorter growing season and increased water stress. The clay and silt loam soils showed higher yield potential compared to the sandy loam soil. There were no differences among the three cultivars and no significant interaction of cultivar with planting date or soil.

Keywords: Crop model, Tropics, Climate, Soil, GLYCIM

Introduction

Soybean [*Glycine max* (L)] is an important legume crop in Thailand. It is used as a vegetable for human consumption, as oil, or as animal feed. Domestic production has remained unchanged over the period from 2009 to 2011 at 170-180,000 Mg annually and currently only meets about 10% of the continually growing total demand (Preechajarn, 2011). Since demand for soybean as a vegetable is low in Thailand, the sale of vegetable soybean, especially to Japan is an important revenue source (Shanmuga-sundaram and Yan, 2010). As the local production of soybean cake is not sufficient to supply the rising demand for animal feed, about 2 million Mg of soybean and soybean cake is imported annually mainly from the Brazil, Argentina and the U.S. (Preechajarn, 2011). Because of demand for soybean as an animal feedstock and oil, and the need for export income from the sale of vegetable soybean, it is has long been necessary to increase Thailand soybean production (Preechajarn, 2011).

In Thailand, the rainy season soybean crop is generally planted at the beginning of May, however to a large extent the exact time of planting depends on the commencement of rain (Anonymous, 1998; (Shanmugasundaram and Yan, 2010). The Asian Vegetable Research and Development Center, Thailand has carried out various experiments to study the effects of agro-climatic conditions and soybean cultivar interactions on seed production. It was seen that as planting date varies from early to late planting, there is a noticable difference in

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soybean yield (Machikowa et al., 2005, Luathong and Pobboon, 1998). Different soil types with differing hydraulic properties and water holding capacities affect soybean growth differently at various growth stages (Srisombun, 2002). Moreover there is positive correlation between yield, total dry matter and leaf area index which is affected by soil fertility, soil water availability, environment, and maturity group of soybean (Parvez et al., 1989).

In tropical climates as in Thailand, future climate change is likely to have a great impact on soybean production (Lobell et al., 2011; Thanacharo-enchanaphas and Rugchati, 2011) through effects on temperature and water availability. Increased temperature significantly reduces the seed yield due to accelerated development and decreased grain filling period (Seddigh and Joliff, 1984). A crop simulation model can be a useful tool to evaluate the potential effects of water deficits and increased temperature on crop yields. During the last 30 years, simulation models have been developed for a number of crop production processes, including weather, soil erosion, phenology, growth, and yield (Anbumozhi et al., 2003). Models of specific crop plant processes have been combined into comprehensive crop simulation models and used by researchers to estimate the agronomic, environmental and economic impacts of modifying cropping systems at specific sites. Examples and lists of these models are available elsewhere (Whisler et al., 1986; Jones et al., 2003). Although these models do not simulate all plant processes in detail, they have brought new understanding of the soil-plant-atmosphere continuum. Evaluation of yield potential and yield gap analysis using a crop simulation model can provide valuable information for the design of a strategic plan for increasing soybean production in Thailand (Banterng et al., 2010). The soybean model GLYCIM (Acock et al., 1985; Acock and Trent, 1991) can be a useful tool to assess and quantify yield potential and yield gaps for various growing conditions.

The objective of this study was to (1) Validate the performance of the soybean model GLYCIM under different planting dates and cultivars. (2) Assess the influence of soil type, weather condition, early and delayed planting dates and cultivars on soybean yield in Sukhothai and Khonkaen provinces of Thailand using the validated model.

Materials and Methods

The soybean model GLYCIM (Acock et al., 1985; Acock and Trent, 1991) has highly mechanistic, dynamic representations of plant growth, development and yield, and soil and weather processes. The environmental inputs necessary to run GLYCIM are daily values of solar irradiance, precipitation, maximum and minimum daily temperature, or hourly mean irradiance, temperature, precipitation and wind speed. It also requires information on physical and hydraulic properties of soil, cultivar parameters, latitude of the field, date of emergence, row spacing, plant population within the row, row orientation, irrigation amount, method and date, and CO_2 concentration in the atmosphere (Timlin et al., 2002). GLYCIM has been designed to simulate the growth of any soybean cultivar on any soil, and at any location and time of year. Simulations are initiated at the cotyledonary stage. In estimating yields, it is assumed that the crop is free from any insect, pest or disease damage. GLYCIM simulates the yield of soybean mainly driven by solar radiation, water availability, daylength and temperature as affected by soybean varietal characteristics. Plant growth in size and phenological stage are predicted by the model (Reddy et al., 1995). The current interface (GUICS - Graphical User Interface for Crop Simulators) was developed to better manage GLYCIM input files and simulation results (Acock et al., 1999).

