ลักษณะที่เกี่ยวข้องกับศักยภาพในการให้ผลผลิตของถั่วเหลืองอายุสั้น: การแสดงออกและการถ่ายทอด

นางสาว ฐิติพร มะชิโกวา

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรดุษฎีบัณฑิต

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CHARACTERS ASSOCIATED WITH YIELD POTENTIAL OF EARLY MATURING SOYBEANS: EXPRESSION AND INHERITANCE

Miss Thitiporn Machikowa

This Thesis is Submitted in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy in Crop Production Technology

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ถั่วเหลืองอายุสั้นเหมาะสมที่จะใช้ปลูกในระบบการปลูกพืช เนื่องจากสามารถปลูกสลับกับการปลูกข้าว หรือกับพืชไร่ชนิดอื่น ๆ อย่างไรก็ตาม พันธุ์อายุสั้นที่ปรับปรุงขึ้นในประเทศไทย และใช้ส่งเสริมอยู่ในปัจจุบันนี้ให้ผลผลิตต่ำกว่าพันธุ์ที่มีอายุยาว ดังนั้น วัตถุประสงค์ของการทดลองนี้ คือ เพื่อศึกษาลักษณะที่เกี่ยวข้องกับการให้ผลผลิตของถั่วเหลืองที่มีอายุเก็บเกี่ยวต่างกัน และเพื่อพัฒนาพันธุ์อายุสั้นให้มีผลผลิตสูงขึ้น โดยแบ่งเป็นการทดลองย่อย ๆ 5 การทดลอง ในการทดลองแรกเปรียบเทียบถั่วเหลืองที่มีอายุต่างกัน 6 พันธุ์ เมื่อให้ปุ๋ย 2 อัตรา คือ อัตราแนะนำของกรมวิชาการเกษตร และสองเท่าของอัตราแนะนำ การทดลองที่ 2 และ 3 ทำการเปรียบเทียบพันธุ์อายุสั้น อายุปานกลาง และอายุยาว เมื่อปลูกที่ความหนาแน่นต่าง ๆ การทดลองที่ 4 เป็นการผสมกลับเพื่อถ่ายทอดลักษณะจำนวนฝักต่อต้นสูง จากพันธุ์ให้ (LJ4) ไปยังพันธุ์รับ (CM2, NS1, ST2) การทดลองที่ 5 เป็นการทดลองเพื่อขยายเวลาก่อนออกดอกของพันธุ์อายุสั้นให้ยาวขึ้น โดยยังมีอายุเก็บเกี่ยวเท่าเดิม การทดลองนี้ได้ผสมข้ามพันธุ์อายุสั้น และอายุปานกลาง กับพันธุ์อายุยาว แล้วทำการคัดเลือกโดยวิธีคัดหนึ่งเมล็ดต่อต้น ผลการทดลองที่ 1 พบว่าผลผลิตของทุกพันธุ์สูงขึ้น เมื่อให้ปุ๋ยในอัตราสูงกว่า ผลการทดลองที่ 2 และ 3 พบว่าผลผลิตต่อพื้นที่ของพันธุ์ต่าง ๆ เพิ่มขึ้น เมื่อเพิ่มประชากรให้สูงขึ้น และยังพบว่าการให้ผลผลิตสูงเกี่ยวข้องกับการเพิ่มน้ำหนักแห้ง และเพิ่มจำนวนฝักต่อต้น ผลการทดลองที่ 4 พบว่าสายพันธุ์ผสมกลับที่คัดเลือกได้มีแนวโน้มที่จะให้จำนวนฝักต่อต้น และให้ผลผลิตสูงกว่าพันธุ์รับ การทดลองสุดท้ายพบว่าสามารถคัดเลือกโดยวิธีคัดหนึ่งเมล็ดต่อต้นเพื่อให้ได้สายพันธุ์ที่มีอายุก่อนออกดอกยาวขึ้น และมีผลผลิตสูงขึ้นด้วย นอกจากนี้การคัดหนึ่งเมล็ดต่อต้น และคัดเลือกสายพันธุ์ในชั่วหลัง ได้สายพันธุ์ที่ให้ผลผลิตสูงกว่าการคัดเลือกในชั่วต้น และสายพันธุ์เหล่านี้ยังมีลำต้นสูงใหญ่ และให้ผลผลิตสูงกว่า พันธุ์อายุสั้นอีกด้วย

สาขาวิชาเทคโนโลยีการผลิตพืช ลายมือชื่อนักศึกษา...

ปีการศึกษา 2546 ลายมือชื่ออาจารย์ที่ปรึกษา..

THITIPORN MACHIKOWA : CHARACTERS ASSOCIATED WITH YIELD POTENTIAL OF EARLY MATURING SOYBEANS : EXPRESSION AND INHERITANCE

THESIS ADVISOR : PROF. PAISAN LAOSUWAN, Ph. D. 120 PP. ISBN 974-533-297-6.

Early maturing variety of soybean is most suitable to the present crop production system in Thailand, since they can fit well in the productions of rice or certain field crops. However, most early varieties are relatively less productive than late maturing varieties. The objectives of this research were to evaluate characters associated with yield in different maturity types and to develop early varieties with favorable plant characters for higher yield. The first study was to compare six varieties of different maturing groups in two fertilizer rates including the recommended rate and double that of the recommended rate. The second and third studies, early, medium and late varieties were compared at different population densities. The fourth study was to use backcross method to transfer high pods per plant from donor parent (LJ4) to recurrent parents (CM2, NS1, ST2). The last experiment was conducted with the aim to extend the vegetative period without increasing days to maturity by crossing medium and late varieties with early ones. Single seed descent (SSD) selection was employed at the early and late generations. In the first study, it was found that higher fertilizer rate increased seed yield of all varieties. The second and third studies showed that the yield of early varieties was increased with higher population densities. The yield was found to be associated with increased dry matter and pods per plant. The fourth study showed that backcrossed lines tended to produce a higher number of pods per plant and higher yield than their respective recurrent parents. The last study showed that lines with longer vegetative periods and higher yields were successfully selected using early and late SSD. However, selected lines in late generation outyielded selections in early generation. These lines were also taller and gave higher yields than those of the early parents.

School of Crop Production Technology Student’s Signature……………..………..…..

Academic Year 2003 Advisor’s Signature…………..…..………..

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Thitiporn Machikowa

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CHAPTER I

General Introduction

Soybean [*Glycine max* (L.) Merr.] is a major leguminous crop in Thailand. The main production area of soybean in Thailand is in the Northern region such as Chiang Mai, Phetchabun, Sukhothai, Kamphaeng Phet and Tak, in the Northeast region such as Loi and Khon Khaen and in the Central region such as Lop Buri. The total plant area in crop year 2001/2002 was 1,323,858 rai. With this area, the production of 229,098 tons was obtained giving a national average yield of 221 kg/rai (Office of Agricultural Economics, 2002). The role and significance of soybeans have been derived from many factors. Firstly, domestic demand rose from 13,000 tons in 1967 to 1,800,000 tons in 2002 and future expectation signifies a continued upward trend because soybean is a high protein food crop which is used in the preparation of a variety of food products such as soybean curd, fermented bean, soysauce, soymilk and edible oil. Secondly, the last decade expansion of both oil and feed industries accelerated.

However, soybean production is not sufficient for national consumption and the number of planted area is in a decreasing trend due to competition with other crop commodities. The main reason that production of the crop has not expanded is that profitability does not compare favorably with alternative higher value crops. In recent years, the competitiveness of soybean has been further decreased by the impact of imports of cheaper soybean meal on local soybean prices. Furthermore, the production of soybean is adversely affected by many factors such as low genetic potential of current varieties, environmental stresses and poor cultural practices.

The soybean can be grown either before or after rice production. At present, 70% of the area under soybean is confined to rained land (Na Lampang et al, 1993). In the future this type of soybean cultivation is come from the rained areas. Early maturing soybean is very suitable for growing conditions and some crop production system in Thailand. A soybean with a short life cycle (85 days) can fit in a period between rice production and certain other field crops. However, most early varieties released to farmers are relatively less productive than later maturing varieties.

In general, early varieties of soybean flower early, have small plant stature, low leaf area index, low biomass and yield. Plant populations and sowing densities need to be adequate to ensure rapid canopy closure and maximize biomass production. Generally, optimum plant populations for early cultivars are greater and optimum row spacings are narrower than later maturity.

Limits to productivity imposed by short crop duration are common in tropics (Hartwig, 1970). The combination of warm temperatures and short photoperiods stimulate precious flowering of most soybean genotypes before adequate biomass to sustain high yield can be accumulated (Mayers et al, 1991a, b, c). In these conditions, biomass production can be increased if flowering can be delayed. Hartwig (1970) suggested that a minimum number of 45 days from emergence to blooming is required to permit sufficient vegetative growth necessary to produced moderate yield. Delayed flowering has been reported to be associated with higher soybean yield (Dunphy et al., 1979). The extension of days to flowering of current early varieties as well as the development of new varieties with a longer vegetative period may result in higher yielding varieties.

References

Dunphy, E. J., Hanway, J. J., and Green, D. E. (1979). Soybean yields in relation to days between specific developmental stages. **Agron. J.** 71: 917 - 920.

Hartwig, E. E. (1970). Growth and reproductive characteristics of soybean [*Glycine max* (L) Merr.] grown under short-days conditions. **Trop. Sci.** 12: 47 - 53.

Office of Agricultural Economics. (2002). Soybean. **Agricultural Economics News Journal** 48: 55 - 57.

Mayers, J. D., Lawn, R. J., and Byth, D. E. (1991a). Adaptation of soybean (*Glycine max* (L.) Merrill) to the dry season of the tropics I. Genotypic and environmental effects on phenology. **Aust. J. Agric. Res.** 42: 497 - 515.

Mayers, J. D., Lawn, R. J., and Byth, D. E. (1991b). Adaptation of soybean (*Glycine max* (L.) Merrill) to the dry season of the tropics II. Genotypic and environmental effects on biomass and seed yield. **Aust. J. Agric. Res.** 42: 517 - 530.

Mayers, J. D., Lawn, R. J., and Byth, D. E. (1991c). Agronomic studies on soybean (*Glycine max* (L.) Merrill) to the dry season of the tropics I. Limits to yield imposed by phenology. **Aust. J. Agric. Res.** 42: 1075 - 1092.

Na Lampang, A. et al. (1993). Country Report 14 – Thailand. In **Proceedings of the Planning Workshop for the Establishment of the Asian Component of a Global Network on Tropical and Subtropical Soybeans: Soybean in Asia** (128 - 150). Bangkok: RAPA Publication.

CHAPTER II

Characters of Early, Medium and Late Maturing Varieties of Soybean and Their Relationships to Seed Yield

Abstract

Three types of soybean varieties including early, medium and late maturing varieties of soybean are grown in Thailand. A two-season field experiment was conducted (1) to evaluate the performance of early, medium and late maturing soybean and their responses to fertilizer levels and (2) to determine the association between yield with morphological and physiological traits. This experiment was conducted at Suranaree University of Technology, Nakhon Ratchasima, in the dry and late rainy seasons, 2000. Six soybean varieties were chosen to represent early (CM2, NS1), medium (KUSL20004, KKU67) and late maturing varieties (LJ4, KKU35). The fertilizer (12-24-12) was applied in two treatments at the rates of 187.5 and 375 kg ha^{-1}, plus without fertilizer used as the control treatment. A split plot in a randomized complete block design with four replications was used. The results showed that late maturing varieties produced a higher yield, total dry matter (TDM), leaf area index (LAI), crop growth rate (CGR), branches per plant, pods, seeds and nodes per plant than those of medium and early varieties. Fertilizer rates were found to affect most characters in both seasons. Soybean varieties applied with fertilizer at 375 kg ha^{-1} produced a higher yield and other characters than at 187.5 kg ha^{-1} and control. Correlation coefficients between yield with pods per plant, TDM (R5), LAI (R5) and CGR (R5) of the three types of soybean were strong and positive in both seasons. This indicates that yield improvement of soybeans may be possible due to selection based on these characters.

Introduction

Soybean varieties grown in Thailand are of three maturity types including early, medium and late maturing varieties. The number of days from emergence to maturity of these three types, averaged over seasons are about 80, 95 and 110 days (Department of Agriculture, 1994). Choice of variety for Thai farmers depends on growing season and systems of cropping. Early and medium varieties are suitable for sequential cropping either before or after rice and certain other field crops (Kaewmeechai et al., 1997), whereas late maturing varieties are best for full season culture in the late rainy season (Luadthong and Pobboon, 1998). These maturity types differ in certain agronomic, morphological and physiological characters and yield potential (Watson, 1958; Tepjun et al., 1998). In general, early and medium varieties have a smaller plant stature and produce lower yield than late varieties (Srisombun et al., 1997). In addition, the traditional use of this type of soybean has been a sequential crop after some other field crops.

Adequate rates of fertilizer application are important factor for successful production of soybeans. The recommended fertilizer for all soybean varieties in Thailand is 12-24-12 (N, P_2O_5, K_2O) formulation applied at 187.5 kg ha^{-1} (Department of Agriculture, 1994). However, higher seed yield may be obtained by increasing fertilizer rates. Higher fertilizer rates than those recommended have been reported to increase early growth and yield of vegetable soybean (Sitadhani, 1991; AVRDC, 1992; Nguyen Thi Xuan Thu, 1993).

Previous research has shown that seed yield of soybean is associated with yield component traits including pods per plant, seeds per pod and seed size (Board, 1987; Carpenter and Board, 1997), morphological traits such as plant height, total dry matter

(TDM), harvest index (HI) (Parvez et al., 1989; Board et al., 1990; Wells, 1993) and physiological traits such as leaf area index (LAI) (Wells, 1993) and crop growth rate (CGR) (Board and Harville, 1996; Thanomsub et al., 1996; Board et al., 1997). Soybean breeders sometimes use these traits for indirect selection for yield. However, the association between yield and some of these characters is variable. Parvez et al., (1989) reported positive correlations between yield with TDM and LAI for both early (May) and late (July) plantings, but the correlations in the late planted materials were greater. A seasonal difference of association between yield with branch dry matter of soybean was reported by Board and Harville (1996).

The objectives of this study were (1) to evaluate the performance of early, medium and late maturing varieties of soybean and their responses to fertilizer 12-24-12 formulation at different rates and (2) to examine yield components, agronomic and physiological characters of these soybeans and to determine the association between seed yield and these characters.

Materials and Methods

This research was conducted at Suranaree University of Technology Experimental Farm, Nakhon Ratchasima, NE Thailand in the dry (planted on 14 January) and late rainy seasons (planted on 11 September), 2000. The soil type was a Chatturat clay loam (Typic Haplustalts). Laboratory tests indicated: 3.25% OM, 29 ppm P_2O_5, 300 ppm K_2O and pH of 6.4. Six soybean varieties were chosen to represent early, medium and late maturing soybeans. They were two early maturing varieties, Chiangmai 2 (CM2), Nakhonsawan 1 (NS1); two medium varieties, KUSL20004, KKU67 and two late varieties, Long Juvenile 4 (LJ4) and KKU35. A fertilizer formula 12-24-12 (N, P_2O_5 and K_2O) were applied at two treatment rates of 187.5 (F1) and 375 (F2) kg ha^{-1}, respectively, plus a control (without fertilizers, F0) to create three levels of soil fertility.

A split-plot arrangement of treatments in a randomized completed block design with four replications was used. Fertilizer levels were the main plots and varieties were the subplots. Each plots consisted of six rows containing two middle rows was used for yield measurement and character determination. The next two outside rows were used for physiological trait determination. Seeds were planted in rows 5 m long with spacings of 50 cm between rows and 20 cm between hills with 2 plants per hill. Each plot was over-planted and thinned to two plants $hill^{-1}$ 12 days after planting. Weed control was made by application of alachlor. Diseases were suppressed by use of benomyl. Methomyl and acephate were used for insect control. Supplemented overhead sprinkler irrigation was applied periodically in the late rainy and regularly in the dry seasons.

Developmental growth stages were determined using a sample of five plants per plot based on the method proposed by Fehr and Caviness (1977). Physiological traits, leaf area index (LAI), total dry matter (TDM) and crop growth rate (CGR), were measured at V3, V5, R1, R3 and R5 stages. LAI and TDM were determined by taking 0.5 m^2 samples from each variety of soybeans at the same stage of growth from the center rows of each plot. Leaf area was determined using a Li-Cor area meter (LI-3100) leaf area meter.

1. Leaf area index was calculated as follow:

$$LAI = \frac{L_A}{AG}$$

where L_A is leaf area and AG = ground area which supports leaf area.

2. Plant samples used to determine LAI were separated into leaf and shoot (stem, pod and seed) fractions and then dried in a forced air dryer at 60 °C for 48 hrs to determine to total dry matter (TDM). TDM was the sum of all plant parts above ground.

3. Crop growth rate was calculated from total dry matter accumulation as:

$$CGR = \frac{1}{AG} \times \frac{(W_2 - W_1)}{(T_2 - T_1)}$$

where W_2 and W_1 are the total dry weight at time T_2 and T_1, AG = ground area which supports leaf area (Hunt, 1978).

4. Yield was measured by harvesting two-center rows (4.8 m^2) of each plot at maturity and converted as:

$$\text{Seed yield}\,(\text{kg ha}^{-1}) = \frac{\text{Yield/plot (g)}}{1{,}000\text{ g}} \times \frac{10{,}000\text{ m}^2}{\text{Harvested area}} \times \frac{100 - 12}{100 - \text{moisture (\%)}}$$

5. Harvest index (HI) was the ratio of seed yield to total above ground biomass at harvest.

6. Seed size was estimated by counting and weighing a 100 seed sample randomly taken from the sample collected for yield.
7. Plant height was measured from the cotyledonary node to the tip of plant.
8. Branches per plant was counted on ten randomly selected plants in each plot.
9. Nodes per plant was counted on ten randomly selected plants in each plot.
10. Pods per plant was counted on ten randomly selected plants in each plot.
11. Seeds per plant was counted on ten randomly selected plants in each plot.

Analysis of variance was performed on the data with the SAS General Linear Models procedure (SAS Institute, 1985). Varieties and fertilizer rates were considered random effects since they were representing mature types and rates of fertilizer.

Results and Discussion

Growth period

Lengths of growth periods in number of days from planting to flowering and to maturity for early, medium and late maturing varieties were statistically different and in ascending order, with the early being the shortest in length and the late the longest (Table 1). In the dry season, each type of soybean variety tended to flower and mature earlier than in the late rainy season. Daylength in mid January is about 30 minutes shorter than in mid September (Table 1, Uthaida, 1999). Because soybean is photoperiod sensitive, it is likely that this difference affected both days to flowering and days to maturity.

Characters of soybean varieties

Differences between seasons and among varieties were significant for all characters measured (Table 2). Fertilizer rates affected all characters except nodes per plant and plant height. Seed yield, TDM, yield components and nodes per plants of early were lower than medium and late varieties (Table 3). Therefore, these characters were closely related to maturity and length of the reproductive period. Averaged across fertilizer levels, KKU35 gave the highest seed yield of 2,576 kg ha^{-1}. This variety was developed as a late maturing variety for full season culture (Luadthong and Pobboon, 1998). On the other hand, early varieties, NS1 and CM2 gave the lowest seed yield which was associated with small plant stature, low TDM and reduced branching.

Positive yield responses were obtained as fertilizer levels increased (Table 4). The means of soybean yield increased as the fertilizer increased from 0 to 187.5 to 375 kg ha^{-1}. All soybean varieties tended to give the highest of seed yield at 375 kg ha^{-1} fertilizer level. However, the rate of increase in yield due to increasing fertilizer from 0 to 187 kg ha^{-1}was higher than that from 187.5 to 375 kg ha^{-1}. The increasing rates of seed yields from 187.5 to 375 kg ha^{-1} were 6.33, 2.80 and 3.52 % for early, medium and late varieties, respectively (Table 4). These increasing rates were not high enough to offset additional fertilizer costs. It can be concluded from this study that more profitable production of soybean varieties can be achieved at a 187.5 kg ha^{-1} fertilizer for Thailand environments.

Leaf area index (LAI), total dry matter (TDM) and crop growth rate (CGR)

Varieties of soybean were different in LAI, TDM and CGR (Table 5). These characters fell into three distinct groups according to maturity types (Fig. 1, 2, 3 and 4). LAI, TDM and CGR of early were lower than medium and late varieties. Fertilizer levels significantly affected these characters (Table 5) which increased as the level of fertilizer increased. This was especially true for LAI and TDM. The differences in LAI and TDM of soybean varieties for all fertilizer levels were obvious at the late stages of growth (Fig. 1 and 2). These indicated the differences in yield potential of each type of soybean. Soybean variety CM2 gave the lowest LAI and TDM at all stages of growth and fertilizer level.