Model validation

The experimental study was conducted at the Agricultural Systems and Engineering Farm, Asian Institute of Technology (AIT), Pathumthani, Thailand (13°50’ N latitude 100°35’ E longitude).

The location of the experimental site has uniform and leveled topography. The soil (Bangkok clay) is a Vertisol (UNO, 1972). This soil is characterized as medium black clayey in texture with thick deposits of soft to very soft clay with low shear strength and very high water content, and high plasticity. The experiment was laid out in a randomized block design with three replications. Three soybean cultivars Chiangmai-2 (CM-2), SJ-5 and Chiangmai-60 (CM-60) were planted on three dates, 2 September, 16 September and 30 September, 2005. The plot size was 3.5 x 3.5 m. The seedlings emerged approximately 5 days after planting; the plants were thinned in order to maintain a uniform plant population (9.8 plants m^{-2}). Plant protection measures determined by the AIT farm manager were followed to maintain pest-free conditions. Irrigation of 1 cm using sprinklers was given once on 12 October, 2005 to all treatments in order to minimize water stress. The daily maximum and minimum temperature, relative humidity, solar radiation, precipitation and wind speed were recorded at a weather station near the experimental site. The soil physical and hydraulic properties such as hydraulic diffusivity, volumetric water content, saturated water content, bulk density, saturated hydraulic conductivity (Klute and Dirkson, 1986), sand & clay content (Gee and Bauder, 1986) were determined at three different depths (20, 60 and 120 cm). The growth parameters such as plant height, number of leaves and branches, vegetative stages (number of main stem leaves), reproductive stages and biomass data were collected weekly. In the case of destructive plant samples, the plant was sub-sampled into leaf, stem, root and leaves, oven dried and weighed. Leaf area was measured with LI-3000A Portable Area Meter (LI-COR, Inc., Lincoln, NE, USA). At harvest, seed and pod yield were recorded for each plot.

Model Calibration

The experimental data from all three cultivars (CM-2, SJ-5 and CM-60) and sowing date 2 Sept. were used for model calibration. For model validation (testing), the data from all three cultivars and sowing dates 16 Sept. and 30 Sept. were used. Parameters for development rates (those that control vegetative and reproductive stages) were optimized separately from those affecting biomass to minimize interdependence. The parameters for the development stages were fit manually by changing the value of the parameter until error was minimized. For the biomass components, we varied the parameters interactively to minimize the Root Mean Square Error (RMSE) for both seed yield (RMSE-yield) and total above-ground biomass at final harvest (RMSE-biomass). In addition, we visually evaluated the time course of estimated and observed total biomass and pod mass.

Assessment Methodology

Two locations from northern Thailand where soybean is an economically important crop were selected for the model application *viz.*, Sukhothai (Latitude: 17°24' 30 N Longitude: 99°82' 30 E) and Khonkaen (Latitude: 16° 25' 60 N, Longitude: 102° 49' 60 E). Thirty seven years of daily weather data (1970 to 2010) were collected for both locations comprising of maximum and minimum daily temperature, sunshine hours, precipitation and wind speed. Three years of weather data were not retained as they were incomplete. Irradiance (MJ) was calculated from sunshine hours using the Angstrom formula (Allen et al., 1998):

$$RI = \left(a + b\frac{SH}{DL}\right) SolarR$$

Where *RI* is irradiance (MJ), *a* and *b* are parameters, *SH* is sunshine hours, *DL* is total hours of day length and SolarR is the integral of photosynthetically active radiation on a cloudless day. SolarR and daylength were calculated using equations given by Campbell and Norman (1998) using latitude and longitude of the sites as input. The parameters *a=0.25* and *b=0.5* were fit to closely match irradiance on cloudless days.

To facilitate simulations, 63 scenarios (for each year of weather data) were created which comprised a combination of seven planting dates starting from early April to late June (2 April, 16 April, 2 May, 16 May, 31 May, 16 June and 30 June) with three different soil types (Table 1) viz. clay (Bangkok clay), sandy loam (That Phanom), silt loam (Phan) and the three cultivars used in the field study (CM-2, CM-60 and SJ-5). The soils were chosen as representative of sandy loam and silt loam textured soils in the Sukhothai and Khonkaen regions. The soil properties were obtained from Yingjajaval (1993). The planting dates provided two week intervals for sowing times but were near the summer solstice. This allowed enough daylength for the soybean plant to flower optimally. The model output obtained from simulations for different scenarios was analyzed across the planting dates, soil types and cultivars for 37 years of available data over the 1970 to 2011 time period.

The simulation results were analyzed using SAS 9.3 (SAS Institute, Cary, NC) Proc Mixed. Variety, soil and planting date were treated as fixed effects. Means comparison was carried out using the lsmeans statement.

Results and Discussion

Model calibration and validation

The fitted parameters for development rates and pod growth for the three cultivars are given in Table 2. The coefficient of determination (r^2) values for growth and development parameters *viz.,* plant height, vegetative stages, reproductive stages, leaf area, number of pods and the biomass parameters *viz.,* stem and root dry weight were all above 0.90 for all three cultivars (Table 3) except for leaf area. Considerable differences were not observed for the fitted parameters for the different cultivars. The

Table 1. List of soil properties used in the model

Name of Soil	Depth (cm)	Soil water content			Bulk Density	Saturated Hydraulic Conductivity
		-1500 kPa	saturation	drained upper limit (33 kPa)		
		$cm^3\ cm^{-3}$			$g\ cm^{-3}$	$cm\ day^{-1}$
That Phanom						
Sandy Loam	10	0.02	0.31	0.07	1.58	5.30
	30	0.04	0.31	0.10	1.45	3.30
	100	0.05	0.34	0.11	1.4	2.30
Phan silt loam	10	0.07	0.46	0.17	1.37	27.5
	30	0.05	0.38	0.15	1.6	3.30
	100	0.05	0.41	0.15	1.5	0.3
Bangkok Clay	25	0.33	0.55	0.43	1.03	0.23
	60	0.36	0.53	0.42	1.09	0.50
	120	0.42	0.58	0.47	0.94	0.58

Table 2. List of cultivar parameters for development rates and biomass properties and their optimized values

Parameters	Value		
	CM-2	SJ-5	CM-60
Slope of V stage on temperature integral (degree day^{-1})	0.0119	0.0120	0.0116
Maximum V stage	13	14	12
Progress rate from R2 towards R6 (degree day^{-1})	0.00514	0.00517	0.00511
R stage to stop vegetative growth	3.32	3.34	3.31000
Potential elongation / dry weight increase in petioles	0.00254	0.00258	0.00251

high r^2 values indicate that GLYCIM simulated the calibration data set well.

Figure 1 shows the simulated and observed plant heights for the validation data set (data not used for calibration) for sowing dates 16 Sept and 30 Sept. The simulated values are close to the measured ones and follow the observed trends well. Figure 1 shows that as the sowing dates are delayed, both simulated and observed plant height per plant decreased. In the case of SJ-5 cultivar the plants attained a height of about 0.5 m at 60 DAP for regular planting date whereas for delayed planting it attained only less than 0.35 m height. (Fig. 1). This difference is due to the decrease in day length that hastens the onset of reproductive stages and results in early cessation of leaf addition and main stem growth (Acock *et al.*, 1997). A similar trend was observed in CM-2 and CM-60 soybean cultivars. Simulated plant height for all three cultivars is slightly under predicted but within the acceptable limit. The error bars suggest little variability in phenological development among the replications. The cultivars showed differences in the total number of main stem leaves (vegetative stages, Fig. 2). The SJ-5 cultivar on average had one to two more main stem leaves (14) as compared to CM-2 (12). Measured and simulated total main stem leaves for both the cultivars (SJ-5 and CM-2) agreed well.