Association between seed yield and other characters of soybeans

Correlation coefficients between seed yield and all characters that might be related to yielding potential of different types of soybean are shown in Table 6. Among the two primary yield component traits of soybean, namely pods per plant and seed size, pods per plant exhibited strong correlation with seed yield for all types of soybean across fertilizer rates and seasons. On the other hand, the correlations between yield and seed size were found variable from as low as r = -0.29^{ns} for medium varieties at F1 to 0.86** for late varieties at the highest fertilizer level. In an extensive review by

Poelhman (1991) he found that both phenotypic and genotypic correlations between seed yield and pods per plant in mungbean were high over a wide range of genetic materials and environments. On the other hand, correlation between seed yield and seed size of the crop ranged from significantly negative to positive. The associations between yield and seed size were variable and more than 70% of the cases were not significant. It could not be concluded in this study that seed size can be used for indirect selection for yield. The correlation between seed yield and branches per plant were high and significant 50% of the cases. The application of these characters for indirect selection for yield may be successful, especially for branching types of soybean.

Among three physiological characters measured at R5 including TDM, LAI and CGR. TDM was strongly correlated with seed yield. This association was significant for all types of varieties in both late rainy and dry seasons and all fertilizer levels. LAI and CGR were also found correlated with seed yield of soybean. In the USA, Board et al. (1990) has shown also that TDM was strongly correlated with seed yield of soybean. Other studies also reported significant correlations between seed yield and TDM, LAI and CGR (Board and Harville, 1996; Board et al., 1996; Board et al., 1997), and between seed yield and pods per plant (Molhotra et al., 1972).

Conclusion

Many traits such as yielding potential, days to flowering, days to maturity, TDM, yield components, agronomic and physiological traits of early maturing varieties of soybean were lower than those of medium and late maturing varieties. Means for seed yield increased as the fertilizer rates increased from 0 to 187.5 to 375 kg ha^{-1}. All soybean varieties tended to give the highest seed yield at 375 kg ha^{-1} fertilizer level. However, the rate of increase in yield due to increasing fertilizer rate from 0 to 187 kg $ha^{-1}$was higher than that from 187.5 to 375 kg ha^{-1}. Yield of soybean was found to be significantly correlated with many characters, particularly pods per plant, TDM and LAI. The data indicated that high yielding plants tended to have a high number of pods per plant, high TDM and LAI. Thus, yield improvement in the future could be made by increasing these characters.

Table 1. Means for days to flowering and to maturity observed in two seasons for early, medium and late maturing varieties of soybean.

Group	Variety	Dry season (14 Jan)		Late rainy season (11 Sep)	
		Days to flowering	Days to maturity	Days to flowering	Days to maturity
		no.			
Early	NS1	27 c[†]	79 d	30 c	80 d
	CM2	27 c	78 d	29 c	80 d
Medium	KUSL20004	29 bc	85 c	33 bc	89 c
	KKU67	29 bc	86 c	35 bc	88 c
Late	LJ4	43 a	115 a	44 a	120 a
	KKU35	34 b	104 b	38 b	109 b

[†]Means within a column followed by the same letter are not significantly different at $P < 0.05$ according to DMRT.

Table 2. Results from F-tests of significances of mean squares obtained from analyses of variance.

Source of Variation	df †	Yield	Seed size	Pods plant^{-1}	Seeds plant^{-1}	Branches plant^{-1}	Nodes plant^{-1}	TDM‡	Plant weight	HI+	Plant height
Seasons (S)	1	**	**	**	**	**	**	**	**	**	**
Fertilizers (F)	2	**	*	**	**	**	ns	*	*	**	ns
Varieties (V)	5	**	**	**	**	**	**	**	**	**	**
S x F	2	**	*	ns	ns	ns	*	*	*	**	ns
S x V	5	*	**	**	**	**	**	**	**	**	**
F x V	10	ns	ns	ns	ns	*	ns	ns	**	*	ns
S x F x V	10	ns	*	ns	ns	ns	*	ns	ns	ns	ns
CV (%)		10.4	4.9	15.2	16.0	14.0	5.6	12.1	17.9	5.6	10.4

† Degree of freedom.

‡ Total dry matter.

+ Harvest index.

*, ** Significant at 0.05 and 0.01 levels of probability, respectively; ns = not significant.

Table 3. Yield and agronomic traits for six soybean varieties across three fertilizer levels.

Variety	Yield	Seed size	TDM	HI	Branches	Pods	Seeds	Nodes
					plant^{-1}			
	kg ha^{-1}	g 100 seeds^{-1}	kg ha^{-1}		no.			
NS1	1,778 d†	19.75 a	3,437 d	0.54 ab	3.3 c	32 c	61 c	10 d
CM2	1,850 d	13.89 d	3,380 d	0.56 a	3.5 bc	37 bc	67 c	10 d
KUSL20004	2,197 b	15.22 c	4,263 c	0.52 b	3.5 bc	42 b	93 b	13 c
KKU67	2,117 c	15.70 c	4,159 c	0.52 b	3.8 b	38 bc	76 c	13 c
LJ4	2,240 b	15.93 c	5,655 a	0.41 c	3.7 b	45 ab	92 b	21 a
KKU35	2,576 a	16.90 b	5,277 b	0.51 b	4.4 a	53 a	113 a	18 b

†Means within a column followed by the same letter are not significantly different at $P < 0.05$ according to DMRT.

Table 4. Yield for six soybean varieties applied with three fertilizer levels across two seasons.

Variety	Yield		
	F0‡	F1	F2
	kg ha^{-1}		
NS1	1,724 b†	1,756 b	1,855 a
CM2	1,768 c	1,827 ab	1,955 a
KUSL20004	2,026 b	2,236 a	2,329 a
KKU67	2,016 b	2,153 a	2,183 a
LJ4	2,043 b	2,301 a	2,377 a
KKU35	2,395 b	2,618 a	2,715 a
Mean	1,995	2,149	2,236

†Means within a row followed by the same letter are not significantly different at $P < 0.05$ according to DMRT.

‡ F0 = no fertilizer applied; F1 = fertilizer treatment (12-24-12) applied at 187.5 kg ha^{-1}; F2 = fertilizer (12-24-12) applied at 375 kg ha^{-1}.

Table 5. Results from F-tests of the significance of mean squares obtained from analyses of variance for physiological characters in the late rainy season.

Source of Variation	df	TDM (R5)	CGR (R5)	LAI (R5)
Fertilizers (F)	2	*	*	**
Varieties (V)	5	**	*	**
F x V	10	ns	ns	*
CV (%)	10	12.1	12.7	16.0

*, ** Significant at 0.05 and 0.01 levels of probability, respectively; ns = not significant.

Table 6. Phenotypic correlation coefficients of yield with other characters of three groups of soybean varieties grown applied with three levels of fertilizer in the dry and late rainy seasons.

Group	Character	Late rainy season			Dry season		
		F0	F1	F2	F0	F1	F2
Early	Nodes plant^{-1}	0.34	-0.03	0.03	0.14	0.63*	-0.06
	Branches plant^{-1}	0.18	0.10	0.85**	0.55*	0.63*	0.63*
	Pods plant^{-1}	0.71**	0.88**	0.66*	0.72**	0.74**	0.82**
	Seed size	0.32	-0.06	0.68*	-0.05	-0.02	-0.17
	TDM (R5)	0.82**	0.86**	0.49	0.79**	0.84**	0.88**
	LAI (R5)	0.62*	0.72**	0.87**	na	0.87**	na
	CGR (R5)	0.56*	0.64*	0.62*	na	0.76**	na
Medium	Nodes plant^{-1}	-0.50	0.04	0.42	0.44	0.67*	-0.05
	Branches plant^{-1}	0.68*	-0.39	0.39	0.19	0.66*	-0.40
	Pods plant^{-1}	0.72**	0.69*	0.75**	0.83**	0.74**	0.96**
	Seed size	0.09	0.13	0.19	0.43	-0.29	0.71**
	TDM (R5)	0.81**	0.89**	0.96**	0.95**	0.77**	0.91**
	LAI (R5)	0.72**	0.86**	0.88**	na	0.88**	na
	CGR (R5)	0.35	0.67*	0.72**	na	0.64*	na
Late	Nodes plant^{-1}	0.48	-0.39	0.63*	0.02	0.72**	0.38
	Branches plant^{-1}	-0.40	0.09	0.69*	0.71**	0.77**	0.39
	Pods plant^{-1}	0.73**	0.76**	0.96**	0.88**	0.74**	0.86**
	Seed size	0.66*	0.12	0.12	0.18	0.56	0.86**
	TDM (R5)	0.87**	0.81**	0.65*	0.57*	0.92**	0.90**
	LAI (R5)	0.42	0.83**	0.72**	na	0.80**	na
	CGR (R5)	0.73**	0.58*	0.63*	na	0.81**	na

*, ** Significant at the 0.05 and 0.01 probability level, respectively; na = not available.

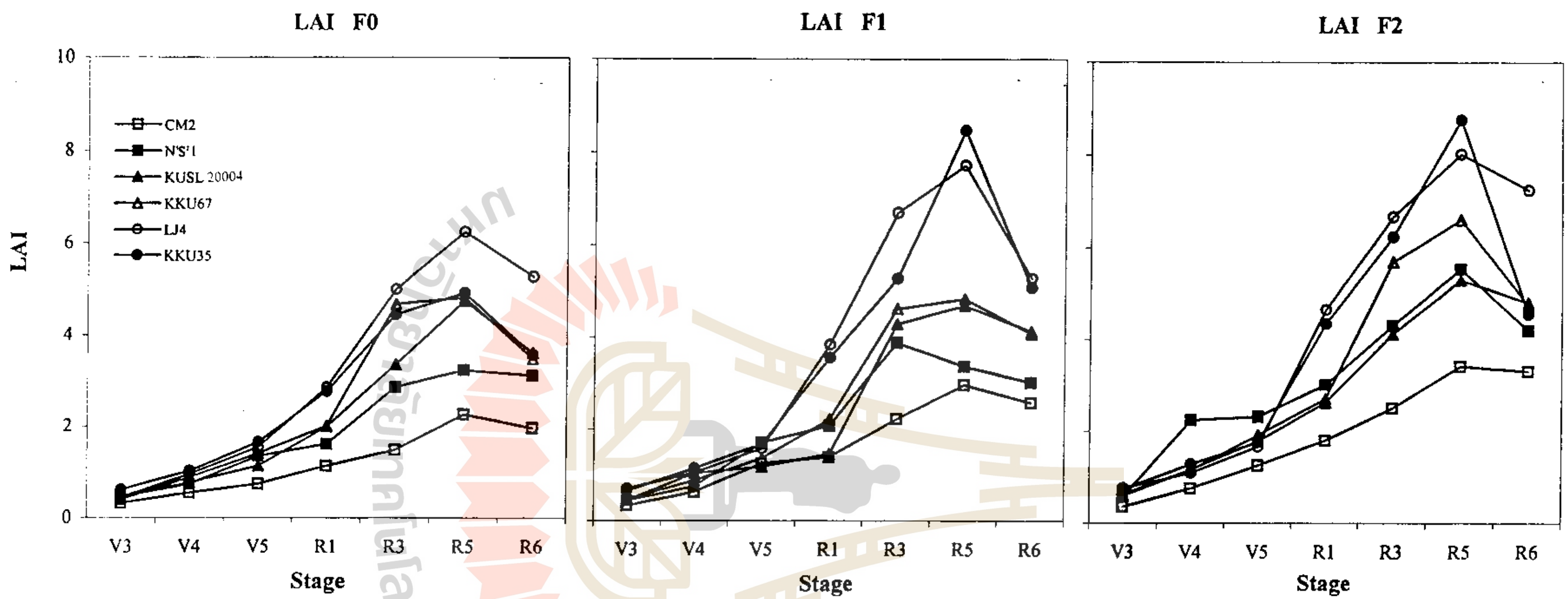


Fig. 1. Leaf area index (LAI) of six soybean varieties applied with three fertilizer rates in the late rainy season.

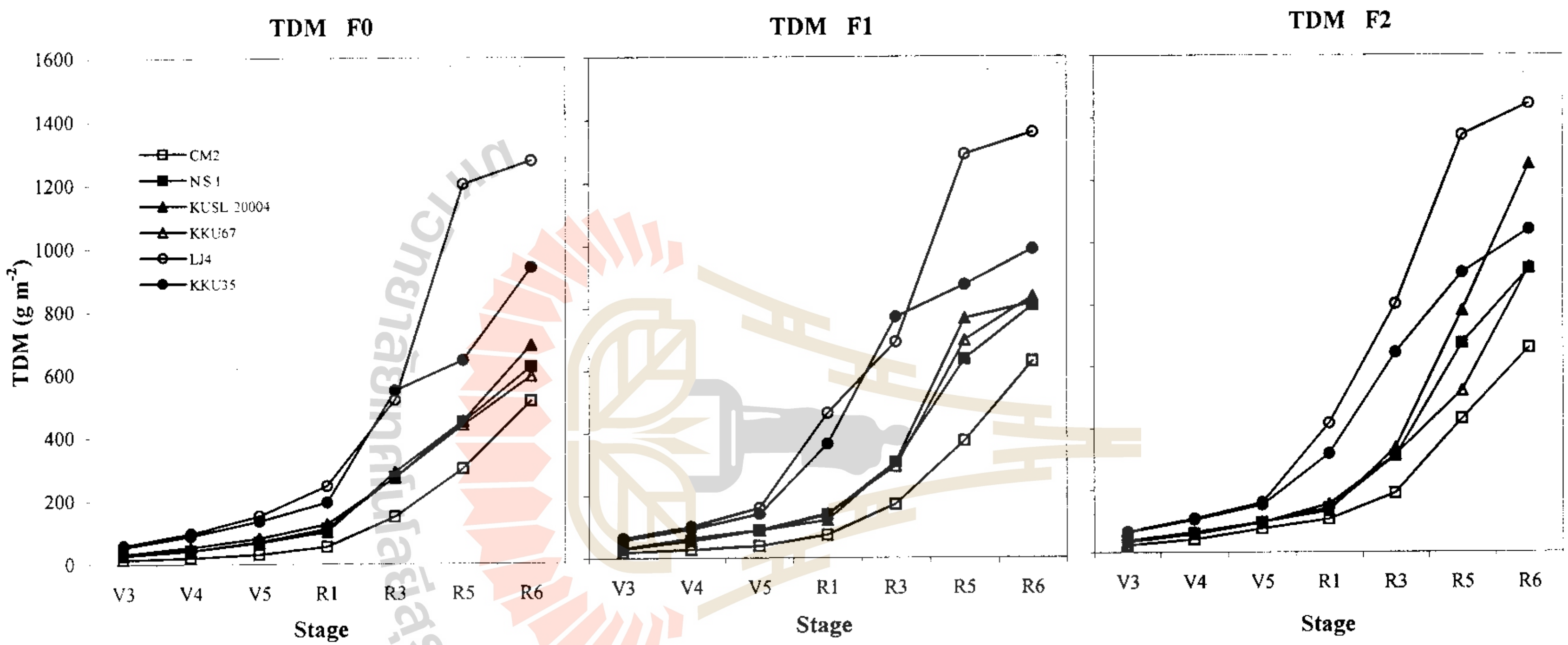


Fig. 2. Total dry matter (TDM) of six soybean varieties applied with three fertilizer rates in the late rainy season.

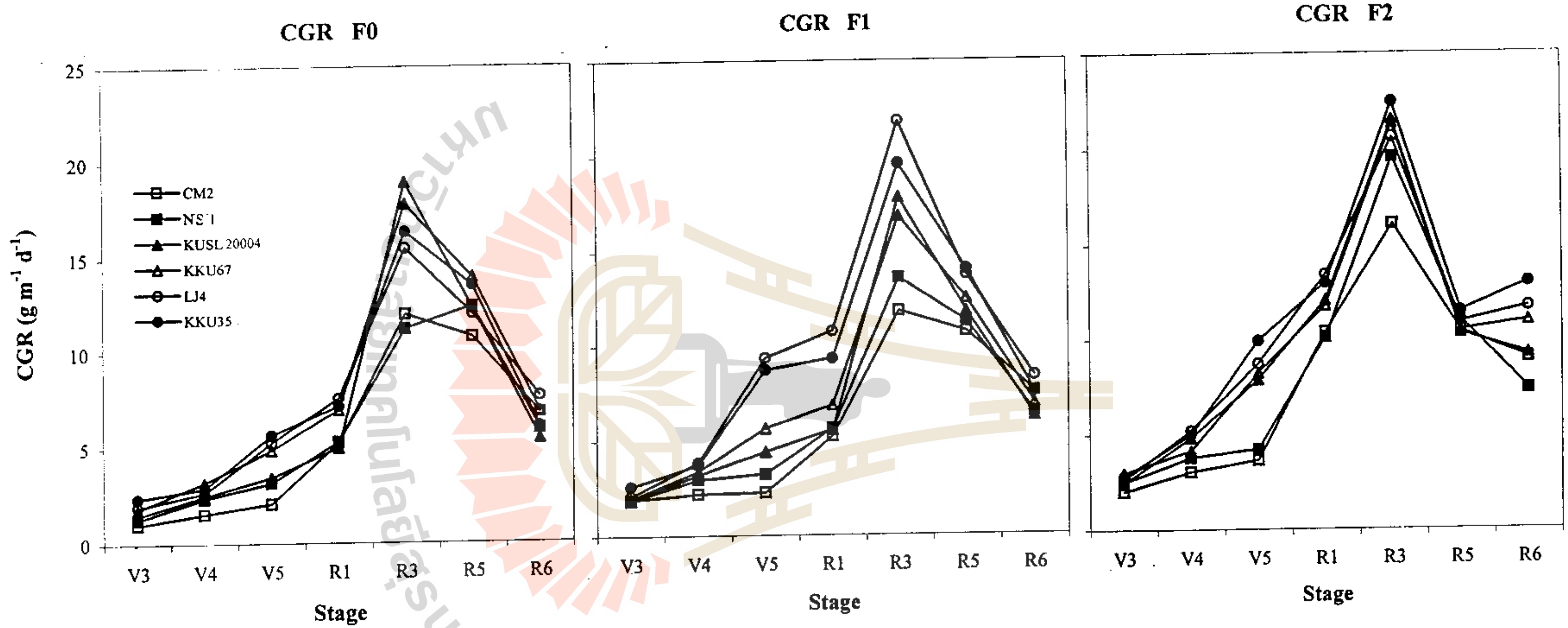
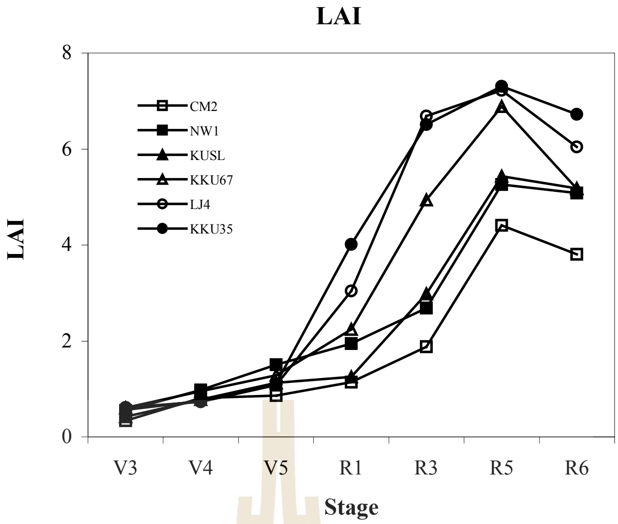
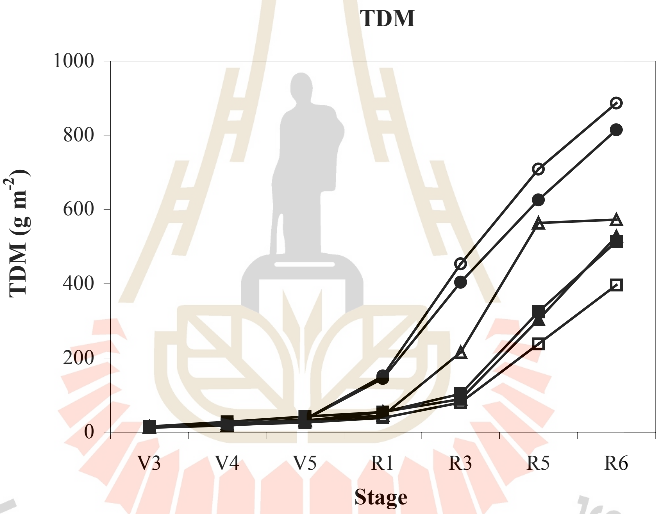
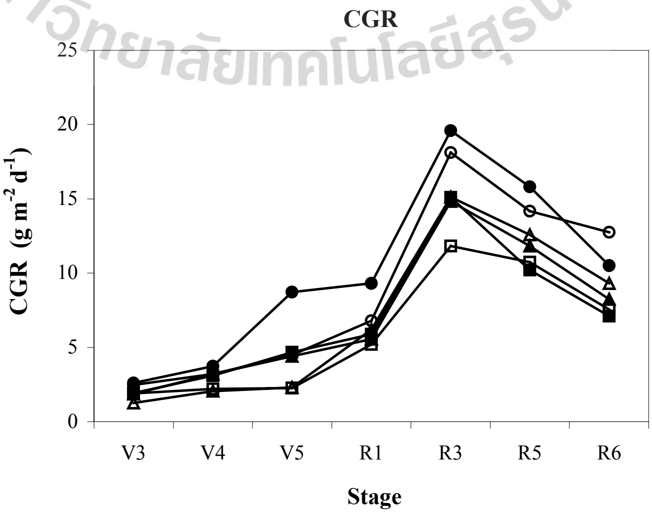


Fig. 3. Crop growth rate (CGR) of six soybean varieties applied with three fertilizer rates in the late rainy season.