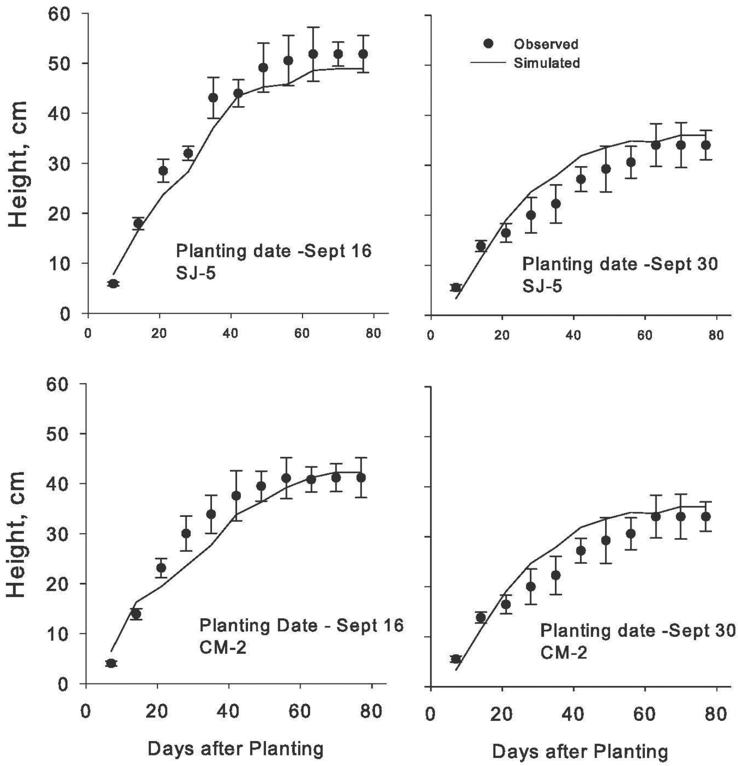

Figure 1. Comparison of simulated and observed seasonal development of plant height for Sept-16 and Sept-30 planted soybean cultivar SJ-5 and CM-2.

Observed seed yield ranged from 1195 kg ha^{-1} (planting date Sept-30 and CM-60 cultivar) to 2202 kg ha^{-1} (planting date 2 Sept and SJ-5 cultivar) whereas simulated seed yield ranged from 1026 kg ha^{-1} (planting date 30 Sept and CM-60 cultivar) to 2316 kg ha^{-1} (planting Sept-2 and SJ-5 cultivar).

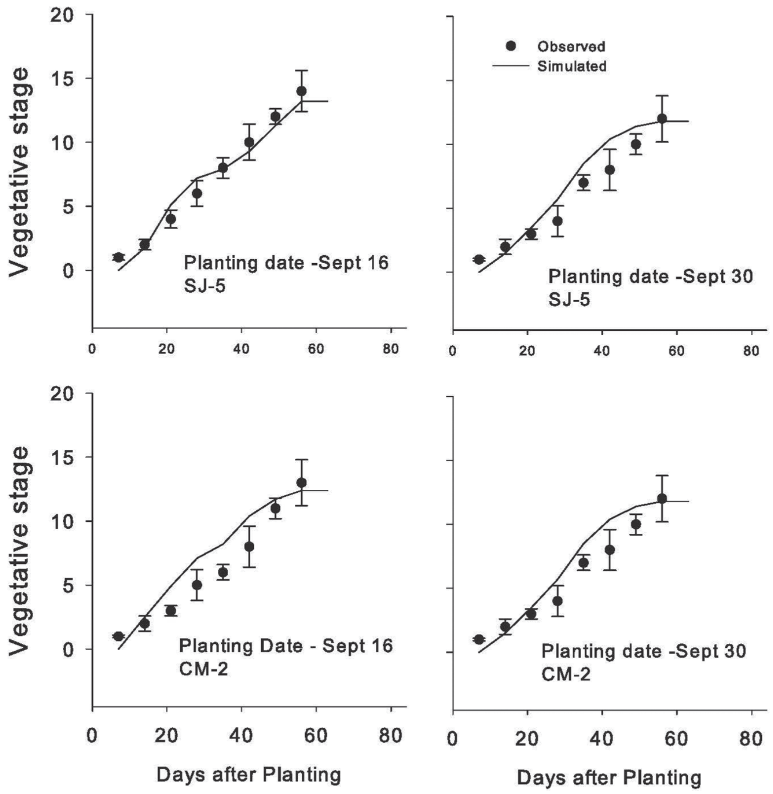

Figure 2. Comparison of simulated and observed mainstem leaf number for Sept-16 and Sept-30 planted soybean cultivars SJ-5 and CM-2.

Table 3. r^2 values for model calibration comprising sowing date 2-Sept and three soybean cultivars CM-2, SJ-5 and CM-60.

Plant component	r^2		
	CM-2	SJ-5	CM-60
Plant height	0.96	0.99	0.97
Mainstem leaf number (vegetative stages)	0.96	0.99	0.93
Reproductive stages	0.98	0.96	0.98
Leaf area	0.90	0.85	0.90
Stem dry weight	0.99	0.92	0.98
Root dry weight	0.95	0.97	0.96
Number of pods	0.94	0.93	0.96

Estimated GLYCIM seed yield was within 15% of measured yield (Fig 3).