LAI
8
6
4
2
0
LAI
CM2
NW1
KUSL
KKU67
LJ4
KKU35
V3
V4
V5
R1
R3
R5
R6
Stage


TDM
1000
800
600
400
200
0
TDM (g m-2)
V3
V4
V5
R1
R3
R5
R6
Stage


CGR
25
20
15
10
5
0
CGR (g m-2 d-1)
V3
V4
V5
R1
R3
R5
R6
Stage

References

AVRDC. (1992). Vegetable soybean production. In **Proceedings of a Training Course** (pp. 51 - 58). Bangkok: Asian Vegetable Research and Development Center.

Board, J. E. (1987). Yield components related to seed yield in determinate soybean. **Crop Sci.** 27: 1296 - 1297.

Board, J. E., and Harville, B. G. (1996). Growth dynamics during the vegetative period affects yield of narrow-row, late-planted soybean. **Agron. J.** 88: 567 - 572.

Board, J. E., Harville, B. G., and Saxton, A. M. (1990). Narrow-row seed yield enhancement in determinate soybean. **Agron. J.** 82: 64 - 68.

Board, J. E., Zhang, W., and Harville, B. G. (1996). Yield rankings for soybean cultivars grown in narrow and with late planting dates. **Agron. J.** 88: 240 - 245.

Board, J. E., Kang, M. S., and Harville, B. G. (1997). Path analyses identify indirect selection criteria for yield of late-planted soybean. **Crop Sci.** 37: 879 - 884.

Carpenter, A. C., and Board, J. E. (1997). Branch yield components controlling soybean yield stability across plant population. **Crop Sci.** 37: 885 - 891.

Department of Agriculture. (1994). **Field crop production.** Bangkok: Kurutsapa Ladpraow (in thai).

Fehr, W. R., and Caviness, C. E. (1977). **Stages of soybean development.** Iowa State Univ. Coop. Ext. Serv. Spec. Rep.

Hunt, R. (1978). **Plant growth analysis.** London: Edward Arnold.

Kaewmeechai, S., Sithipong, S., Srisombun, S., Pichitporn, S., Tumsan, S., Dangpradub, S., and Supapornhemin, P. (1997). Early maturity soybean: Line CM 8728-B-2. In **Proceedings National Soybean Research Conference VI** (pp. 23 - 25). Bangkok: Kasetsart University Press.

Luadthong, S., and Pobboon, T. (1998). Soybean medium and late maturity varietal development. In **Proceedings National Soybean Research Conference VII** (pp. 127 - 135). Bangkok: Sukhothai Thammathirat University.

Molhotra, R. S., Singh, K. B., and Dhaliwal, H. S. (1972). Correlation and path-coefficient analyses in soybean (*Glycine max* (L) Merr.). **Indian J. Agric. Sci.** 42: 26 - 29.

Nguyen Thi Xuan Thu. (1993). **AVRDC -TOP. 11 th Training Report 1993**. AVRDC, Bangkok: Kasetsart University.

Parvez, A. Q., Gardner, F. P., and Boote, K. J. (1989). Determinate and indeterminate type soybean cultivar responses to pattern, density and planting date. **Crop Sci.** 29: 150 - 157.

Poehlman, J. M. (1991). **The mungbean.** New Delhi: Oxford & IBH Publishing.

SAS Institute, Inc. (1985). **SAS user's guide: Statistics**, version 5 ed. Cary, NC. SAS Institute, Inc.

Sitadhani, K. (1991). Cultivation practices for vegetable soybean. In **Vegetable Soybean Production: Proceedings of Training Course** (pp. 19 - 21). Chiang Mai: Thailand.

Srisombun, S., Pookpakdi, A., Korntong, A., Nakiracks, P., Sirichumphan, V., Laohasiriwong, S., Wajananawat, W., Potan, N., Senanarong, N., and Benjasil, V. (1997). The potential productivity of late maturity varieties of soybeans in Thailand. In **Proceedings National Soybean Research Conference VI** (pp. 36 - 42). Bangkok: Kasetsart University Press.

Thanomsub, W., Boonpradub, S., Promkum, S., Watanasit, A., Pichitporn, S., and Maolanont, T. (1997). Effects of irrigation during different growing periods on three soybean cultivars in silty clay loam (Ratchaburi Series) soil. In **Proceedings**

National Soybean Research Conference VI (pp. 127 - 139). Bangkok: Kasetsart University Press.

Tepjun, V., Kaewmeechai, S., and Cooper, M. (1998). Intergrating physiological understanding and plant breeding for soybean improvement programs. In **Proceedings National Soybean Research Conference VII** (pp. 46 - 55). Bangkok: Sukhothai Thammathirat.

Utaida, N. (1999). **Effects of planting dates on different characters of soybean varieties and lines.** M.S. Thesis, Suranaree University of Technology.

Watson, D. J. (1958). The dependence of net assimilation rate on leaf area index. **Ann. Bot.** 22: 37 - 54.

Wells, R. (1993). Dynamics of soybean growth in variable planting patterns. **Agron. J.** 85: 44 - 48.

CHAPTER III

Effects of Population Densities on Yield and other Characters of Different Types of Soybean

Abstract

The yield of early maturing varieties of soybean [*Glycine max* (L.) Merr.] when planted in the same population densities is lower than those of medium and late maturing varieties. The objective of this research was to study the response of early, medium and late varieties of soybean to increase population densities. The study was conducted at Nakhon Ratchasima (16°N Lat) in the dry season (January) and in the late rainy season (September) planting dates using cultivars Chiangmai 2 (CM2, early variety), KKU67 (medium variety) and KKU35 (late variety). The normal DOA prescribed 50-cm spacing between rows was used with different within-row spacings which resulted in population densities of 100,000, 200,000, 300,000 and 400,000 plants ha^{-1}. Experimental design used in the study was a split plot with four replications. Varieties of soybean were in the main plots, and plant population densities were in the subplots. The results showed that increased population densities increased seed yield and affected pods per plant, seeds per plants, branches per plant, total dry matter, plant weight and plant height. However, seed size and nodes per plant were not affected by changing population densities. With high population densities, the difference in increased yield between early and medium varieties was lower than with low population densities indicating that optimal population densities for the early variety were higher than that for the medium and late varieties.

Introduction

In Thailand, the soybean [*Glycine max* (L.) Merr.] crop is usually grown for the extraction of oil and production of meal for animal feed. It is also known among farmers that soybean is a soil improving crop due to nitrogen fixation by the symbiotic bacteria *Bradyrhizobium japonicum*. Today, the crop is grown mainly in the Northern and Northeastern part of the country in different systems of cropping in three seasons including the early rainy season, the late rainy season and in irrigated areas in the dry season. In 2001, about 234,000 ha were grown with the crop giving grain yields of 319,015 tons. However, production is not sufficient for national consumption and the number of hectares being produced is in a decreasing trend due to competition with other crop commodities. The traditional system for soybean production has been as a sequential crop after rice, corn and other field crops. Soybean varieties grown in these systems are of three types: early, medium and late varieties. The early variety is probably most suitable for all the present production systems, but the yield is relatively low due to low genetic yielding potential. However, the application of optimal plant population (optimal population for highest seed yield) may ameliorate the problem.

The application of adequate population densities is necessary to obtain the highest yield for each type of soybean. Many studies have shown that the population densities of soybean should vary in the range of 70,000 - 500,000 plants ha^{-1} depending on environmental and genetic factors. These varied plant densities results in differences in growth, lodging, leaf area index, seed yield and yield components (Shibles and Weber, 1966; Costa et al., 1980; Herbert and Litchfield, 1982; Board and Harville, 1996; Carpenter and Board, 1997a). However, these studies were conducted in temperate climates, with growing seasons of about 150 days. Similar results were found in tropical climates using plant densities of 100,000 - 600,000 plants ha^{-1} (Piramarn and Boonklinkajorn, 1974; Siripin, 1998; Sutakom, 1998). Furthermore, it has been found further that varied inter-row spacings produced a larger effect on yield than varied intra-row spacings (Costa et al., 1980).

In Thailand, the usual planting rate is 200,000 plants ha^{-1} and practical inter-row spacing for soybean has been fixed at 50 cm (Department of Agriculture (DOA), 1994). However, variation in plant densities is still possible by changing intra-row spacings. Carpenter and Board (1997b) showed that increasing plant population 234% by reducing intra-row spacing resulted in only a 9% yield increase. However, this experiment was done with a late variety which had a large plant stature and in a temperate climate with a long growing season. In tropical climates, early varieties may show a greater yield response to reduced intra-row spacings. The objective of this study was to determine the responses of early, medium and late varieties in varied population densities resulting from varying intra-row spacings. Each type of soybean may require a different plant density for optimal and economic yields.

Materials and Methods

Studies were conducted at Suranaree University of Technology experimental farm, Nakhon Ratchasima, Northeast Thailand (16°N Lat) on Chatturat clay loam (Typic Haplustalts) in two seasons, one in the dry season (planted on 20 January) and the other in the late rainy season (planted on 18 September). Three soybean varieties representing three types including Chiangmai 2 (CM2, early variety), line KKU67 (medium variety) and KKU35 (late variety) were tested in four population densities. The descriptions of these varieties are given in Table 1. The population densities were created by varying spacings between hills and the number of plants hill^{-1}: 50 x 20 (1) cm (between rows and between hills in cm with 1 plant hill^{-1}), 50 x 20 (2) cm, 50 x 20 (3) cm and 50 x 10 (2) cm. These resulted in the respective populations of 100,000; 200,000; 300,000 and 400,000 plants ha^{-1}. The experiment was conducted in a split-plot design with four replications. Soybean varieties were the main plots and population densities were the subplots. The recommended fertilizer 12-24-12 (N, P_2O_5, K_2O) was applied during seedbed preparation at the rate of 187.5 kg ha^{-1}. Each subplot consisted of four rows 5-m long and spaced 50-cm apart. During planting soybean seeds were inoculated with bacteria *Bradyrhizobium japonicum* planted in hills 3 - 5 seeds per hill and thinned to the final stands at 12 days after planting. Weed control was made by application of alachlor. Diseases were suppressed by use of benomyl. Methomyl and acephate were used for insect control. Supplemented overhead sprinkler irrigation was applied periodically in the late rainy and regularly in the dry seasons.

Data measurements were made in the two-center rows for plant height, grain yield and seed size. Ten plants in each plot were sampled as representative plants for measurement of the number of pods, seeds, branches and nodes per plant. The plants were oven-dried to measure plant weight, which was subsequently used for determining total dry matter (TDM).

1. Days to flowering were recorded as the number of days from planting to first bloom.
2. Days to maturity were recorded as the number of days from planting to 95% pods turned brown.
3. Yield measurement in kg ha^{-1} was calculated at 12% moisture as follows:

$$\text{Seed yield}\,(\text{kg ha}^{-1}) = \frac{\text{Yield/plot (g)}}{1{,}000\,\text{g}} \times \frac{10{,}000\,\text{m}^2}{\text{Harvested area}} \times \frac{100-12}{100-\text{moisture (\%)}}$$

4. Plant weight was measured as the total dry weight of the above ground parts of the plant.
5. Total dry matter (TDM) was measured as the sum of dry weight of all plant parts above ground.
6. Seed size was measured as the weight of 100 seeds randomly sampled from whole seed in each plot.
7. Branches per plant, nodes per plant, pods per plant and seeds per plant were counted on ten randomly selected plants in each plot.
8. Plant height was measured from the cotyledonary node to the tip of plant.

For each experiment, analyses of variance were performed using PROC GLM (SAS Institute, 1985). Varieties and populations were considered random effects since they were representing matured types and ranges of populations. The data were analysed in a split-split plot model to identify the combined effect of the two seasons.

Results and Discussion

The combined analyses of variance showed that seasons (S), varieties (V) and populations (P) affected yield and almost all other characters. Varieties differed in yield potential and interacted with seasons but not with populations. This indicated that soybean varieties and plant populations were suitable for particular seasons for the characters under study. Because the variety by season interaction was significant for all traits, the results for each season are presented separately. Soybean varieties were significantly different in yield, yield components and other characters both in the dry and late rainy seasons (Tables 2 and 3). In both seasons, population densities also produced significant differences in all characters except seed size and nodes per plant. However, for each season no variety x population density interaction was significant for any character indicating that these soybean varieties showed similar response to increased populations in both seasons.

Mean yields of early (CM2), medium (KKU67) and late varieties (KKU35), averaged over four population densities, were in ascending order, that is, the longer a variety grew the higher the seed yield. The early variety (CM2) was characterized by having small plant stature and low yield components (Tables 4 and 5). This resulted in a low yield potential. Similarly, other characters including pods per plant, seeds per plant, nodes per plant, total dry matter (TDM), plant dry weight and plant height were significantly different and ranked in the same order. CM2 gave the lowest yield in both tests due to the smaller plant stature and earlier maturity.

Effect of population density on yield

In both seasons, the mean soybean yields increased in ascending order as the population densities increased from 100,000 to 200,000, 300,000 and 400,000 plants ha^{-1}

(Tables 4 and 5). However, the rate of increase in yield was lower than the rate of increase in population density. Averaged over all varieties, a 300% population increase from 100,000 to 400,000 plants ha^{-1} resulted in a yield increase of 28% in the dry season and 36% in the late rainy season. The increase in yield due to the increase of population from 200,000 to 400,000 plants ha^{-1} in this experiment was 3 to 4 times larger than the yield increase observed by Carpenter and Board (1997b) when they increased within row density. Increases in seed yield in high populations were probably due to increases in crop canopy area, which gave more efficient light interception (Shibles and Weber, 1966). Seed yield of soybean has been shown to be highly correlated with TDM (Parvez et al., 1989; Board et al., 1996).

The recommended spacing for all soybean varieties in Thailand is 50 cm between rows and 20 cm between hills with 2 plants per hill or equivalent to 200,000 plants ha^{-1} (Department of Agriculture, 1994). In this study, the increase of yield from 1,635 to 1,823 kg ha^{-1} (11.50%) for the dry season and from 2,174 to 2,534 kg ha^{-1} (16.55%) due to the increase of population from 200,000 to 400,000 plants ha^{-1} were quite satisfactory (Tables 4 and 5). This increase was even greater for the early variety, 30.6% for the dry and 21.4% for the late rainy season (Table 6). This increase in yield was high enough to offset additional seed costs, especially for early varieties of soybean. A linear relationship was found between yield and population densities for all varieties in both seasons (Fig. 1). The regression coefficients for yield on population densities of CM2 for dry and late rainy seasons were 215.7 and 256.7 kg ha^{-1}/100,000 plants ha^{-1}, respectively, which were higher than those of medium and late varieties. This indicates the higher rate of increase of seed yield in response to population densities of early maturing variety.

Effect of population densities on other characters

Branches per plant, pods per plant, seeds per plant and TDM of all varieties significantly decreased with the increase in population densities (Tables 4 and 5). Increased population density was also found by Carpenter and Board (1997a) to reduce pods per plant. In this study we found that the decrease of two yield components as density increased viz. pods and seeds per plant was slower for the early variety than for the late. For example, in the dry season, the increase in plant populations from 100,000 to 400,000 plants ha^{-1} for CM2 decreased pods per plant by 43.36% whereas with KKU35 pods per plant decreased 61.58%. This was due to the competition between plants. A similar pattern was found for seeds per plant. However, the effect of population densities only slightly affected seed size. Therefore, increasing plant density was an effective means for increasing the seed yield of the early variety of soybean.

Conclusion

In conclusion, with fixed row spacing, population densities obtained from increased plants within rows resulted in an increased yield of early, medium and late varieties of soybean. In the dry season, the increase in yield of the early variety was greater than those of the medium and late varieties. However, the differences of increase due to increased population among varieties in the late rainy season were slight. This yield increase of all varieties was due to a lower rate of decrease in yield components as the population density increased. The results also showed that the optimal population densities may be higher than those used in this study, especially for the early variety. Furthermore, the yield potential of the early variety of soybean might be increased by manipulating plant densities both between and within row spacings. Soybean is grown in Thailand between 16˚ to 20˚ N latitudes. Growing seasons are typically between 90 - 120 days with both late rainy and dry seasons. Therefore, these results may apply to other regions at similar latitudes and growing conditions.

Table 1. Descriptions of three soybean varieties used in this study.

Variety	Days to flowering	Days to maturity	Plant height	Seed size	Reference
	.... no.		cm	g 100 seeds^{-1}	
CM2	29	79	40	15.47	Uthaida and Laosuwan, 2001
KKU67	36	85	65	15.25	Laosuwan et al., 1997
KKU35	38	110	85	16.71	Laosuwan et al., 1997

Table 2. Results from F-tests of the significance of mean squares obtained from combined analyses of variance.

Source of Variation	df	Yield	Seed size	Pods plant^{-1}	Seeds plant^{-1}	Branches plant^{-1}	Nodes plant^{-1}	Total dry matter	Plant weight	Days to flowering	Days to maturity	Plant height
Seasons (S)	1	**	**	**	**	**	*	**	**	**	**	**
Varieties (V)	2	**	**	**	**	**	**	**	**	**	**	**
S x V	2	**	**	*	*	**	*	**	**	ns	ns	**
Populations (P)	3	**	**	**	**	**	ns	**	**	ns	ns	**
V x P	6	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
S x P	3	ns	ns	**	**	*	ns	*	*	ns	ns	ns
CV (%)		12.3	5.7	17.7	16.0	16.4	11.7	10.2	11.4	5.5	6.1	9.0

*, ** Significant at 0.05 and 0.01 levels of probability, respectively; ns = not significant.

Table 3. Results from F-tests of the significance of mean squares obtained from analyses of variance.

Source of Variation	df	Yield	Seed size	Pods plant^{-1}	Seeds plant^{-1}	Branches plant^{-1}	Nodes plant^{-1}	Total dry matter	Plant weight	Days to flowering	Days to maturity	Plant height
							Dry season					
Varieties (V)	2	**	**	**	**	*	**	**	**	**	**	**
Populations (P)	3	**	ns	**	**	**	ns	**	**	ns	ns	*
V x P	6	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
CV (%)		19.1	15.9	18.4	17.1	19.6	10.9	14.8	13.7	6.8	7.1	13.9
							Late rainy season					
Varieties (V)	2	**	**	*	**	**	**	**	**	**	**	**
Populations (P)	3	**	ns	**	**	**	ns	**	**	ns	ns	**
V x P	6	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
CV (%)		11.2	9.1	19.1	20.6	22.6	12.7	10.2	11.8	8.1	10.2	9.4

*, ** Significant at 0.05 and 0.01 levels of probability, respectively; ns = not significant.

Table 4. Means of all soybean traits grown in the dry season for three varieties averaged over four plant populations and four plant populations averaged over three varieties.

Entry	Yield	Seed size	Pods	Seeds	Branches	Nodes	Total dry matter	Plant weight	Days to flowering	Days to maturity	Plant height
			plant^{-1}								
	kg ha^{-1}	g 100 seeds^{-1}	no.				kg ha^{-1}		no.		cm
Varieties			**Average over populations**								
CM 2	1,436	13.42	31	56	3.5	10	2,568	1,130	27	78	36.2
KKU 67	1,537	14.13	31	61	2.8	12	2,889	1,351	31	85	38.9
KKU 35	1,640	15.10	36	75	4.3	15	3,278	1,637	36	103	52.8
$LSD_{0.05}$	101	0.68	4	12	0.6	1.9	292	205	3	4	12.8
Populations (plant ha^{-1})			**Average over varieties**								
100,000	1,424	15.01	45	87	4.4	13	2,605	1,180	31	91	40.1
200,000	1,635	14.09	38	75	3.8	13	3,105	1,471	31	90	44.4
300,000	1,687	14.02	31	62	3.7	13	3,212	1,524	31	90	45.6
400,000	1,823	14.01	27	53	3.0	13	3,535	1,712	31	90	49.8
$LSD_{0.05}$	107	0.51	3	8	0.6	0.1	311	166	1.1	1.8	4.1

Table 5. Means of all soybean traits grown in the late rainy season for three varieties averaged over four plant populations and four plant populations averaged over three varieties.

Entry	Yield	Seed size	Pods	Seeds	Branches	Nodes	Total dry matter	Plant weight	Days to flowering	Days to maturity	Plant height
			plant^{-1}								
	kg ha^{-1}	g 100 seeds^{-1}	no.				kg ha^{-1}		no.		cm
Varieties					**Average over populations**						
CM 2	2,071	16.20	33	67	3	10	3,868	1,797	30	80	49
KKU 67	2,245	17.02	41	82	3	12	4,549	2,304	34	88	59
KKU 35	2,603	16.41	45	91	4	17	5,663	3,060	38	105	72
$LSD_{0.05}$	158	0.57	3.8	9	0.8	2	298	252	3	5	9.0
Populations (plant ha^{-1})					**Average over varieties**						
100,000	1,860	17.01	58	118	4	13	3,871	2,011	34	92	56
200,000	2,174	16.84	41	83	3	13	4,404	2,230	34	91	64
300,000	2,353	16.57	33	68	3	13	4,944	2,591	34	91	65
400,000	2,534	16.16	30	60	2	13	5,412	2,878	34	91	69
$LSD_{0.05}$	150	0.62	6	18	0.7	0.03	278	106	0.4	1.5	7.1

Table 6. Means of soybean seed yield grown at two dates using four population densities.

Season	Variety	Plant population density (plants ha^{-1})			
		100,000	200,000	300,000	400,000
		kg ha^{-1}			
Dry	CM2	1,090	1,330	1,546	1,737
	KKU67	1,356	1,473	1,632	1,730
	KKU35	1,580	1,670	1,850	1,970
	$LSD_{0.05}$	129	114	116	104
Late rainy	CM2	1,639	2,010	2,183	2,441
	KKU67	1,856	2,135	2,330	2,582
	KKU35	2,390	2,420	2,720	2,880
	$LSD_{0.05}$	160	144	138	122

* $LSD_{0.05}$ for comparing between means of population densities within each variety.

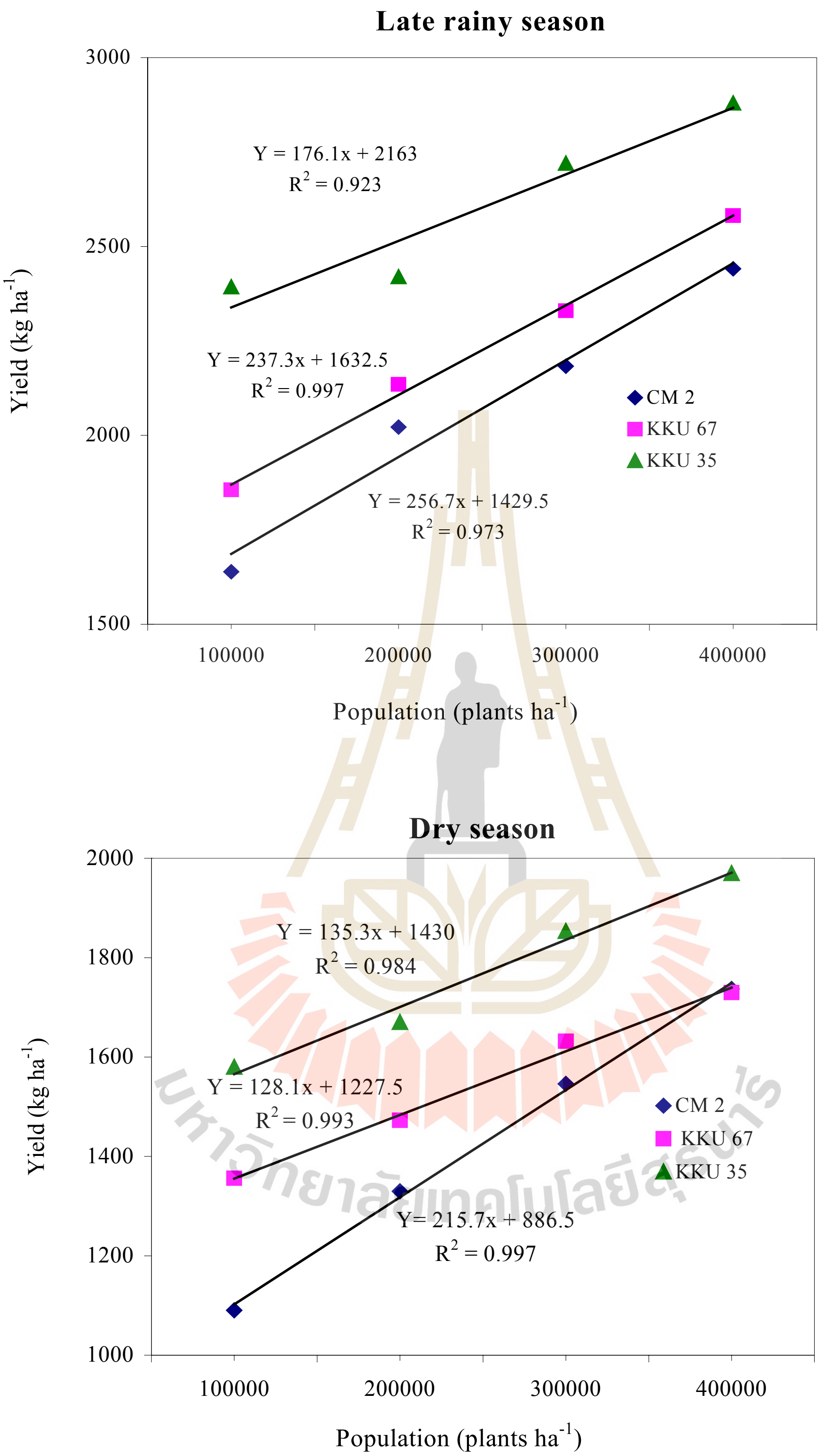


Fig. 1. Relationship between population densities and seed yield of three soybean varieties grown in two seasons.

References

Board, J. E., and Harville, B. G. (1996). Growth dynamics during the vegetative period affects yield of narrow-row, lated-planted soybean. **Agron. J.** 88: 567 - 572.

Board, J. E., Zhang, W., and Harville, B. G. (1996). Yield rankings for soybean cultivars grown in narrow and wide rows with late planting dates. **Agron. J.** 88: 240 - 245.

Carpenter, A. C., and Board, J. E. (1997a). Branch yield components controlling soybean yield stability across plant population. **Crop Sci.** 37: 885 - 891.

Carpenter, A. C., and Board, J. E. (1997b). Growth dynamic factors controlling soybean yield stability across plant populations. **Crop Sci.** 37: 1520 -1526.

Costa, J. A., Oplinger, E. S., and Pendleton, J. W. (1980). Response of soybean cultivars to planting patterns. **Agron. J.** 72: 153 - 156.

Department of Agriculture (DOA). (1994). **Field crop production.** Bangkok: Kurutsapa Ladpraow (in thai).

Herbert, S. J., and Litchfield, G. V. (1982). Partitioning soybean seed yield components. **Crop Sci.** 22: 1074 - 1079.

Laosuwan, P., Nangmai, M., and Tantum, P. (1997). Soybean yield trials. **In Food Legumes Project Research Report for 1996.** Institute of Agriculture Technology, Suranaree University of Technology.

Parvez, A. Q., Gardner, F. P., and Boote, K. J. (1989). Determinate and indeterminate type soybean cultivar responses to pattern, density and planting date. **Crop Sci.** 29: 150 - 157.

Piramarn P., and Boonklinkajorn, P. (1974). A study on the effect of plant population on soybean grain yield. **Thai J. Agr. Sci.** 7: 111 - 118.

SAS Institute, Inc. (1985). **SAS user's guide: Statistics,** version 5 ed. Cary, NC. SAS Institute, Inc.

Shibles, R. M., and Weber, C. R. (1966). Interception of soybean relation and dry matter production by various soybean planting patterns. **Crop Sci.** 6: 55 - 58.

Siripin, S. (1998). Soybean growth and yield as affected by increasing plant population. **In National Soybean Research Conference VII** (pp. 200 - 207). Bangkok: Sukhothai Thammatirat University.

Sutakom, S. (1998). The study on optimum plant density of RM. 1 and CM. 60. In **National Soybean Research Conference VII** (188 - 199). Bangkok: Sukhothai Thammatirat University.

Uthaida, N., and Laosuwan, P. (2001). Effect of planting dates on soybean II. Effects of planting dates on different characters of soybean varieties and lines. **Suranaree J. Sci. Technol.** 8: 178 - 188.

CHAPTER IV

Response of Early, Medium and Late Varieties of Soybean to Decreased Between Row and Within Row Spacings

Abstract

Early maturing varieties of soybean [*Glycine max* (L.) Merr.] produce a lower yield than those of medium and late maturing varieties due to small plant stature and less profuse branching. The objective of this study was to determine the yield response of early, medium and late maturing varieties to different between row and within row spacings. The experiment was carried out in the dry and late rainy seasons. The study was grown in a split-split plot design with three replications. Three varieties of soybean, CM2, KUSL20004 and KKU35, representing early, medium and late varieties, respectively, were used as the main plots. Three row widths including 50, 40 and 30 cm were the subplots and three plant spacings within row of 10, 5 and 2.5 cm were the sub-subplots. Varieties, row widths and plant spacings affected yields and most other characters. Seed yield of CM2 averaged over all spacings, outyielded KUSL20004 and KKU35. The rate of increase due to decreasing row width was greater than the rate of increase due to decreasing plant spacing. The increase in plant densities reduced all yield components accept seed size. This study showed that seed yield of early variety of soybean could be increased by increasing population densities over those recommended.

Introduction

Soybean (*Glycine max* (L.) Merr.) is grown widely in the North and Northeast of Thailand. The production areas of the crop are located between 16º and 20º N latitude with daylength between 11.50 - 13.00 hours (Fig. 1). Soybean varieties recommended to farmers can be classified into three groups of maturity viz. early, medium and late maturing varieties with their respective days to maturity of about 80, 95 and 110 days (Department of Agriculture, 1994). In most production areas, soybeans are grown as sequential crops either after or before rice and certain other field crops. Such a production system requires early maturing varieties which need less than 90 days from planting to maturity.

Early maturing soybean varieties are small, short stature and low yielding. However, their yield might be increased by increasing the plant population per unit area. This can be done by decreasing row width, decreasing plant spacing within a row, or both. In a study of soybeans at two between row spacings, 100 and 50 cm, Lehman and Lambert (1960) reported that seed yields were higher at the narrower spacing between rows. The effects of spacing within rows on yield were variable due to the different responses of varieties used in the study. In Thailand, Piramarn and Boonklinkajorn (1974) found that soybean grain yield was increased between 78 to 134 kg ha^{-1} when population densities within row were increased between 10 to 20 plants per meter. In a study using 50-cm row width, Machikowa et al. (2003, unpublished data) found that increasing population densities by increasing number of plant within row between 5 to 20 plants per meter resulted in seed yield increases between 86 and 190 kg ha^{-1} depending on varieties and seasons.

Many experiments on soybeans conducted in the United States showed that significant increases in grain yield can be obtained by narrowing the space between rows. Averaged over three plant densities and 5 years in Illinois, Gardner (1978 cited in Parvez et al., 1989) obtained 12 to 14 % more seed yield from 18 cm rows with MG III than from 90 cm rows. In a study conducted at Baton Rouge (LA) using soybean varieties Maturing Group V and VI grown at 100 cm and 50 cm rows, Board et al. (1990) found that the narrow rows resulted in a greater yield. Costa et al. (1980) at Arlington, Wisconsin, using soybean cultivars in different maturity groups (MG 0 though MG II) grown in 27 cm and 76 cm row widths, found that all cultivars produced higher seed yields in narrow spacings and the early cultivars (Group 0 maturity) generally exhibited a greater yield responses (+27 %) to narrow row spacings than the cultivars in Maturity Groups I and II (+19 %).

The previous studies were conducted in temperate climates at latitudes 45, 40, 30° N with maturity groups 0 though II, III and V + VI, respectively. Little is known about the effects of row spacing on soybean yields in tropical climates, and the relative effects on early, medium and late maturing varieties. With the introduction of early maturing varieties into production, it is important to develop a cultural system that will achieve high productivity. Yield increases may be obtained from early maturing varieties by increasing the plant population per unit area above that being used for medium or late varieties. The objective of this study was to determine the yield response of early, medium and late maturing varieties to different between row and within row spacings, in both dry and late rainy production seasons.

Materials and Methods

Field experiments were conducted at Suranaree University of Technology experimental farm at Nakhon Ratchasima, Northeast Thailand (16º N lat) in the dry and late rainy seasons, 2001. The soil type of the experimental site was Chatturat clay loam (Typic Haplustalts). Laboratory tests indicated: 3.25 % OM, 29 mg kg^{-1} P_2O_5, 300 mg kg^{-1} K_2O and pH of 6.4. The recommended fertilizer 12-24-12 (N, P_2O_5 and K_2O) formulation was applied and plowed under at the rate of 187.5 kg ha^{-1}. Weed control was made by application of alachlor. Diseases were suppressed by use of benomyl. Methomyl and acephate were used for insect control. Supplemented overhead sprinkler irrigation was applied periodically in the late rainy and regularly in the dry seasons.

Three soybean varieties or lines including Chiangmai 2 (CM2, early maturing variety), KUSL20004 (medium maturing line) and KKU35 (late maturing variety) were used in this study. They were grown at three row widths and three plant spacings. The CM2 plants are short, small and mature in 80 - 85 days. KKU35 plants are relatively tall and mature in 110 - 120 days. KUSL20004 is intermediate in plant height to CM2 and KKU35 and mature in 95 - 100 days.

The experimental design used in the study was a split-split plot arranged in a randomized complete block design with three replications. The three varieties of soybean were the main plots. Three row widths of 30, 40 and 50 cm were subplots and within row plant spacings of 2.5, 5 and 10 cm were sub-subplots. At the 30 cm row width, the within row spacings of 2.5, 5 and 10 cm resulted in plant populations of 1,333,333, 666,666 and 333,333 plants ha^{-1}. At the 40 cm row width, the respective within row spacings provided plant populations of 1,000,000, 500,000 and 250,000 plants ha^{-1}. In 50-cm rows, the three respective plant populations were

200,000, 400,000 and 800,000 plants ha^{-1}. All plots consisted of four rows each 4-m long. All data were collected on the two center rows. All plots were over-planted and thinned to one plant per hill about ten days after emergence. The planting date in the dry season was 15 January and in the late rainy season was 14 September 2001.

Data measurements made on the two inner rows were days to maturity, seed yield, plant height, lodging, seed size, branches per plant, pods per plant, seeds per plant and yield per plant.

1. Days to flowering were recorded as the number of days from planting to first bloom.
2. Days to maturity were recorded as the number of days from planting to 95% pods turned brown.
3. Yield measurement in kg ha^{-1} was calculated at 12% moisture as follows:

$$\text{Seed yield}\,(\text{kg ha}^{-1}) = \frac{\text{Yield/plot (g)}}{1{,}000\,\text{g}} \times \frac{10{,}000\,\text{m}^2}{\text{Harvested area}} \times \frac{100-12}{100-\text{moisture (\%)}}$$

4. Seed size was measured as the weight of 100 seeds randomly sampled from the whole seeds in each plot.
5. Lodging was rated at harvest based on the percent of plants lodged as 1 = no lodging, 5 = 100% lodged.
6. Yield per plant was counted on ten randomly selected plants in each plot.
7. Branches per plant was counted on ten randomly selected plants in each plot.
8. Nodes per plant was counted on ten randomly selected plants in each plot.
9. Pods per plant was counted on ten randomly selected plants in each plot.
10. Seeds per plant was counted on ten randomly selected plants in each plot.
11. Plant height was measured from the cotyledonary node to the tip of plant.

For each experiment, analyses of variance for the split-split plot design were performed using PROC GLM (SAS Institute, 1985). Varieties, row widths and plant spacings were fixed effects. Respective errors were used to test each effect and interaction.

Results and Discussion

In a combined analysis of variance, season effects and interactions were highly significant for all traits (data not shown). Thus, the analysis of each season is presented separately (Table 1). Soybean varieties representing three maturity types were significantly different for yield and all other characters in both seasons. Similarly, row widths and plant spacings affected seed yield, lodging, branches per plant, pods per plant, seeds per plant and yield per plant in both seasons but not seed size and plant height in the dry season. Therefore, yield increases with increased plant populations were due to increased numbers of seed not larger seeds. The significant interactions of variety x row width and variety x plant spacing indicated for seed yield that variety performance for this trait was associated with these spacings.

Seed yield

Generally, seed yield and plant growth were greater in the late rainy season than in the dry season (Tables 2 and 3). It was surprising that the yield of CM2, the early maturing variety did not differ from KUSL20004 and KKU35, the medium and late varieties in the dry season and was significantly higher than KKU35 in the late rainy season (Table 2). This was due to the high and positive yield responses of the early variety to higher population densities obtained from decreasing row width and plant spacing (Table 4). Yield responses to decreasing row width and to plant spacing were similar in order, the closer the rows and the plants within rows the better the yield. On the average, the yield increases from 50 cm to 40 cm between rows and 40 cm to 30 cm between rows were 3.54% to 9.77%, respectively. The increases in yield due to decreasing plant spacing from 10 cm to 5 cm and from 5 cm to 2.5 cm were 7.74% and 1.13%, respectively. However, the rate of increase due to decreasing row width in the dry season was higher than that in the late rainy season, while the rate of increase due to decreasing plant spacing was only slightly greater in the late rainy season. In the late rainy season soybean grew vigorously and tended to lodge at a higher rate as the row width decrease. This may have affected yields (Table 4).

The significant interactions of varieties x row widths and varieties x plant spacings indicated that varieties responded differently to these spacings. The yield increases due to decreasing row width averaged over plant spacings for CM2 from 50 cm to 40 cm and to 30 cm row widths were 2.94% and 17.57%, respectively (Table 4). The responses of KUSL20004 and KKU35 to the spacings were different. With KUSL20004, increases in yield of 7.09% were obtained by decreasing row width from 50 cm to 40 cm rows, but no significant increase was found between 40 cm and 30 cm rows. On the other hand, no significant yield increases were obtained by changing row widths of KKU35. A similar response was obtained with decreasing plant spacings. The yield of CM2 increased linearly with 10 cm, 5 cm and 2.5 cm spacings. The positive yield responses of KUSL20004 and KKU35 were obtained from changing10 cm to 5 cm plant spacings, but the response tended to be negative from 5 cm to 2.5 cm plant spacings (Table 4). This may have been due to increased lodging at the closer spacings (Table 5). The differential increase in seed yield due to decreasing row width and plant spacing are given in Fig 2a and 2b, respectively. On the average, CM2 gave a higher increase due to decreasing row width than the other two varieties. With the exception of CM2, the differential increase in the dry season was greater than the late rainy season. The yield increases from 40 cm to 30 cm were generally greater than from 50 to 40 cm with exceptions of those of KUSL20004 and KKU35 in the late rainy season. Yield increase of CM2 due to decreasing within row spacings were greater in both seasons than KUSL20004 and KKU35. Moreover, the patterns of increase were different. For

CM2, the increase due to decreasing plant spacings from 5 cm to 2.5 cm was higher than from 10 cm to 5 cm for both seasons while this was opposite for KUSL20004 and KKU35. The highest yield was obtained for CM2 at 30 cm row width and 2.5 to 5 cm plant spacings. These trials indicated that early variety, due to small plant stature and less branching, were more tolerant to high populations than medium and late varieties and showed a positive response to increased plant population. Similar findings were reported by Costa et al. (1980).