The coefficient of determination (r^2) values for the

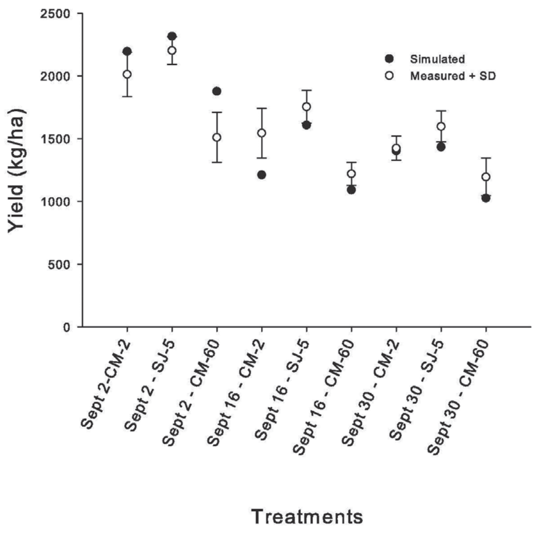

Figure 3. Comparison of simulated and observed seasonal seed yield (kg ha^{-1})

correspondence between simulated and observed plant height, vegetative stages, reproductive stages, leaf area, stem and root dry weight, and number of pods per plant for sowing dates 16 Sept and 30 Sept and for all three cultivars (CM-2, SJ-5 and CM-60) are shown in Table 3. For all the variables, the values of the coefficient of determination are above 0.90 except for one value of 0.85 for leaf area in SJ-5, which indicates that the model simulates the measured validation data well for a given location and climatic conditions. The exercise confirmed that the soybean model GLYCIM was able to realistically simulate the phenological parameters and yield for the treatments in this study.

Simulation of soybean yield as a function of planting date

We performed a series of simulations to assess soybean productivity at Sukhothai and Khonkaen located in the northern part of Thailand considering seven planting dates starting from early April to late June with three soil types and three soybean cultivars. By utilizing different weather and soil data it was possible to determine the interacting effects of weather and soil types as planting date changes (Mall et al., 2004). The mean weather data and their distribution are shown in Figure 4. Maximum temperatures occur in the spring, in the months of April and May. Solar radiation also reaches a maximum in the spring and decreases during the summer months due to cloud associated with summer rains. There were two peaks of precipitation, one in June, the other in late August, early September. Precipitation was high from May through November.

Soil and planting date both had significant effects on simulated yields (p<.001; Table 4). In addition there was a significant interaction between soil and planting date indicating that the effect of soil on yields varied by planting date (p<.001). Yields on the different soils were significantly different from each other (Table 4). Average yields were highest for the Bangkok Clay (3058 kg ha^{-1}) and lowest for the Than Phanam Sandy Loam (2532 kg ha^{-1}).

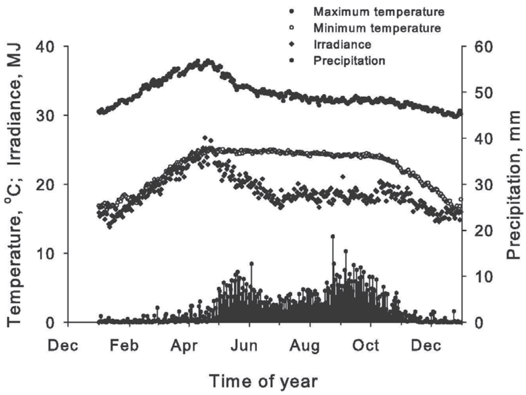

Figure 4. Mean daily temperature, solar radiation, and precipitation for the 37 year period of simulations.

Although significantly different, the yield difference between the clay and silt loam soils (142 kg ha^{-1}) were not as large as the yield differences for the clay and silt loam compared to the sandy loam soil (526 and 384 kg ha^{-1} respectively). These results are due to differences in soil water holding capacity (Table 1). The silt loam and clay soils have higher water holding capacity as compared to the sandy loam.

There was no significant variety effect or significant interaction of variety with the other terms. The varieties do actually differ in maturity time. The cultivar CM-2 is an early maturing variety (70 to 80 days), while CM-60 and SJ-5 are late maturing varieties (90 to 100 days) (Tantasawat et al., 2011). In a previous study the three varieties, were found to have different genetic properties (Tantasawat et al., 2011). The lack of cultivar effect in the simulated results likely occurred because the variety parameters based on the field experiments did not differ greatly (Table 2). Additional field data may be necessary to obtain parameters more specific to the genetic characteristics of the cultivar.