Other characters

Three varieties of soybean were different in all characters under this study (Table 1). CM2 had smaller seed size, lower plant height, fewer pods per plant, fewer seeds per plant, less yield per plant, less lodging and fewer days to maturity, and more branches per plant than KUSL20004 and KKU35 (Tables 2 and 3). Seed size was not affected by the reduction of row width and plant spacing indicating that this character was quite stable and did not cause the yield losses due to the increased population densities. Pods per plant, branches per plant, seeds per plant and yield per plant decreased as the row width and plant spacing decreased. Other authors have found similar responses in their experiments (Hicks et al., 1969; Bullock et al., 1998). The rates of decrease for pods per plant, branches per plant, seeds per plant and yield per plant as row width decreased were higher than those due to the decrease in plant spacing. An increase in population density has been found to be associated with an increase in lodging (Lueschen and Hicks, 1977; Herbert and Litchfield, 1984). In this study, we also found that lodging was more severe as the population densities increased. However, because CM2 plants were short and small, the rate of lodging due to decreased row width and/or plant spacing was lower than those of the other varieties.

Conclusion

This study showed that an early maturing soybean variety can produce yield equal to or higher than those of medium and late varieties if suitable population densities are employed. Soybean variety CM2, a relatively new variety developed for planting as a second crop after rice responded positively to increased densities. Increasing population density by decreasing row width was more effective for increasing seed yield than decreasing the spacing between plants. The increase in population density was usually accompanied by increased lodging which was more severe with later maturing varieties. It can be concluded from this study that in tropical environments optimum production of early soybean varieties can be achieved at row widths of 30 - 40 cm with 5 cm spacing between plants.

Although CM2 is the most popular early variety of soybean in Thailand, the variety is characterized by having small plant stature, low node and branch numbers, are low number of days from planting to flowering. These characters of soybean are associated with low yielding potential, unless plant populations are high enough to permit a closed canopy during reproductive growth. While, late maturing varieties had high pods per plant, large plant stature and long vegetative period. These characters have been reported to associate with higher soybean yield (Board, 1987; Dunphy et al., 1979). In the future, breeding programs should focus on development of early varieties with a more favorable plant type for high yield. This would include increased plant height and longer vegetative period long enough to accumulate the photosynthate needed for higher yields, while maintaining total days to maturity similar to CM2.

Table 1. Analysis of variance for eight characters of three soybean varieties in the dry and late rainy seasons.

Source of Variation	df	Yield	Seed size	Plant height	Lodging	Branches	Pods	Seeds	Yield
						plant^{-1}			
				Dry season					
Varieties (V)	2	**	**	**	**	**	*	**	**
Row widths (R)	2	**	ns	**	**	**	**	**	*
Plant spacings (P)	2	**	ns	**	**	**	**	**	**
V x R	4	**	ns	ns	**	*	ns	*	ns
V x P	4	**	ns	ns	**	ns	ns	**	*
R x P	4	ns	ns	ns	ns	ns	ns	*	ns
Vx R x P	8	ns	ns	ns	**	ns	ns	*	ns
CV (%)		14.5	3.4	11.5	12.3	8.5	9.6	8.3	15.9
				Late rainy season					
Varieties (V)	2	**	**	**	**	**	*	**	**
Row widths (R)	2	**	ns	ns	**	**	**	**	**
Plant spacings (P)	2	**	ns	**	**	**	**	**	**
V x R	4	**	ns	ns	ns	*	*	*	*
V x P	4	**	ns	ns	ns	**	*	ns	ns
R x P	4	ns	ns	ns	ns	ns	ns	ns	ns
Vx R x P	8	**	ns	ns	ns	ns	ns	ns	ns
CV (%)		14.7	2.9	8.7	8.2	10.7	8.9	10.5	14.1

*, ** Significant at 0.05 and 0.01 levels of probability, respectively; ns = not significant.

Table 2. Yield and yield components of three soybean varieties grown in three row widths and plant spacings.

Entry	Yield		Seed size		Pods per plant	
	Dry	Late rainy	Dry	Late rainy	Dry	Late rainy
	kg ha^{-1}		g 100 seeds^{-1}		no.	
Variety (Type)						
CM2 (Early)	2,183	2,499	14.06	15.19	25.43	27.18
KUSL20004 (Medium)	2,100	2,448	14.13	15.63	27.14	29.51
KKU35 (Late)	2,028	2,215	13.95	15.87	26.64	29.61
LSD $_{0.05}$	ns	157.1	0.16	0.25	3.62	2.29
Row width						
50 cm	1,955	2,277	13.88	15.66	29.56	32.34
40 cm	2,029	2,353	13.87	15.50	25.51	29.66
30 cm	2,326	2,482	13.98	15.53	24.14	24.31
LSD $_{0.05}$	166.2	156.8	ns	ns	3.17	2.20
Plant spacing						
10 cm	2,014	2,224	14.05	15.50	34.47	35.44
5 cm	2,135	2,431	13.99	15.56	25.10	28.80
2.5 cm	2,161	2,457	14.10	15.62	19.64	22.06
LSD $_{0.05}$	ns	152.2	ns	ns	3.56	2.68

Table 3. Plant characters of three soybean varieties grown in three row widths and three plant spacings.

Entry	Branches per plant		Seeds per plant		Yield per plant	
	Dry	Late rainy	Dry	Late rainy	Dry	Late rainy
	.... no.	....	....	....	.... g	....
Variety (Type)						
CM2 (Early)	1.83	2.30	51.02	53.23	6.76	7.86
KUSL20004 (Medium)	1.64	1.66	64.24	66.20	8.80	11.30
KKU35 (Late)	1.52	1.83	62.43	66.02	7.55	9.70
LSD $_{0.05}$	0.18	0.24	7.06	6.57	1.14	1.39
Row width						
50 cm	1.73	2.32	65.97	68.68	8.29	10.93
40 cm	1.78	2.18	57.75	62.56	7.38	9.64
30 cm	1.48	1.79	56.17	52.00	7.44	8.29
LSD $_{0.05}$	0.21	0.25	6.79	6.10	0.72	1.38
Plant spacing						
10 cm	2.23	2.72	75.65	77.80	10.07	12.10
5 cm	1.55	2.11	58.09	60.90	7.28	9.52
2.5 cm	1.20	1.47	44.01	46.69	5.76	7.24
LSD $_{0.05}$	0.20	0.25	6.87	5.27	1.00	1.22

Table 3. Continued.

Entry	Plant height		Lodging		Days to maturity	
	Dry	Late rainy	Dry	Late rainy	Dry	Late rainy
	cm		1-5†		no.	
Variety (Type)						
CM2 (Early)	46	48	1.89	2.07	79.1	81.7
KUSL20004 (Medium)	58	65	2.53	2.46	85.6	87.7
KKU35 (Late)	75	82	2.90	3.32	100.5	105.5
LSD $_{0.05}$	6.3	8.2	0.37	0.38	0.52	0.41
Row width						
50 cm	58	63	1.93	1.96	88.8	92.0
40 cm	61	63	2.28	2.57	88.4	91.6
30 cm	60	69	3.11	3.32	88.0	92.1
LSD $_{0.05}$	ns	5.9	0.34	0.41	0.35	0.39
Plant spacing						
10 cm	56	61	1.92	2.04	88.7	91.8
5 cm	60	65	2.32	2.61	88.4	91.7
2.5 cm	63	69	3.08	3.19	88.1	91.4
LSD $_{0.05}$	4.6	5.0	0.36	0.40	0.38	0.34

† Score; 1 = no lodging, 5 = 100% lodged.

Table 4. Means yield of three soybean varieties averaged across two seasons for three row widths over three plant spacings and three plant populations over three row widths.

Entry	Variety		
	CM2	KUSL20004	KKU35
		kg ha^{-1}	
Row width			
50 cm	2,145	2,158	2,045
40 cm	2,208	2,311	2,054
30 cm	2,596	2,353	2,265
LSD $_{0.05}$	168.4	152.4	146.7
Plant spacing			
10 cm	2,106	2,187	2,065
5 cm	2,332	2,333	2,184
2.5 cm	2,511	2,301	2,115
LSD $_{0.05}$	171.2	150.9	135.5

Table 5. Means yield of three soybean varieties grown in three row widths and three plant spacings in the dry and late rainy seasons.

Variety	Row width	Plant spacing	Dry		Late rainy	
			Yield	Lodging	Yield	Lodging
	cm	cm	kg ha^{-1}	1-5†	kg ha^{-1}	1-5
CM2	50	10	1,830 b	1.0 b	1,879 c	1.1 b
		5	2,190 a	1.3 a	2,187 b	1.2 b
		2.5	2,211 a	1.5 a	2,570 a	1.7 a
	40	10	1,839 c	1.1 c	2,141 c	1.5 b
		5	2,009 b	1.6 b	2,345 b	1.9 b
		2.5	2,258 a	2.2 a	2,656 a	2.3 a
	30	10	2,350 b	1.6 c	2,596 b	2.1 c
		5	2,413 ab	2.3 b	2,846 a	2.3 b
		2.5	2,547 a	2.8 a	2,822 a	3.0 a
KUSL20004	50	10	1,925 a	1.1 b	2,172 b	1.1 c
		5	1,963 a	1.4 b	2,459 a	1.8 b
		2.5	2,013 a	1.8 a	2,416 a	2.1 a
	40	10	1,962 b	1.8 b	2,510 a	1.9 c
		5	2,138 a	2.0 ab	2,599 a	2.1 ab
		2.5	2,109 ab	2.2 a	2,547 a	2.3 a
	30	10	2,205 a	2.3 a	2,347 a	2.5 b
		5	2,341 a	2.5 a	2,499 a	2.6 b
		2.5	2,243 a	3.1 a	2,480 a	3.3 a
KKU35	50	10	1,793 a	1.2 c	2,244 ab	1.5 b
		5	1,853 a	1.8 b	2,372 a	1.9 a
		2.5	1,815 a	2.0 a	2,194 b	2.4 a
	40	10	1,920 a	2.0 b	1,971 b	2.6 a
		5	1,973 a	2.3 b	2,252 a	2.8 a
		2.5	2,055 a	2.6 a	2,151 a	2.8 a
	30	10	2,306 a	2.4 c	2,154 b	2.7 c
		5	2,334 a	2.8 b	2,318 a	3.1 b
		2.5	2,200 a	3.2 a	2,275 ab	3.5 a

† Score; 1 = no lodging, 5 = 100% lodged.

* Means within the same column within each row width of each variety followed by the same letter are not significantly different at $P < 0.05$ according to DMRT.

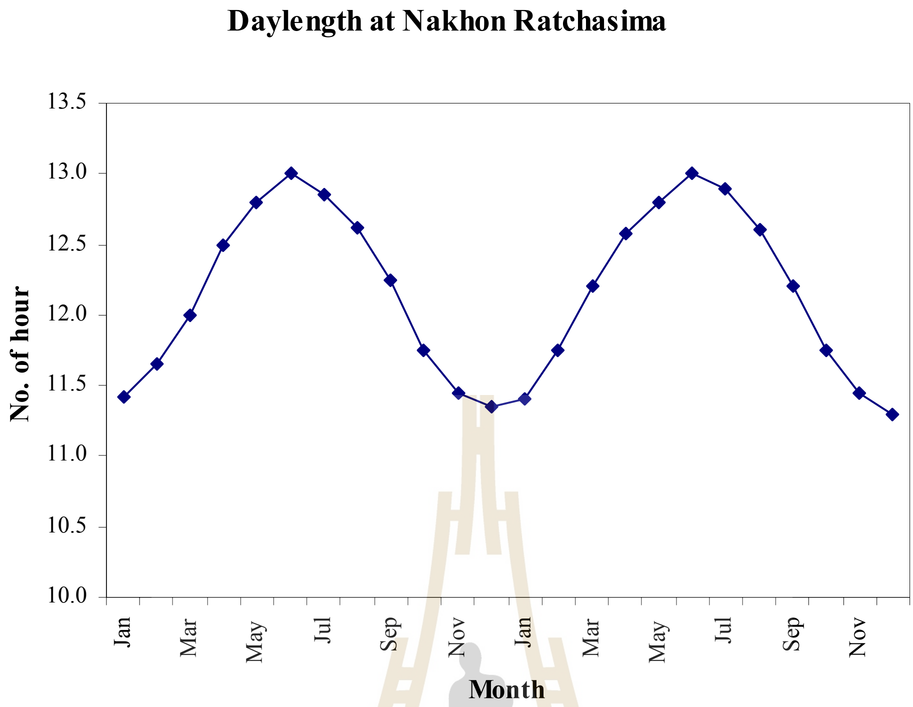


Fig. 1. Daylength at Nakhon Ratchasima from January 2000 to December 2001.

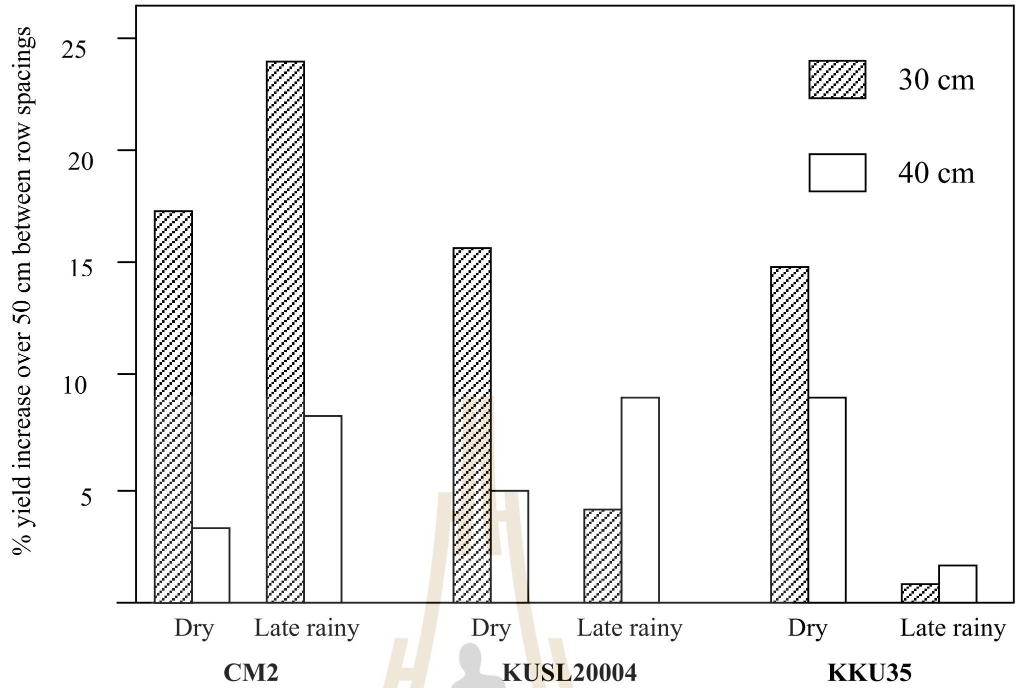


Fig. 2a. Percent yield increase of 40 and 30 cm over 50 cm between row spacings of CM2, KUSL20004 and KKU35 representing early, medium and late maturing varieties.

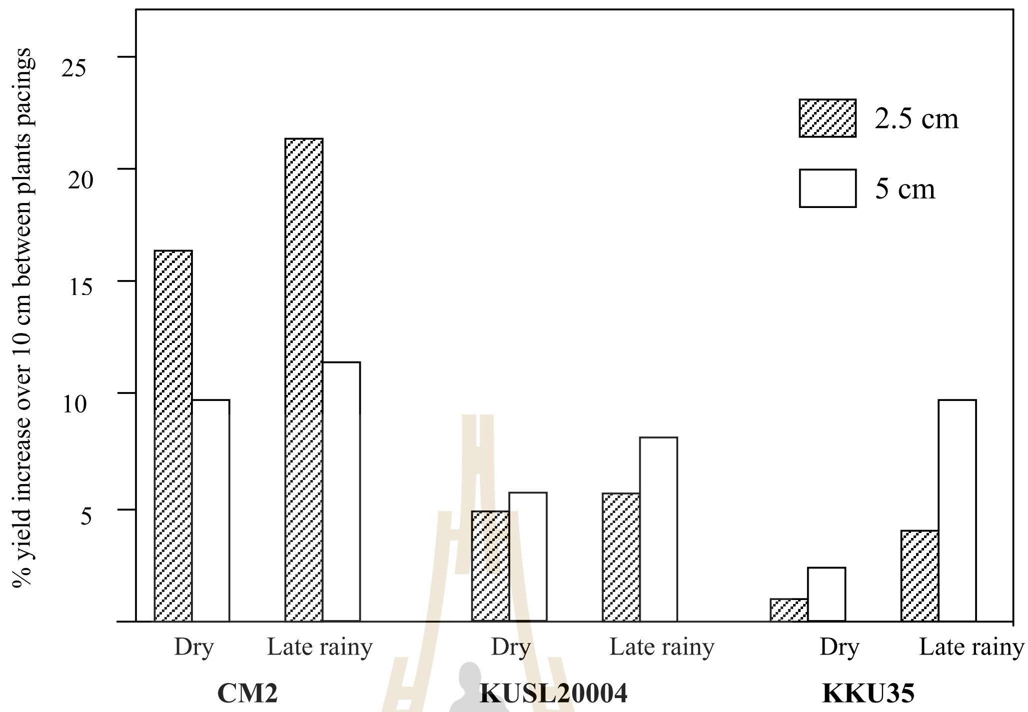


Fig. 2b. Percent yield increase of 5 and 2.5 cm over 10 cm plant spacing of CM2, KUSL20004 and KKU35 representing early, medium and late varieties of soybean.

References

Board, J. E. (1987). Yield components related to seed yield in determinate soybean. **Crop Sci.** 27: 1296 - 1297.

Board, J. E., Harville, B. G., and Saxton, A.M. (1990). Branch dry weight in relation to yield increases in narrow-row soybean. **Agron. J.** 82: 540 - 544.

Bullock, D., Khan, S., and Rayburn, A.. (1998). Soybean yield response to narrow rows is largely due to enhanced early growth. **Crop Sci.** 38: 1011 - 1016.

Costa, J. A., Oplinger, E. S., and Pendleton, J. W. (1980). Response of soybean cultivars to planting patterns. **Agron. J.** 72: 153 - 156.

Department of Agriculture. (1994). **Field crop production.** Bangkok: Kurutsapa Ladpraow (in thai).

Dunphy, E. J., Hanway, J. J., and Green, D. E. (1979). Soybean yields in relation to days between specific developmental stages. **Agron. J.** 71: 917.

Herbert, S. J., and Litchfield, G. V. (1984). Growth response of short season soybean to variations in row spacing and density. **Field Crops Res.** 9: 163 - 171.

Hicks, D. R., Pendleton, J. W., Bernard, R. L., and Johnston, T. J. (1969). Response of soybean plant types to planting patterns. **Agron. J.** 61: 290 - 293.

Lehman, W. F., and Lambert, J. W. (1960). Effects of spacing of soybean plants between and within rows on yield and its components. **Agron. J.** 52: 84 - 86.

Lueschen, W. E., and Hicks, D. R. (1977). Influence of plant population on field performance of three soybean cultivars. **Agron. J.** 69: 390 - 393.

Parvez, A. Q., Gardner, F. P., and Boote, K. J. (1989). Determinate and indeterminate type soybean cultivar responses to pattern, density and planting date. **Crop Sci.** 29: 150 - 157.

Piramarn P., and Boonklinkajorn, P. (1974). A study on the effect of plant population on soybean grain yield. **Thai J. Agr. Sci.** 7: 111 - 118.

SAS Institute, Inc. (1985). **SAS user's guide: Statistics**, version 5 ed. Cary, NC. SAS Institute, Inc.

CHAPTER V

Development of Early Varieties of Soybean by Backcross Breeding Method

Abstract

Early maturing varieties in Thailand are small plant stature, low yield components and low yielding. The improvement of certain traits such as plant size and number of pods per plant of these varieties may result in an increased seed yield. The objective of this study was to improve early maturing varieties for high pods per plant leading to yield increase by backcross method. The experiment was conducted at SUT farm, Nakhon Ratchasima. High pods per plant from donor parent 'Long Juvenile 4' (LJ4) was backcrossed to three early maturing parents CM2, NS1 and ST2. Each step was conducted following the standard backcrossing method until BC_3F_1s were obtained. The BC_3F_1 seeds were generated to produce BC_3F_2 and BC_3F_3 and selections were made for pods per plant and other desirable characters such as plant height and short days to maturity. The selected BC_3F_4 lines plus four parents were evaluated for pods per plant, seed yield and agronomic traits with three replications. Three lines including lines 103, 108 and 309 outyielded their respective recurrent parents. This yield increase was due to the increase of pods and seeds per plant. These results demonstrated that backcross breeding can be used to improve seed yield due to the increase of yield components.

Introduction

Soybean production in Thailand is becoming more and more depending on a sequential cropping with other field crops. This production method requires early maturing varieties harvested in less than 90 days. In the present time, three early varieties of soybean are recommended to farmers in the country. They are Chiangmai 2 (CM2), Nakhonsawan 1 (NS1) and Sukhothai 2 (ST2). These varieties are usually short, have small in plant stature and of low yields. The improvement of certain traits such as plant height, branches per plant, pods per plant, etc. of these varieties may result in an increase of seed yield.

The backcross method is a popular breeding procedure used in improving simple inherited characters of crops. The early example of backcross breeding was the development of wheat variety, Baart, resistant to bunt (Briggs, 1930 quoted in Jensen, 1988). Source of resistance 'Martin' used as the donor parent was crossed with 'Baart' as the recurrent parent. Backcross breeding method was employed to improve mungbean varieties Kamphaeng Saen 1, Kamphaeng Saen 2 and PSU 1 for resistance to Cercospora leaf spot (caused by *Cercospora cenescens*). These three varieties were crossed with a resistant line, VC3689A, and backcrossed to recurrent parents for four times. Three varieties obtained from this program were SUT2, SUT3 and SUT4, respectively (Laosuwan et al., 1997; Laosuwan et al., 1999). Chaiteing (2002) improved mungbean variety 'CN 36' for resistance to powdery mildew by backcrossing. CN 36 was used as a recurrent parent and two resistant variety/line, SUT4 and VC1210A as donor parents. Three backcrosses to recurrent parent were done. Ten lines obtained were resistant to powdery mildew and higher yielding than their recurrent parent.

The application of backcross breeding method for improvement of quantitative characters has not been popular among plant breeders due to the difficulties in identifying desirable genotypes in each backcross generation. In backcross breeding for improving protein in soybean, in each generation of backcrossing, Wilcox and Cavin (1995) selfed pollinated until F_5 to obtained plants with higher protein concentration and resembling recurrent parent for further backcrossing. However, backcrossing may be effective in improving yield component traits such as seed size, number of pods and seeds per plant as these characters are not easily affected by environment.

Identification of soybean components that contribute to high yield would provide direction for breeding programs to improve seed yield. High seed yield of soybean was found associated with high number of pods per plant (Anand and Torrie, 1963; Malhotra et al., 1971; Board, 1987). Heritability estimates of pods per plant were moderate to high ranging from 0.22 to 0.83 (Johnson et al., 1955; Alam and Muresan, 1985). Therefore, high pods per plant might be transferred to early maturing soybeans by backcrossing.

The objective of this study was to improve early maturing soybean varieties for high number of pods per plant and plant height.

Materials and Methods

Three early maturing varieties of soybean including CM2, NS1 and ST2 were used as recurrent parents in the backcross method by crossing with a soybean line Long Juvenile 4 (LJ4). LJ4 was tall, big in stature and has a high number of pods per plant. The F_1 crosses obtained were CM2 x LJ4, NS1 x LJ4 and ST2 x LJ4. The F_1 seeds from each cross were planted and crossed with the recurrent parent to obtain BC_1F_1 seeds. In the next step, BC_1F_1 seeds were planted in the greenhouse in January, 2001. Seventeen BC_1F_1 plants from CM2 x LJ4, 15 BC_1F_1 plants from NS1 x LJ4 and 18 BC_1F_1 plants from ST2 x LJ4 were grown and crossed with their respective recurrent parents to produce BC_2F_1 seeds. BC_2F_1 seeds were harvested from the early maturing plants with high number of pods per plant. They were self-pollinated to obtain BC_2F_2 seeds. These seeds were planted and used as female parent to cross with respective recurrent parents. This procedure was repeated until BC_3F_1 was obtained. For each backcross, the plants were selected first for high pods per plant then for yield and agronomic traits such as big plant stature, plant height and low days to maturity. The BC_3F_1 seeds were planted to produce BC_3F_2 seeds (Fig. 1). These seeds were planted, early maturing lines with a high pods per plants were identified and harvested separately.

Twelve, nine and eight plants were selected for high pods per plant from crosses of CM2 x LJ4, NS1 x LJ4 and ST2 x LJ4, respectively. The BC_3F_3 seeds from individually selected plants were planted separately for seed multiplication. The BC_3F_4 seeds harvested from each row and recurrent parents (CM2, NS1, and ST2) were grown in a randomized complete block design with three replications in September, 2002. Each line was grown in four-row plots spaced 50-cm apart. Each row was 4 m long with plants spacing within row of 20-cm apart with 2 plants per hill. The data measurements in each plot were made in two center rows for days to flowering, days to maturity and number of pods per plant. The BC_3F_4 lines showing high number of pods per plant for all three replications were selected. Six lines including lines no. 103 and 108 from CM2 recurrent parent, lines 204 and 207 from NS1 recurrent parent, lines 303 and 309 from ST2 recurrent parent were selected. Ten plants in each plot were sampled as representative plants for measurements of plant height, number of pods and nodes per plant. Yield and seed size were measured after harvesting as follows:

1. Yield measurement in kg ha^{-1} was calculated at 12% moisture as follows:

$$\text{Seed yield}\,(\text{kg ha}^{-1}) = \frac{\text{Yield/plot (g)}}{1{,}000\,\text{g}} \text{ x } \frac{10{,}000\,\text{m}^2}{\text{Harvested area}} \text{ x } \frac{100 - 12}{100 - \text{moisture (\%)}}$$

2. Seed size was measured as weight of 100 seeds randomly selected in all replications.
3. Plant height was measured from the cotyledonary node to the tip of the plant.
4. Ten plants were randomly selected from all plots to count for pods per plant, seeds per plant, branches per plant and nodes per plants.
5. Days to flowering were recorded as the number of days from planting to first flower.
6. Days to maturity were recorded as the number of days from planting to 95% pods turned brown.

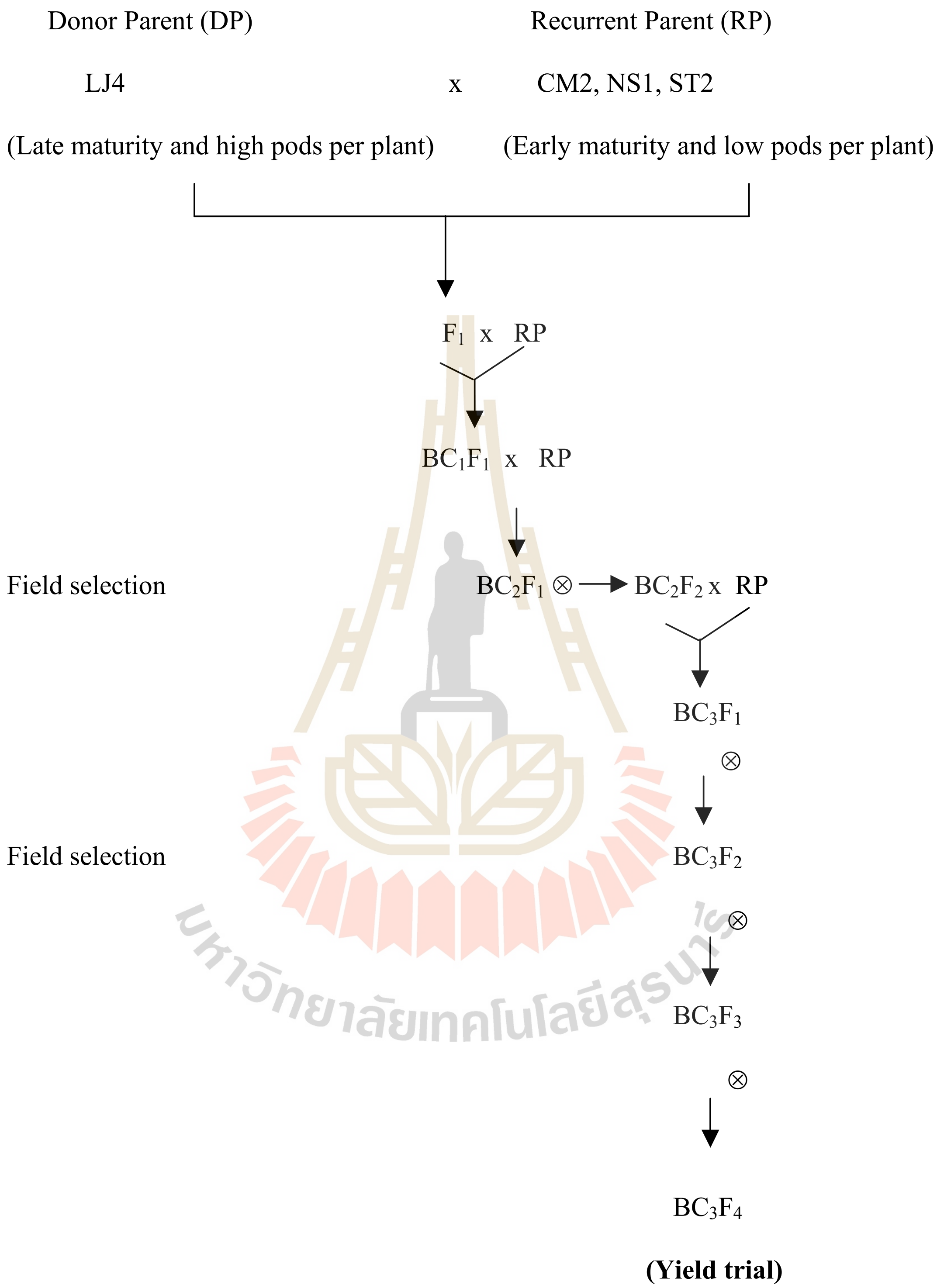


Fig. 1. Diagram for backcross breeding and selection for early maturity and high number of pods per plant.

Results and Discussion

Results from analysis of variance of six selected lines plus four parental checks are shown on Table 1. Significant differences were found between parents and backcross lines and among lines for yield, pods per plant, seeds per plant, nodes per plant, branches per plant, seed size, height, days to flowering and days to maturity. The significant difference of parent vs line signified that it was successful in improving early maturing varieties by backcross method.

Means for yield and other characters of backcrossed lines and their recurrent parents are shown in Table 2. In this study, the selection for days to flowering could be made easily as there were limited number of plants in each generation of backcrossing and gene frequencies of recurrent parents increase rapidly due to backcrossing. Therefore, the selection was concentrated on days to maturity.

Seed yield of lines 103, 108 were significantly higher than CM2 (recurrent parents, 2,356 kg ha^{-1}). Lines 103 and 108 produced 13.16 and 16.21% more seed yield than CM2. Lines 204, 207 and 309 also outyielded their respective recurrent parents.

Line 309 had the highest pods per plant and were higher than ST2, the recurrent parent. Pods per plant of lines 103 and 108 were 25.1 and 28.6 which were higher than that of CM2 (19.2 pods per plant). With the exception of line 303, all other lines gave higher seeds per plant than their respective recurrent parents, especially line 309 which gave 70.1 seeds. For branches per plant, there were only three lines outnumbered their respective recurrent parents. These lines were 103, 204 and 303.

Theoretically, the performance of these lines and recurrent parent should be similar as they have similar genetic background. Therefore, any difference should be attributable to the pods per plant. Since pods per plant associates with seeds per plant, seeds per plant increased as the increase of pods and branches per plant (Board, 1987; Herbert and Litchfield, 1982; Carpenter and Board, 1997). The significant differences from the recurrent parent were found for seed size and height. However, in this type of breeding, we have retained these characters such as plant height, seed size and other characters associated with yield in each backcross cycle and eliminated undesirable characters and late days to maturity.

Conclusion

The results showed that early maturing varieties can develop for number of pods per plant by backcross breeding method. The selected lines gave higher pods per plant and seed yield than their recurrent parents. The yield increase was due to the increase of number of pods per plant. Therefore, increasing number of pods per plant was effective for increasing seed yield. These results demonstrated that backcross breeding can be used to improve seed yield due to the increase of yield components. However, these characters should have high heritability.

Table 1. Analysis of variance of yield and other characters of soybean lines selected from backcross progenies.

Source of Variation	df	Yield	Days to flowering	Days to maturity	Seed size	Plant height	Nodes	Branches	Pods	Seeds
							plant^{-1}			
Blocks	2	17.0	0.04	0.38	0.02	18.54	0.17	0.01	6.0	42.31
Parent vs backcross	1	943.5**	1.12*	2.32*	4.62**	74.51*	0.24	0.38*	121.71**	768.87**
Lines	9	574.6**	0.26	0.71	7.20**	53.60**	5.64*	0.74**	107.43**	628.52**
Error	18	82.1	0.14	0.32	0.17	14.25	0.07	0.05	12.53	75.43
CV (%)		11.42	3.22	2.81	2.24	13.45	2.45	12.83	13.97	17.56

*, ** Significant at 0.05 and 0.01 probability levels, respectively.

Table 2. Yield and other characters of soybean lines selected from backcross progenies.

No.	Line/Variety	Yield	Days to flowering	Days to maturity	Seed size	Plant height	Nodes plant^{-1}	Branches plant^{-1}	Pods plant^{-1}	Seeds plant^{-1}
		kg ha^{-1}	no.	no.	g 100 seeds^{-1}	cm	no.	no.	no.	no.
103	CM2 x LJ4	2,616 b†	30 c	81.0 c	17.81 cd	54 c	10 c	2.3 b	25.1 cd	52.5 c
108	CM2 x LJ4	2,688 ab	30 c	80.7 c	18.20 c	52 c	10 c	1.4 c	28.6 c	57.5 bc
204	NS1 x LJ4	2,519 b	30 c	80.3 c	19.95 b	50 c	10 c	2.6 b	24.6 cd	53.5 c
207	NS1 x LJ4	2,619 b	30 c	80.7 c	19.85 b	53 c	10 c	1.6 c	28.6 c	54.2 c
303	ST2 x LJ4	2,519 b	30 c	81.3 bc	17.16 de	65 bc	14 b	2.2 b	28.7 c	48.6 c
309	ST2 x LJ4	2,588 b	31 b	82.3 b	17.91 cd	68 b	14 b	1.3 c	33.3 b	70.1 b
Parent	CM2	2,356 c	30 c	80.3 c	16.59 e	40 d	10 c	1.4 c	19.2 d	38.7 d
Parent	NS1	2,325 c	30 c	80.3 c	21.06 a	37 d	10 c	1.6 c	17.7 d	34.7 d
Parent	ST2	2,525 b	31 b	83.0 b	16.45 e	61 c	13 bc	2.1 b	28.0 c	53.3 c
Parent	LJ4	2,841 a	44 a	122.0 a	16.56 e	105 a	18 a	4.2 a	45.0 a	94.6 a
Mean		2,699	30.3	81.1	18.5	53.0	11.2	1.9	27.3	53.0

† Means within a column followed by the same letter are not significantly different at $P < 0.05$ according to DMRT.

References

Alam, S., and Muresan, T. (1985). The inheritance of some quantitative characters in soybean. **Thai J. Agric. Sci.** 18: 101 - 108.

Anand, S. C., and Torrie, J. H. (1963). Heritability of yield and other traits and interrelationship among traits in the F_2 and F_4 generations of three soybean crosses. **Crop Sci.** 3: 508 - 511.

Board, J. E. (1987). Yield components related to seed yield in determinate soybean. **Crop Sci.** 27: 1296 - 1297.

Briggs, F. N. (1930). Breeding wheats resistant to bunt by backcrossing method. **J. Am. Soc. Agron.** 22: 239 - 244. Quoted in Jensen, N. F. (1988). **Plant breeding methodology.** New York: John Wiley & Son.

Carpenter, A. C., and Board, J. E. (1997). Branch yield components controlling soybean yield stability across plant population. **Crop Sci.** 37: 885 - 891.

Chaiteing, B. (2002). **Inheritance of powdery mildew resistance in mungbean and development of markers-assisted selection**. Ph.D. Dissertation, Suranaree University of Technology.

Herbert, S. J., and Litchfield, G. V. (1982). Partitioning soybean seed yield components. **Crop Sci.** 22: 1074 - 1079.

Johnson, H. W., Robinson, H. F., and Comstock, R. E. (1955). Estimate of genetic and environmental variability in soybeans. **Agron. J.** 47: 314 - 318.

Laosuwan, P., Nangmai, M., Sawng-Un, C., and Polchim, S. (1997). Yield trials of backcross progenies of mungbeans. **Suranree J. Sci. Technol.** 4: 35 - 44.

Laosuwan, P. (1999). Mungbean varietal improvement : A review. **Songklanakarin J. Sci. Technol.** 30: 41 - 48.

Malhotra, R. S., Singh, K. B., and Dhaliwal, H. S. (1972). Correlation and path-coefficient analyses in soybean (*Glycine max.* (L.) Merr.). **Indian J. Agric. Sci.** 42: 26 - 29.

Wilcox, J. R., and Cavins, J. F. (1995). Backcrossing high seed protein to a soybean cultivar. **Crop Sci.** 35: 1036 - 1041.

CHAPTER VI

Improvement of Early Maturing Varieties of Soybean by Using Variety Cross

Abstract

Soybeans with a short life cycle can fit in a period between rice production and other field crops. However, most available varieties of this type are relatively less productive than later maturing varieties. Therefore, it is important to develop higher yielding early varieties that are suitable to this system. The objectives were (1) to select soybean lines for early maturity using early x late and early x medium variety crosses and (2) to evaluate the efficiency of single seed descent methods employed in early and late generation selection. Eighteen crosses were created by crossing medium and late with early. F_2 plants from these crosses were advanced by conventional single seed descent (CSSD) and modified single seed descent (MSSD) methods. Three of these crosses were selected for further study based on long vegetative period and early maturity. In the F_6 generation 102 selected lines were evaluated for seed yield, days to flowering, days to maturity and agronomic traits. Lines with longer vegetative period than the early parent and significantly higher yields than the check (SJ5) were successfully selected using both methods. Consistent yield advantages were found for CSSD selection when the mean yield of all lines from each cross were compared. The lines from CSSD selection also had longer vegetative period, were earlier, had larger seed size and taller than lines from MSSD method. The results indicated that late generation selection for single seed descent was more effective in selecting lines with longer vegetative period, a high yield and early maturity than the early generation selection.

Introduction

The traditional system for soybean production in Thailand has been a sequential cropping after rice, corn and other field crops. Early maturing varieties, which require less than 90 days to maturity, are needed to fit into this system to exploit available moisture in the late rainy season and be harvested before the next crop. However, most soybean varieties currently recommended to farmers mature more than 100 days after planting. These varieties are not suitable for use in the present cropping system. Due to their late maturity, they are usually affected by drought at the seed filling period. Three early maturing varieties have been recommended to farmers but are not popular due to their small plant stature and low yield (Department of Agriculture, 1994). Therefore, it is important to develop new varieties of soybean that are suitable for the present and future systems of crop production in the country.

In general, early varieties of soybean flower early, have small plant stature, produce low leaf area index, low plant dry matter and yield. Hartwig (1970) suggested that a minimum number of 45 days from emergence to blooming is required to permit sufficient vegetative growth necessary to produce moderate yield. Delayed flowering has been reported to be associated with higher soybean yield (Dunphy et al., 1979). However, none of the early varieties recommended to farmers in Thailand flower later than 31 days after emergence. The extension of days to flowering of current early varieties as well as the development of new varieties with a longer vegetative period may result in higher yielding varieties. Hartwig and Kiihl (1979) found that Long Juvenile (LJ) soybean genotypes exhibit a photoperiod response that delays flowering, but maturity under short day conditions is also delayed. This genetic material may be used to improve delayed flowering of present early maturing varieties recommended to farmers. James et al. (1994) found that the long-juvenile trait delayed flowering on average of ten days under normal conditions (high temperatures and short days). Futhermore, long-juvenile strains (developed and selected by Dr. Kuell Hinson) were evaluated at two locations in south USA. These strains produced higher seed yields than conventional cultivars (Shipe et al., 1994).