There were significant differences among planting dates. Generally the highest yields occurred when soybean was planted in early to mid May (Table 4). The lowest yields occurred when planted in late

Table 4. Mean yields as a function of soil, variety and planting date for Sukhothai and Khonkaen

Location	Treatment	Label	Mean (kg ha^{-1})
Sukhothai	Soil	Bangkok Clay	3058[a¶]
		Phan Silt Loam	2916[b]
		That Phanom Sandy Loam	2532[c]
	Variety	CM-2	2857[a]
		CM-60	2789[a]
		SJ-5	2858[a]
	Planting date	2-Apr	2850[bc]
		16-Apr	2882[bc]
		2-May	3021[ab]
		16-May	3111[a]
		31-May	2825[c]
		16-June	2801[c]
		30-June	2356[d]
KhonKaen	Soil	Bangkok Clay	3219[a]
		Phan Silt Loam	3031[b]
		That Phanom Sandy Loam	2607[c]
	Variety	CM-2	2963[a]
		CM-60	2909[a]
		SJ-5	2990[a]
	Planting date	2-Apr	3194[a]
		16-Apr	3112[ab]
		2-May	3162[a]
		16-May	3253[a]
		31-May	2936[b]
		16-June	2702[c]
		30-June	2306[d]

[¶]Mean values followed by the same letter in the superscript are not significantly different

June. The low yields at late planting are partly due to the adverse impact of thermal and water stress during reproductive stages of the crop. The length of the growing period from first flower to maturity also affects seed yield. This period is shortest for the planting dates before late May and early June and decreases again after that (Table 5). Longer growing season time is associated with higher yield as the plant has more time to assimilate carbon that contributes to greater pod weights. It has been suggested that soybean yields in Thailand can be increased if breeders can lengthen the period before flowering (Tantasawat et al., 2011).

There was a significant interaction between soil and planting date ($p<0.001$). This means that the optimum planting date varied by soil. The planting dates that had the highest yields were earlier for the sandy loam soil than for the silt loam or clay soil for both sites (Tables 6 and 7). Soybeans planted to the Phan Silt Loam and That Phanam sandy loam were decreased more by late planting than soybean planted in the Bangkok Clay (Tables 6 and 7). The sandy loam soils had lower water holding capacity and thus were more impacted by the decreasing rainfall later in the year. Tables 6 and 7 also show distribution of yields among soils, planting date and cultivar. There was not a significant cultivar effect, thus no one cultivar had a clear advantage over all soils and planting dates.

Relative yield potential (%) was tabulated for the two locations, Sukhothai and Khonkaen in Thailand across different planting dates, soil types and cultivars (Table 8). The potential yield for a cultivar was calculated by dividing simulated yield by

*Table 5***.** Mean length of time between first flower (R1) and physiological maturity simulated by GLYCIM for each variety, soil and planting date.

Planting date	Sukhothai			Khonkaen		
	Time from first flower to harvest (days)					
Soil Type- Bangkok clay						
	CM-2	CM-60	SJ-5	CM-2	CM-60	SJ-5
2-Apr	66.9	63.0	67.8	67.5	63.5	68.3
16-Apr	73.9	70.1	73.8	74.9	71.2	74.7
2-May	79.0	76.1	80.6	79.2	75.3	79.8
16-May	80.4	76.7	81.1	79.8	76.6	80.6
31-May	79.6	76.6	80.6	80.3	76.3	80.3
16-Jun	78.0	73.0	78.2	79.3	74.0	79.6
30-Jun	74.8	69.5	77.0	74.7	69.4	77.1
Soil Type- Phan silt loam						
	CM-2	CM-60	SJ-5	CM-2	CM-60	SJ-5
2-Apr	67.3	63.6	68.0	67.8	63.7	68.6
16-Apr	74.1	70.7	74.0	74.8	71.4	74.8
2-May	79.0	76.3	80.6	79.2	76.0	79.8
16-May	81.2	76.5	81.1	79.9	76.4	80.5
31-May	78.5	75.0	80.9	79.4	74.7	80.3
16-Jun	76.6	72.1	78.0	77.5	71.7	79.4
30-Jun	72.2	67.4	75.0	71.7	67.8	74.8
Soil Type- That Phanam sandy loam						
	CM-2	CM-60	SJ-5	CM-2	CM-60	SJ-5
2-Apr	67.6	64.3	68.6	68.5	64.8	68.7
16-Apr	74.8	71.1	74.3	75.3	71.8	75.1
2-May	79.2	76.6	80.9	79.9	76.5	80.1
16-May	80.7	76.3	81.9	79.7	76.8	80.8
31-May	78.8	74.3	81.3	79.4	74.2	81.1
16-Jun	75.9	71.8	78.0	77.0	71.6	78.8
30-Jun	72.0	67.5	74.5	71.6	66.9	73.9

highest yield for a range of planting dates within a soil and variety (Tables 6 and 7). For the locations across planting dates it is clearly evident that for early planting dates (2 April and 16 April) the total yield loss relative to May 16 ranges from 7% to 17% (Table 8). Whereas, in delayed planting dates starting from end of May to end of June, there is a dramatic yield loss in the range of 30 to 45%.