Empig and Fehr (1971) evaluated single seed descent (SSD), cross bulk, restricted cross bulk and maturity-group bulk methods for soybean improvement. Mean yield of lines did not differ among methods, but the SSD method was more effective in retaining early-maturing segregates and less time consuming. Byron and Orf (1993) compared the three selection procedures: pedigree, SSD and single seed descent with early maturity selection for selection of early lines from populations created by crossing parents from MG 00 and 0 with parents from MG II and III. The results indicated no differences among selection procedures for maturity and yield. Keawmeechai et al. (1997), using SSD, developed 27 populations by crossing between early and late maturing parents. From these populations, 6 lines of early maturing and high yielding were selected.

Little information is available on the best procedure for developing varieties with a longer vegetative period and earlier maturity, while maintaining yielding ability. The objectives of this research were (1) to select soybean lines with later flowering and early maturity using early x late variety crosses and (2) to evaluate the efficiency of single seed descent methods employed in early and late generation selections.

Materials and Methods

Crossing among early, medium and late varieties.

These studies were conducted at Suranaree University of Technology experimental farm, Nakhon Ratchasima, Northeast of Thailand (lat 16º N). Nine soybean varieties representing three types of maturity, early, medium and late, were used as parents. Early maturing varieties were Chiangmai 2 (CM2), Nakhonsawan 1 (NS1) and Sukhothai 2 (ST2). Medium varieties were KKU67, KUSL20004 and SJ2. Late varieties were KKU35, Long juvenile 4 (LJ4) and Chakkrabhandhu 1 (CB1) (Table 2). All medium and late maturing parents were high yielding varieties with good agronomic traits (Appendix, Table 1).

The crosses were made among groups (early, medium and late) in a factorial manner (Table 1). They were crossed in September, 2000. Eighteen F_1 hybrids and nine parents were planted on January 9, 2001. The hybrids and their parents were tested in the field at Suranaree University Experimental Farm (SUT farm). They were planted in rows of 50-cm width with 10 cm between plants with one plant per hill. Individual plants were recorded for days to flowering and days to maturity and subjected to analyses of variance by PROC GLM (SAS Institute, 1985). Heterosis was calculated for days to flowering and to maturity as percent increase or decrease over mid-parent. Heterosis percentages for individual crosses were computed as follow:

$$\text{Heterosis } (\%) = [(F_1 - MP) / MP] \times 100$$

where F_1 = F_1 mean of each cross and MP = mid-parent mean in each cross.

Selections in advanced populations

The procedure for this experiment is presented diagrammatically in Figure 1. In May, 2001, F_2 seeds from 18 crosses were planted at an average seeding rate of 20 seeds m^{-2}.

They were planted at SUT farm and Suwan farm (100 km west from SUT farm). CM2 was planted every 20th row as a reference for flowering and maturity selection. F_2 plants in each cross were advanced by using the conventional single seed descent (CSSD) procedure as described by Brim (1966) and a modification of single seed descent (MSSD). For CSSD, one random seed per plant was harvested from each F_2 plant and subsequent generations. These seeds were bulked before planting. All the randomly selected seeds from CSSD were planted in subsequent generations. There may have been some crop damage and non-emergence in each generation but the numbers were still high (Table 6). The MSSD was made in two steps. In the first step, F_2 plants which flowered later than CM2 were selected. In the second step, the selected plants in the first step were selected for days to maturity not longer than CM2. With this two steps method, three crosses were selected. With this method, about 10% of plants in each F_2 generation were selected based on days to flowering and days to maturity. Selected seeds were bulked before planting. These selection procedures were followed again in the F_3 generation. The number of plants in the F_3 generation in all crosses ranged from 60 to 90 plants. In the F_4 generation, individual plants were selected according desired traits, i.e. days to flowering, days to maturity, good plant type and yield as compared to the check (CM2). Plants were selected in a sequential culling procedure. First, those plants which were at least three days later flowering than CM2 were selected. Second, those later flowering plants which were similar in maturity to CM2 were saved. Finally, the later flowering plants with favorable maturity were selected for yield and other traits that were superior to CM2. A total of 331 lines were selected from all methods and crosses. Selected plants were harvested and threshed separately. The selected 331 F_5 lines were planted in plant-to-row for seed multiplication and selected by comparing to CM2, the standard check. The selection in the F_5 generation was based on days to flowering and maturity. From each cross population, 17 lines were selected for each method of selection.

Heritability estimates

A total of 165 random F_2 plants (55 plants from each three crosses including CB1 x NS1, LJ4 x NS1 and LJ4 x CM2) were individually harvested. Thirty-five F_3 seeds were randomly selected from each plant for planting the following season. Unreplicated $F_{2:3}$ progeny rows were planted in September, 2001. Days to flowering and days to maturity were recorded for each progeny row. The data were used to estimate heritability using parent-offspring regression. Parent-offspring regression coefficients (b) were calculated from regression of $F_{2:3}$ progeny row means onto parental F_2 plants using PROC REG. Narrow sense heritability for days to flowering and days to maturity were computed as:

$$h^2 = \frac{2}{3} b_{(F_3,\ F_2)}$$

where h^2 = narrow sense heritability and $b_{(F3,\ F2)}$ = regression coefficients of offspring (F_3) family means in one environment on parent (F_2) individuals in the previous season (Smith and Kinman, 1965).

Preliminary yield trial

Seventeen early maturing lines with long vegetative periods were selected with each method in each population and were evaluated in the F_7 generation. The F_7 seeds of lines from three crosses, LJ4 x CM2, LJ4 x NS1 and CB1 x NS1, were planted in a split plot design with three replications. Two selection methods were main plots, lines from each method within crosses were sub plots. Total of 102 entries were evaluated. Each main plot consisted of 17 CSSD lines, 17 MSSD lines plus three check varieties (CM2, NS1 and SJ5). CM2, NS1 and SJ5 were planted randomly in every replications. Each plot consisted of four 4-m rows spaced 50 cm apart. Within each row, the hills were spaced 20 cm apart with two plants per hill (i.e. 20 plants m^{-2}). The experiment was planted at two locations. The lines were planted between 5 January at the SUT farm and 15 January, 2003 at the Suwan farm. Alachlor was applied as pre-emergence herbicide on the date of planting. Additional weed control was done manually as needed. Diseases were suppressed by use of benomyl. Methomyl and acephate were used for insect control. Overhead sprinkler irrigation was applied once a week as there was no rain in the planting season.

Data were collected for both locations for days to flowering, days to maturity, seed yield, seed size, pods per plant, seeds per plant and branches per plant. At harvest, two middle rows of each plot were harvested at maturity. Seed harvested from each plot was recorded in grams per plot and converted to kilograms per hectare. Ten plants were selected at random from the interior portion of the center two rows for determination of yield components. The traits measured for were the following:

1. Days to flowering were recorded as the number of days from planting to first bloom.
2. Days to maturity were recorded as the number of days from planting to 95% pods turned brown.
3. Yield measurement in kg ha^{-1} was calculated at 12% moisture as follows:

$$\text{Seed yield}\,(\text{kg ha}^{-1}) = \frac{\text{Yield/plot (g)}}{1{,}000\,\text{g}} \times \frac{10{,}000\,\text{m}^2}{\text{Harvested area}} \times \frac{100-12}{100-\text{moisture (\%)}}$$

4. Seed size measured as weight of 100 seeds randomly sample from the whole seeds in each plot.
5. Nodes per plant was counted on ten randomly selected plants from each plot.

6. Branches per plant was counted on ten randomly selected plants from each plot.
7. Pods and seeds per plant were counted on ten randomly selected plants from each plot.
8. Plant height measured from the cotyledonary node to the tip of plant.

Statistical analysis

Locations and replications were considered random effects, while methods, and the seventeen lines within method per cross were considered fixed effects. The data were analyzed statistically using PROC GLM (SAS Institute, 1985). Phenotypic correlation coefficients were calculated among variables using PROC CORR of the SAS software (SAS Institute, 1992). Genotypic correlations between traits were computed as:

$$r_g = Cov_{g(xy)} / (Var_{g(x)}\ Var_{g(y)})^{1/2}$$

where Cov and Var are the genotypic covariance and variance components, respectively for trait x and y (Falconer, 1989; Laosuwan, 2003).

Table 1. Crosses between groupings of nine soybean varieties.

Group	Variety	Late			Medium		
		CB1	LJ4	KKU35	KUSL20004	KKU67	SJ2
Early	CM2	X	X	X	X	X	X
	NS1	X	X	X	X	X	X
	ST2	X	X	X	X	X	X

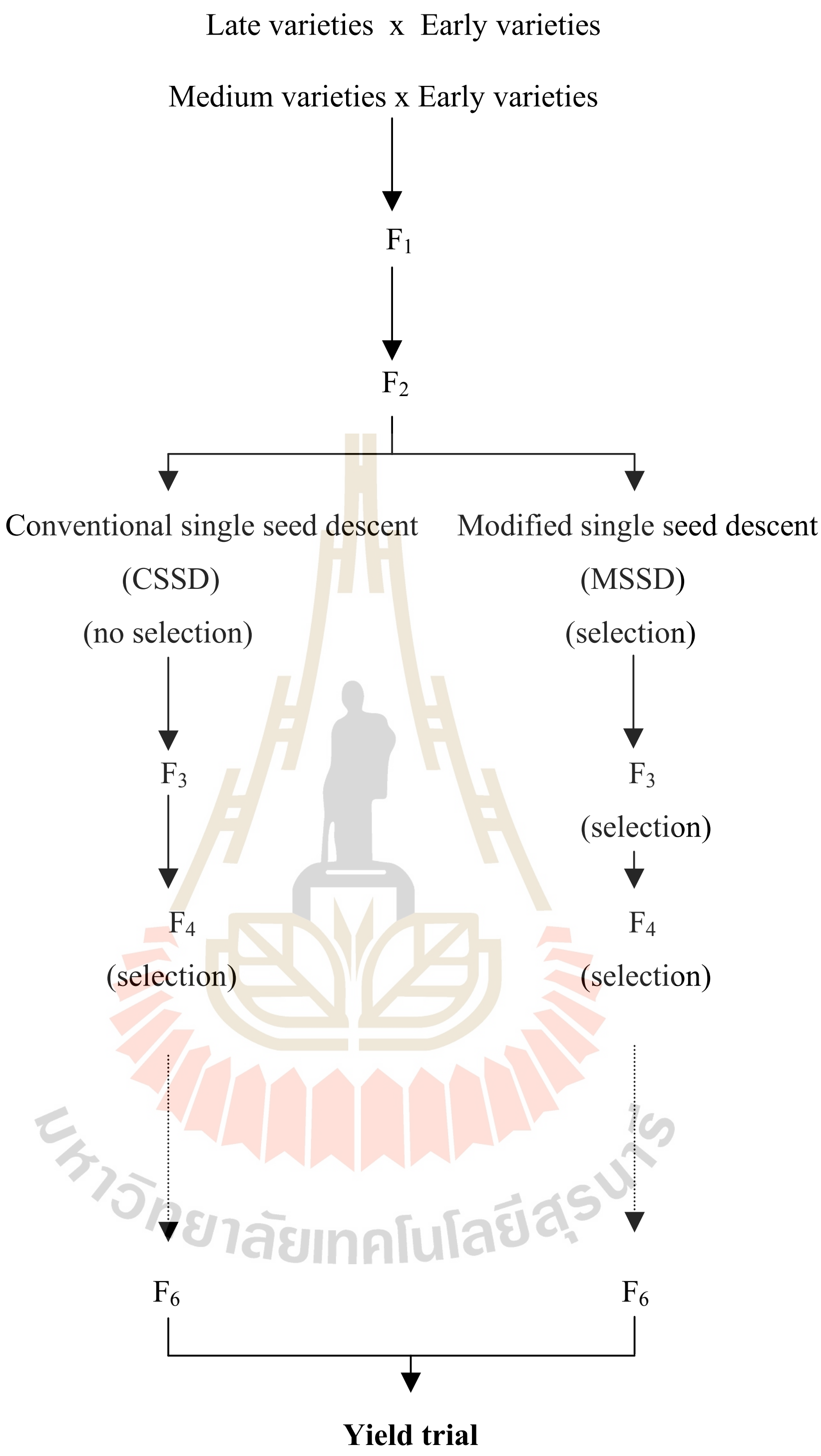


Fig. 1. Procedures for single seed descent (SSD) selection for late flowering and early maturity.

Results and Discussion

Days to flowering, days to maturity and heterosis

Means for days to flowering of early, medium and late parental varieties were in the ranges of 28 - 31, 33 - 37 and 40 - 45 days, respectively (Table 2). Similarly, days to maturity of the respective groups were 79 - 86, 90 - 96 and 101 - 124 days. Means plant height were in the ranges of 48 - 56, 63 - 68 and 74 - 107 cm, respectively.

Means for days to flowering and days to maturity of F_1s obtained from crossing between different types of soybean fell within the ranges of their respective parents (Table 3). Many of them gave higher days to flowering and lower days to maturity than mid-parents suggesting the improvement by selection of these characters should be possible. Heterotic effects of 18 F_1 crosses are given in Table 4. Among these, 17 crosses exhibited negative mid-parent heterosis for days to flowering. The remaining F_1 from LJ4 x CM2 showed positive heterosis. For days to maturity, 15 crosses gave negative heterosis. Kaw and Menon (1979) also found negative heterosis for these traits. The genes contributing to heterosis appeared to be dominant for early days to flowering and days to maturity. The results showed that there was potential to select lines that flower later than the early parents with days to maturity earlier than that of the mid-parent.

The analyses of variance for days to flowering and days to maturity of parents and F_1s given in Table 5 showed that both general and specific combining abilities (gca, sca) were important for both characters. The relative importance of gca indicated that the selection of lines with desirable characters of days to flowering and maturity would be possible.

At this stage, three crosses LJ4 x CM2, LJ4 x NS1 and CB1 x NS1 were selected for further selection (Table 6). The criteria for selection were that they should have acceptable days to flowering and days to maturity. Days to flowering should be low in negative heterosis, i.e. not very different from the mid-parent and they should have acceptable plant type. On the other hand, selected lines should have negative heterosis for days to maturity. Acceptable plant type was defined as larger plant stature, and higher pods and seeds per plant than early maturing parents.

Phenotypic variance in F_2 through F_4

Days to flowering in F_2 generation ranged from 28 to 47 days in all crosses (Table 7). Days to maturity were in the ranges of 78 - 96, 78 - 123 and 78 - 124 for CB1 x NS1, LJ4 x NS1 and LJ4 x CM2, respectively (Table 8). For CSSD method, ranges for days to flowering and days to maturity in F_2 through F_4 were in similar magnitudes as there were no selection in those generations. Means for the traits also varied little among F_2 though F_4. With the MSSD method, ranges in the F_4 generation for days to flowering and days to maturity were quite small in all crosses due to early generation selection. In addition, means for both traits in F_4 tended to be earlier than F_2 and F_3. Estimates of phenotypic variances in F_2 through F_4 for days to flowering and to maturity were calculated on an individual plant basis (Tables 7 and 8). The advanced CSSD populations had larger variances than the MSSD method due to no selection within early generations. For the MSSD populations, phenotypic variances of F_3 and F_4 were very much lower than that of F_2 due to selections made in F_2. The results indicated that there were very little genetic variability remaining in the F_4.

Heritability

Narrow sense heritability was calculated for days to flowering and days to maturity for all three populations (Table 9). Heritabilities for days to flowering ranged from 0.62 to 0.74 and days to maturity ranged from 0.57 to 0.63. The heritability estimates in this study were similar to those reported by other workers. Weber and Moorthy, (1952) found narrow sense heritability for days to flowering ranging from 0.66 to 0.83, days to maturity ranging from 0.67 to 0.86. Alam and Muresan (1985) found that the heritability for days to flowering and to maturity were 0.60 and 0.45, respectively. The moderate to high heritability of these traits indicates that it should be possible to select a longer vegetative period with early maturity.

Selection in F_4

Individual plants were selected for desirable characters in the F_4 generation in the selection nursery. Days to flowering ranged from 28 to 46 days and days to maturity ranged from 78 to 124 days (Tables 7 and 8). Selections were made for lines within these ranges. The numbers of best lines which flowered at least three days later than the check (CM2) but matured about the same date with the check are shown in Table 10. The CSSD method gave a small advantage over the MSSD method as it provided a higher number of good lines.

Selection methods and performance of F_7 lines from selection

Analyses of variance of selected F_7 lines for different traits measured in the three crosses are given in Tables 11, 12 and 13. Method effects on yield and seed size were significant in all crosses. In each cross, lines selected by each method were significantly different for days to flower, days to maturity, seed size and plant height. No significant differences were found for number of nodes, branches, pods and seeds per plant.

Considering all three crosses, the results indicated consistent differences between selection methods for yield (Appendix, Tables 2, 3 and 4). The averages of all lines from the CSSD method were higher yielding than lines from the MSSD method (Table 14). When the top five lines from each cross were selected, the lines from CSSD were superior in yield to lines selected by MSSD method (Tables 15, 16 and 17). Furthermore, lines from CSSD method had longer vegetative periods, earlier, and had larger seed size and plant stature than lines selected by the MSSD method. However, selection method had no apparent effect on number of nodes, branches, pods and seeds per plant. From these results, the CSSD method was superior to the MSSD method, because it was more effective in retaining a long vegetative period and early maturing lines. Also, CSSD permitted a greater genetic gain in yield than MSSD.

Correlation coefficients between days to flowering and days to maturity with yield, yield components and other characters are shown in Table 18. The significant phenotypic correlation between days to flowering and seed yield found in all crosses indicated that extending days to flowering is important to breed soybean for high yielding potential (Tomkins and Shipe, 1996). Genetic correlation between these two characters also high in all crosses. Positive phenotypic correlation coefficients were also found significant between days to flowering, branches per plant and plant height.

Lines should be improved for extended days to flowering with reduced days to maturity to obtain ideal genotypes with acceptable growing periods and there should be no correlation between days to flowering and days to maturity. Yet, days to flowering was highly correlated with days to maturity. It was difficult to increase days to flowering without increasing days to maturity.

Conclusion

The genes contributing to heterosis appeared to be dominant for early days to flowering and days to maturity. Since, from 18 F_1 crosses it was found that 17 crosses and 15 crosses exhibited negative heterosis for days to flowering and days to maturity, respectively. Heritabilities for these two traits were moderate to high 0.62 to 0.74 for days to flowering and 0.57 to 0.63 for maturity. Lines with longer vegetative period and higher yield were successfully selected using both methods. Yield advantages were found for CSSD selection when the mean yield of all lines and the best five lines from each cross were compared. The lines from CSSD method also had longer vegetative period, earlier, had larger seed size and taller than lines from the MSSD method.

Table 2. Means for days to flowering and days to maturity of nine parents grown at Suranaree University of Technology, Nakhon Ratchasima (NM), 2000.

Group	Parent	Days to flowering	Days to maturity	Plant height
		—— no. ——		cm
Early	CM2	28.0	79.0	48
	NS1	29.0	80.0	44
	ST2	31.0	86.0	56
Medium	KSUL20004	33.0	90.0	63
	KKU67	34.0	91.0	60
	SJ2	37.0	96.0	68
Late	CB1	40.0	101.0	74
	KKU35	41.0	108.0	86
	LJ4	45.0	124.0	107
	$LSD_{0.05}$	3.2	5.5	17.4

Table 3. Means for days to flowering and days to maturity of 18 F_1s grown at Suranaree University of Technology, NM, 2000.

Parent	Days to flowering			Days to maturity		
	CM2[‡]	NS1	ST2	CM2	NS1	ST2
	no.					
LJ4[†]	35.6	33.2	33.5	87.2	82.2	86.0
KKU35	31.2	32.1	32.6	84.4	85.0	87.4
CB1	30.5	31.1	32.7	83.5	82.1	89.0
KKU67	28.3	28.6	29.5	80.9	80.2	82.2
SJ2	29.7	29.7	30.1	80.7	81.8	83.9
KUSL20004	28.2	28.3	29.8	79.5	79.7	81.6

[†] Female parents : LJ4, KKU35, CB1, KKU67, SJ2, KUSL20004.