Reduction in potential yield varied by soil types. Across three soil types varying from clay to silt loam it was clearly seen that largest yield loss (40 to 45%) relative to the date with the highest yield occurred

Table 6. Mean GLYCIM simulated soybean yield (kg ha^{-1}) and variance for seven different planting dates and three cultivars across the three different soil types and 37 years of weather for Sukhothai, Thailand.

Planting date	Bangkok Clay						Phan Silt Loam						That Phanom Sandy Loam					
	CM-2		CM-60		SJ-5		CM-2		CM-60		SJ-5		CM-2		CM-60		SJ-5	
	Mean	Error	Mean	Error	Mean	Error	Mean	Error	Mean	Error	Mean	Error	Mean	Error	Mean	Error	Mean	Error
	Kg ha-1																	
2-Apr	2807[c]	129.6[¶]	2921[abc]	135.2	2769[c]	127.2	3100[ab]	121.8	3146[a]	128.2	2981[abc]	135.8	2688[ab]	135.1	2568[ab]	136.3	2669[bc]	135.6
16-Apr	2821[c]	145.7	2833[bc]	144.1	2795[c]	142.3	3068[abc]	114.9	3109[a]	120.4	3071[abc]	99.2	2800[a]	153.0	2660[a]	153.5	2781[ab]	157.9
2-May	3050[bc]	133.5	2980[abc]	131.4	2988[abc]	129.8	3184[ab]	124.4	3174[a]	123.0	3195[ab]	133.4	2899[a]	157.9	2742[a]	144.7	2978[ab]	150.4
16-May	3213[ab]	150.7	3117[ab]	148.8	3268[ab]	142.2	3356[a]	126.7	3234[a]	115.4	3350[a]	144.4	2751[ab]	137.9	2616[ab]	142.1	3098[a]	139.3
31-May	3457[a]	124.7	3280[a]	138.4	3355[a]	143.1	2689[c]	108.6	2877[ab]	133.8	2824[bc]	149.1	2215[cd]	107.2	2406[cd]	139.5	2324[cd]	133.5
16-Jun	3435[a]	132.0	3223[a]	116.6	3285[a]	148.5	2880[bc]	161.5	2665[b]	112.3	2731[c]	181.6	2396[bc]	177.9	2234[bc]	156.8	2361[cd]	213.9
30-Jun	3056[bc]	98.8	2663[c]	124.9	2897[bc]	154.0	2211[d]	118.9	2119[c]	89.9	2278[d]	130.1	1930[d]	98.1	2009[d]	83.9	2038[d]	136.0

¶Means values followed by the same letter within a column are not significantly different

†Variance results from the use of 37 years of weather data.

Table 7. Mean GLYCIM simulated soybean yield (kg ha^{-1}) and variance for seven different planting dates and three cultivars across the three different soil types and 37 years of weather for Khonkaen, Thailand.

Planting date	Bangkok Clay						Phan Silt Loam						That Phanom Sandy Loam					
	CM-2		CM-60		SJ-5		CM-2		CM-60		SJ-5		CM-2		CM-60		SJ-5	
	Mean	Error	Mean	Error	Mean	Error	Mean	Error	Mean	Error	Mean	Error	Mean	Error	Mean	Error	Mean	Error
	Kg ha-1																	
2-Apr	3201[abc¶]	167.9[†]	3306[a]	168.4	3053[bc]	153.6	3327[a]	149.3	3354[a]	133.9	3133[b]	129.2	3162[a]	156.7	3087[a]	151.7	3126[a]	165.2
16-Apr	3011[c]	140.1	3058[ab]	139.7	2952[c]	127.8	3277[ab]	133.3	3228[ab]	112.4	3297[b]	122.7	3129[a]	141.7	2941[a]	133.0	3116[a]	124.4
2-May	3111[bc]	139.4	3263[a]	157.9	2995[c]	137.2	3445[a]	125.1	3394[a]	100.6	3417[ab]	129.2	2947[a]	148.6	2899[a]	138.5	2986[a]	138.8
16-May	3463[ab]	143.6	3214[a]	142.4	3427[ab]	150.4	3408[a]	102.1	3236[ab]	119.2	3681[a]	121.8	2957[a]	136.2	2731[a]	133.7	3128[a]	150.2
31-May	3405[ab]	144.6	3348[a]	149.5	3495[a]	141.7	2950[bc]	128.2	2957[b]	142.7	3289[b]	137.2	2220[b]	123.6	2222[b]	118.2	2535[b]	136.7
16-Jun	3571[a]	128.9	3352[a]	125.8	3426[ab]	140.9	2657[c]	150.1	2410[c]	126.9	2549[c]	180.2	2102[b]	165.0	2171[b]	136.8	2057[c]	159.1
30-Jun	3109[bc]	106.8	2752[b]	89.7	3084[bc]	105.9	2098[d]	92.2	2239[c]	66.5	2294[c]	125.6	1666[c]	99.4	1783[c]	83.2	1747[c]	118.9

¶ Mean values followed by the same letter in the superscript within a column are not significantly different

† Variance results from the use of 37 years of weather data.

Table 8. Relative yield Potential¶ (%) for each variety and soil as a function of planting date for locations Sukhothai and Khonkaen

Planting date	Sukhothai Yield Potential (%)			Khonkaen Yield Potential (%)		
Soil Type- Bangkok clay						
	CM-2	CM-60	SJ-5	CM-2	CM-60	SJ-5
2-Apr	81.2	89.1	82.5	89.6	97.9	87.4
16-Apr	81.6	86.4	83.3	84.3	90.5	84.5
2-May	88.2	90.9	89.1	87.1	96.6	85.7
16-May	92.9	95.0	97.4	97.0	95.2	98.0
31-May	100	100	100	95.4	99.1	100
16-Jun	99.4	98.3	97.9	100	100	98.0
30-Jun	88.4	81.2	86.3	86.6	81.5	88.2
Soil Type- Phan Silt Loam						
	CM-2	CM-60	SJ-5	CM-2	CM-60	SJ-5
2-Apr	92.4	97.3	89.0	96.6	98.8	85.1
16-Apr	91.4	96.1	91.7	95.1	95.1	89.6
2-May	94.9	98.2	95.4	100	100	92.8
16-May	100	100	100	98.9	95.3	100
31-May	80.1	89.0	84.3	85.6	87.1	89.3
16-Jun	85.8	82.4	81.5	77.1	71.0	69.2
30-Jun	65.9	65.5	68.0	60.9	66.0	62.3
Soil Type- That Phanam sandy loam						
	CM-2	CM-60	SJ-5	CM-2	CM-60	SJ-5
2-Apr	92.7	93.7	86.2	100	100	99.9
16-Apr	96.6	97.0	89.8	98.9	95.3	99.6
2-May	100	100	96.1	93.2	93.9	95.4
16-May	94.9	95.4	100	94.5	88.5	100
31-May	76.4	87.8	75.0	70.2	72.0	81.0
16-Jun	82.6	81.5	76.2	66.5	70.3	65.7
30-Jun	66.6	73.3	65.8	52.7	57.8	55.9

¶ Relative yield potential is calculated as the ratio between simulated yield for a particular planting date, variety, and soil, and yield for the planting date with highest yields (represented as 100%) among the different varieties and soils. For example the yield for CM-2 planted on Bangkok Clay on 2-April is 81.2% that of the planting on 16-Jun for the same soil and variety.

in the sandy loam soil followed by silt loam up to 35%. Whereas, in the clay soil, the yield loss was 15-20%. The greatest negative effect of soil on crop productivity is the decrease of water holding capacity of the soil with secondary effects coming from loss of nutrient and soil biota (Algarswamy, et al., 2000). In a similar study on the effect of planting date on soybean production in the Phu Pha Man district, Banterng et al. (2010) reported that the optimum planting dates were June 15 to July 15 for the CM 60 and SJ 5 varieties. The comparison planting dates were 15 and 30 May, 15 and 30 June, 15 and 30 July and 15 and 30 August. The annual rainfall in Phu Pha Man is 1226 mm from May to October.

From the results, it can be concluded that the soybean model GLYCIM was adequate to simulate the effects of planting date and cultivar on soybean yield and development. In general, the results from simulation studies using variations in planting date and soil type indicate that delaying the planting date from end of May to end of June may reduce soybean productivity by decreasing the length of the growing season and hence yield. The thermal stress on the soybean crop at the selected locations in Thailand could reduce the yield of soybean up to 35%. Soil type affected simulated yields where yields were lower for the loam textural soil than for the clay or silt loam. The effect was grater for late plantings when there was less rainfall. The best yields for the clay soil were for the later plantings as opposed to those for the sandy loam and silt soils where the best yields occurred with the earlier plantings. There were no differences in simulated yields among cultivars in this study. The cultivars CM-60, SJ-5 and CM-2 had similar yields across planting dates and soil type. The Soybean model, GLYCIM estimated yield well for the given cultivars, soil types and sowing dates for tropical conditions. This study demonstrates that soybean model GLYCIM can be used across the tropical region (Thailand) for decisions with respect to selection of planting dates, cultivars and soil type for different locations and seasons so as to assess potential yields under the field conditions in varied environments.

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