[‡] Male parents : CM2, NS1, ST2.

Table 4. Heterosis percentages for days to flowering and days to maturity of 18 crosses planted at Suranaree University of Technology, NM, 2000.

Parent	Days to flowering			Days to maturity		
	CM2[‡]	NS1	ST2	CM2	NS1	ST2
	no.					
LJ4[†]	0.3	-7.8	-11.8	-5.2	-11.6	-9.5
KKU35	-6.9	-5.6	-9.4	-1.9	-2.3	-1.8
CB1	-7.6	-7.2	-7.9	-0.6	-3.4	2.3
KKU67	-5.7	-6.2	-9.2	1.1	-1.0	-1.0
SJ2	-5.7	-7.2	-11.5	-0.4	-0.2	-0.1
KUSL20004	-4.4	-5.7	-6.9	0.6	-0.4	-0.5

[†] Female parents : LJ4, KKU35, CB1, KKU67, SJ2 and KUSL20004.

[‡] Male parents : CM2, NS1, ST2.

Table 5. Analysis of variance for days to flowering and days to maturity of nine soybean parents and 18 crosses planted at Suranaree University of Technology, NM, 2000.

Source of Variation	df	Days to flowering	Days to maturity
Crosses vs Parents	1	58.86**	81.82**
Parents	7	162.74**	1755.25**
Male	2	12.23**	120.36**
Female	5	11.69**	58.16**
Male x female	10	11.36**	94.65**
CV (%)		6.21	3.16

** Significant at 0.01 probability level.

Table 6. Number of plants for three cross populations selected by MSSD and CSSD.

Generation	CSSD†			MSSD‡		
	CB1x NS1	LJ4 x NS1	LJ4 x CM2	CB1 x NS1	LJ4 x NS1	LJ4 x CM2
F_1	12	18	20	12	18	20
F_2	624	870	960	624	870	960
F_3	586	752	868	160	180	190
F_4	604	670	742	70	84	80
F_5	56	71	85	30	42	47
F_6	28	34	38	20	24	21
F_7	17	17	17	17	17	17

† Conventional single seed descent selection.

‡ Modified single seed descent selection.

Table 7. Ranges, means and phenotypic variances (σ^2_{Ph}) for days to flowering of three populations.

Generation	F_2		F_3		F_4	
	CSSD[†]	MSSD[‡]	CSSD	MSSD	CSSD	MSSD
			CB1 x NS1			
Range	28 - 47	28 - 47	28 - 45	30 - 40	28 - 45	30 - 37
Means	34.96	34.96	34.71	33.45	34.36	33.32
σ^2_{Ph}	27.66	27.66	24.36	12.55	23.58	8.67
			LJ4 x NS1			
Range	28 - 47	28 - 47	28 - 46	30 - 40	28 - 46	30 - 38
Means	35.11	35.11	34.98	34.36	34.88	34.20
σ^2_{Ph}	39.64	39.64	35.66	13.83	36.54	9.67
			LJ4 x CM2			
Range	28 - 47	28 - 47	28 - 46	30 - 40	28 - 46	30 - 38
Means	36.05	36.05	35.75	34.30	35.32	33.74
σ^2_{Ph}	30.11	30.11	27.78	11.24	26.65	7.68

[†] Conventional single seed descent selection.

[‡] Modified single seed descent selection.

Table 8. Ranges, means and phenotypic variances (σ^2_{Ph}) for days to maturity of three populations.

Generation	F_2		F_3		F_4	
	CSSD[†]	MSSD[‡]	CSSD	MSSD	CSSD	MSSD
			CB1 x NS1			
Range	78 - 96	78 - 96	78 - 96	78 - 86	78 - 92	79 - 85
Means	85.63	85.63	85.29	83.61	84.87	83.06
σ^2_{Ph}	29.07	29.07	21.39	14.37	20.65	10.74
			LJ4 x NS1			
Range	78 - 123	78 - 123	78 - 122	78 - 86	78 - 121	79 - 85
Means	85.89	85.89	85.64	83.63	85.09	83.41
σ^2_{Ph}	30.79	30.79	31.19	18.85	29.87	13.57
			LJ4 x CM2			
Range	78 - 124	78 - 124	78 - 124	79 - 87	78 - 122	79 - 85
Means	85.67	85.67	85.47	83.24	84.98	82.91
σ^2_{Ph}	32.88	32.88	27.95	16.01	28.03	11.26

[†] CSSD = conventional single seed descent selection.

[‡] MSSD = modified single seed descent.

Table 9. Narrow sense heritability (h^2) for days to flowering and days to maturity of three cross populations.

Population	Days to flowering	Days to maturity
CB1 x NS1	0.62 ± 0.002	0.60 ± 0.070
LJ4 x NS1	0.66 ± 0.026	0.63 ± 0.027
LJ4 x CM2	0.74 ± 0.028	0.57 ± 0.044
Average	0.67	0.60

Table 10. Number of the best F_4 lines selected by conventional single seed descent and modified single seed descent procedures.

Entry	CSSD†			MSSD‡		
	No.	Flowering	Maturity	No.	Flowering	Maturity
CB1 x NS1	6	33 - 36	80 - 83	3	32 - 35	80 - 83
LJ4 x NS1	6	32 - 36	80 - 83	4	33 - 36	80 - 83
LJ4 x CM2	8	33 - 37	80 - 83	4	32 - 36	80 - 83
CM2 (Check)	-	30	80	-	30	80

† Conventional single seed descent.

‡ Modified single seed descent.

Table 11. Analysis of variances for eight characters of CB1 x NS1 population grown at SUT farm and Suwan farm, NM, 2003.

Source of Variation	df	DF[†]	DM[‡]	Yield	Seed size	Nodes	Branches	Pods	Seeds	Plant height
						$plant^{-1}$				
Locations (L)	1	**	**	**	**	**	*	**	**	**
Methods (M)	1	ns	ns	**	**	ns	*	ns	ns	ns
L x M	1	*	*	**	ns	ns	ns	ns	ns	ns
Method 1[¶]										
Entries [+]	19	*	*	ns	ns	ns	ns	ns	ns	*
L x Entries	19	**	**	**	**	**	*	**	**	ns
Method 2 [§]										
Entries	19	ns	**	ns	ns	ns	ns	ns	ns	*
L x Entries	19	**	ns	**	**	ns	ns	*	ns	ns
CV (%)		3.0	2.0	12.5	6.0	7.0	12.9	13.4	11.2	10.5

[†] Days to flowering

[‡] Days to maturity

[+] Entries = 17 lines + 3 checks

[¶] Conventional single seed descent

[§] Modified single seed descent

*, **, ns = Significant at 0.05, 0.01 level of significant and not significant, respectively.

Table 12. Analysis of variances for eight characters of LJ4 x NS1 population grown at SUT farm and Suwan farm, NM, 2003.

Source of Variation	df	DF†	DM‡	Yield	Seed size	Nodes plant^{-1}	Branches plant^{-1}	Pods plant^{-1}	Seeds plant^{-1}	Plant height
Locations (L)	1	ns	**	**	**	**	ns	**	**	**
Methods (M)	1	**	**	**	**	ns	ns	*	*	ns
L x M	1	**	ns	ns	*	ns	ns	ns	ns	ns
Method 1 ¶										
Entries +	19	**	**	ns	ns	ns	*	ns	ns	*
L x Entries	19	ns	*	**	*	**	*	**	ns	ns
Method 2 §										
Entries	19	**	**	ns	ns	ns	*	ns	ns	*
L x Entries	19	ns	ns	**	**	**	ns	**	ns	ns
CV (%)		3.4	3.2	9.9	6.1	7.6	9.5	12.7	14.3	15.2

† Days to flowering

‡ Days to maturity

+ Entries = 17 lines + 3 checks

¶ Conventional single seed descent

§ Modified single seed descent

*, **, ns = Significant at 0.05, 0.01 level of significant and not significant, respectively.

Table 13. Analysis of variances for eight characters of LJ4 x CM2 population grown at SUT farm and Suwan farm, NM, 2003.

Source of Variation	df	DF†	DM‡	Yield	Seed size	Nodes plant^{-1}	Branches plant^{-1}	Pods plant^{-1}	Seeds plant^{-1}	Plant height
Location (L)	1	ns	**	**	**	**	**	**	**	**
Method (M)	1	**	ns	**	**	ns	ns	ns	ns	ns
L x M	1	ns	**	ns	ns	*	ns	ns	ns	ns
Method 1¶										
Entries +	19	**	**	ns	ns	ns	*	ns	ns	*
L x Entries	19	**	*	**	**	*	ns	**	ns	ns
Method 2 §										
Entries	19	**	**	ns	ns	ns	ns	ns	ns	*
L x Entries	19	**	**	**	**	**	ns	**	*	ns
CV (%)		2.9	4.0	10.4	5.5	8.3	12.6	15.8	16.3	14.8

† Days to flowering

‡ Days to maturity

+ Entries = 17 lines + 3 checks

¶ Conventional single seed descent

§ Modified single seed descent

*, **, ns = Significant at 0.05, 0.01 level of significant and not significant, respectively.

Table 14. Means over locations of each population for yield, days to flowering, days to maturity and seed size of three cross populations selected by two procedures, NM, 2003.

Procedure	Yield	DF[†]	DM[‡]	Seed size	Nodes	Branches	Pods	Seeds	Plant height
					plant^{-1}				
	kg ha^{-1}	no.		g 100 seeds^{-1}	no.				cm
				CB1 x NS1					
CSSD[¶]	2,693	34.5	82.4	17.63	10.4	2.2	30.6	56.7	54.7
MSSD[§]	2,537	33.7	82.8	17.05	10.5	2.5	28.4	50.3	52.3
$LSD_{0.05}$	76	0.24	0.24	0.29	0.2	0.3	2.7	5.7	3.2
				LJ4 x NS1					
CSSD	2,732	34.9	82.2	19.38	10.5	2.1	30.4	62.4	60.2
MSSD	2,651	34.0	82.8	18.02	10.7	2.0	30.7	60.2	55.5
$LSD_{0.05}$	85	0.34	0.28	0.32	0.2	0.2	2.9	4.5	3.7
				LJ4 x CM2					
CSSD	2,723	35.1	82.3	16.72	10.81	2.0	31.0	60.2	59.3
MSSD	2,647	34.6	82.6	16.09	11.04	2.1	30.1	58.1	55.8
$LSD_{0.05}$	92	0.28	0.23	0.25	0.25	0.2	3.7	5.7	3.4

[†] Days to flowering

[‡] Days to maturity

[¶] Conventional single seed descent

[§] Modified single seed descent

Table 15. Means over locations of five best lines obtained from CB1 x NS1 population, 2003.

Entry	Yield	DF†	DM‡	Seed size	Nodes	Branches	Pods	Seeds	Plant height
					plant^{-1}				
	kg ha^{-1}	no.		g 100 seeds^{-1}	no.				cm
Conventional single seed descent									
CSSD-1106	2,650	34.8	81.7	16.9	9.6	1.8	27.0	51	48
CSSD-1110	2,822	35.3	82.7	16.7	10.5	2.2	30.5	59	60
CSSD-1113	2,743	34.8	82.3	15.4	10.3	2.2	28.3	53	51
CSSD-1115	2,779	34.7	81.8	18.7	10.8	2.1	30.5	55	48
CSSD-1117	2,874	34.2	82.5	18.9	10.6	1.9	27.8	57	55
CM2	2,474	30.0	81.2	16.3	10.5	1.9	27.1	53	48
NS1	2,561	30.8	81.7	20.2	10.2	1.5	25.5	49	46
SJ5	2,757	36.0	99.0	17.5	13.0	2.6	34.8	72	68
LSD $_{0.05}$	159	1.0	1.0	1.1	0.9	0.8	6.1	9.9	8.4
Modified single seed descent									
MSSD-1202	2,615	32.8	81.7	16.9	10.2	2.5	29.5	52	56
MSSD-1203	2,617	33.5	82.8	17.1	10.5	2.6	30.3	57	58
MSSD-1211	2,663	33.7	82.2	17.6	10.6	2.4	29.8	54	57
MSSD-1215	2,610	34.2	82.3	18.9	10.2	2.4	30.4	57	59
MSSD-1216	2,742	33.7	84.2	16.7	10.6	2.0	34.3	63	61
CM2	2,526	30.0	81.0	16.3	10.0	1.9	27.1	51	46
NS1	2,559	30.5	81.8	18.7	10.0	1.5	27.3	50	48
SJ5	2,777	36.0	100.2	16.7	13.0	3.0	32.7	66	71
LSD $_{0.05}$	174	1.1	1.0	1.3	0.9	1.4	5.3	7.4	7.2

† Days to flowering.

‡ Days to maturity.

Table 16. Means over locations of five best lines obtained from LJ4 x NS1 population, 2003.

Entry	Yield	DF†	DM‡	Seed size	Nodes	Branches	Pods	Seeds	Plant
					plant^{-1}				height
	kg ha^{-1}	no.		g 100 seeds^{-1}	no.				cm
Conventional single seed descent									
CSSD-2101	2,682	34.3	81.2	18.0	9.9	2.3	30.2	50	59
CSSD-2104	2,976	32.7	80.5	20.0	10.2	1.9	30.5	58	57
CSSD-2108	2,941	36.2	83.3	18.3	10.0	2.0	29.9	64	56
CSSD-2109	2,903	33.8	80.8	19.2	10.1	1.7	28.8	56	60
CSSD-2111	2,526	32.8	81.2	20.9	10.0	1.6	22.9	45	48
CM2	2,559	31.0	81.0	16.7	10.0	2.1	30.8	57	42
NS1	2,570	30.8	81.5	20.0	10.0	2.1	26.3	51	46
SJ5	2,703	36.0	99.0	17.2	13.0	2.7	32.5	65	67
LSD $_{0.05}$	148	1.4	1.0	1.3	1.0	0.7	5.1	9.1	8.3
Modified single seed descent									
MSSD-2206	2,807	34.3	82.2	19.8	9.7	1.9	27.3	57	53
MSSD-2207	2,702	35.7	81.7	17.7	10.1	2.2	32.1	52	55
MSSD-2208	2,882	33.5	82.8	17.3	10.9	2.1	35.5	78	74
MSSD-2209	2,740	35.8	81.7	16.4	10.7	2.1	29.0	49	46
MSSD-2215	2,799	34.8	83.3	16.1	10.7	2.1	31.4	61	65
CM2	2,568	30.0	80.8	16.8	10.0	2.1	34.3	58	45
NS1	2,608	31.0	81.0	19.8	10.0	1.6	24.1	45	46
SJ5	2,737	36.0	98.0	16.5	13.0	3.2	38.5	74	62
LSD $_{0.05}$	162	1.0	1.3	1.2	0.9	0.7	4.4	8.3	7.1

† Days to flowering.

‡ Days to maturity.

Table 17. Means over locations of five best lines obtained from LJ4 x CM2 population, 2003.

Entry	Yield	DF†	DM‡	Seed size	Nodes	Branches	Pods	Seeds	Plant height
					plant^{-1}				
	kg ha^{-1}	no.		g 100 seeds^{-1}		no.			cm
Conventional single seed descent									
CSSD-3102	2,650	34.8	80.6	16.7	11.0	1.8	32.0	69	57
CSSD-3105	2,818	33.7	81.2	15.6	10.9	1.7	27.8	55	65
CSSD-3108	2,870	33.3	80.3	17.9	11.0	1.7	30.7	59	69
CSSD-3110	2,857	36.5	82.2	16.2	10.8	1.9	36.1	68	55
CSSD-3114	2,728	35.2	80.4	16.9	11.1	2.0	29.1	61	56
CM2	2,572	30.0	80.3	16.7	10.5	1.9	26.2	52	42
NS1	2,589	30.4	81.3	19.5	10.2	1.3	25.5	43	48
SJ5	2,730	36.1	100.0	17.6	12.9	3.0	37.6	72	63
$LSD_{0.05}$	165	1.1	1.0	1.2	1.2	0.7	4.3	6.7	7.5
Modified single seed descent									
MSSD-3202	2,754	33.7	82.5	15.7	11.4	1.8	29.9	60	44
MSSD-3206	2,733	35.3	82.3	18.5	10.5	1.6	29.0	57	61
MSSD-3211	2,818	32.7	82.6	17.9	10.5	2.0	26.5	57	58
MSSD-3215	2,750	34.7	83.2	16.4	11.5	2.3	35.7	64	57
MSSD-3217	2,888	33.3	81.6	16.8	11.3	2.5	29.4	56	66
CM2	2,549	30.0	80.5	16.4	10.0	1.6	24.4	45	41
NS1	2,658	31.0	81.2	19.7	10.0	1.9	30.1	54	47
SJ5	2,669	36.0	98.0	17.2	12.5	3.0	43.5	81	67
$LSD_{0.05}$	156	1.1	1.0	1.3	0.8	0.8	5.0	7.5	8.2

† Days to flowering.

‡ Days to maturity.

Table 18. Phenotypic and genotypic correlation coefficient between days to flowering, days to maturity with yield and other characters of the selected lines combined over methods of three populations, NM, 2003.

Character	Maturity	Yield	Seed size	Nodes	Branches	Pods	Seeds	Plant
				plant $^{-1}$				height
				CB1 x NS1				
Flowering	0.56*	0.46*	-0.49*	0.33	0.43*	0.53*	0.43*	0.45*
	(0.58)	(0.59)	(-0.51)	(0.50)	(0.52)	(0.65)	(0.68)	(0.66)
Maturity		-0.43*	0.54*	0.45*	0.47*	0.32	0.42*	0.51*
		(-0.58)	(0.55)	(0.61)	(0.62)	(0.63)	(0.67)	(0.66)
				LJ4 x NS1				
Flowering	0.53*	0.45*	-0.43*	0.32	0.45*	0.42*	0.40*	0.43*
	(0.59)	(0.51)	(-0.51)	(0.58)	(0.56)	(0.52)	(0.57)	(0.60)
Maturity		-0.35	0.74**	0.35	0.38	0.36	0.35	0.47*
		(-0.51)	(0.56)	(0.58)	(0.51)	(0.52)	(0.58)	(0.56)
				LJ4 x CM2				
Flowering	0.50*	0.55*	-0.56*	-0.55*	0.38	0.55*	0.45*	0.33
	(0.62)	(0.67)	(-0.54)	(-0.55)	(0.63)	(0.59)	(0.64)	(0.58)
Maturity		0.34	0.53*	0.52*	0.40	0.38	0.38	0.49*
		(0.50)	(0.58)	(0.63)	(0.63)	(0.61)	(0.63)	(0.63)

*, ** Significant at the 0.05 and 0.01 probability levels, respectively.

Genotypic correlation coefficient in parenthesis.

References

Alam, S., and Muresan, T. (1985). The inheritance of some quantitative characters in soybean. **Thai J. Agric. Sci.** 18: 101 - 108.

Brim, C. A. (1966). A modified pedigree method of selection in soybeans. **Crop Sci.** 6: 220.

Byron, D. F., and Orf, J. H. (1991). Comparison of three selection procedures for development of early-maturing soybean lines. **Crop Sci.** 31: 656 - 660.

Department of Agriculture. (1994). **Field crop production.** Bangkok: Kurutsapa Ladpraow (in thai).

Dunphy, E. J., Hanway, J. J., and Green, D. E. (1979). Soybean yields in relation to days between specific developmental stages. **Agron. J.** 71: 917 - 920.

Empig, L. T., and Fehr, W. R. (1971). Evaluation of methods for generation advance in bulk hybrid soybean populations. **Crop Sci.** 11: 51 - 54.

Falconer, D. S. (1989). **Introduction to quantitative genetics** (3rd ed). New York: Longman.

Hartwig, E. E. (1970). Growth and reproductive characteristics of soybean [*Glycine max* (L) Merr.] grown under short-days conditions. **Trop. Sci.** 12: 47 - 53.

Hartwig, E. E., and Kiihl, R. A. S. (1979). Identification and utilization of a delayed flowering character in soybean for short-day conditions. **Field Crops Res.** 2: 145 - 151.

James, A. T., Chotiyanwong, A., Laohasiriwong, S., Nakiracks, P., Neumaier, N., Pintongkum, S., Pookpakdi, A., Promdeeraj, T., Sirichumpan, V., Lawn, R. J., and Imrie, B. C. (1994). Exploiting the long juvenile trait in Asian production systems. In **Proceedings: World Soybean Research Conference V** (pp. 69 - 73). Bangkok: Kasetsart University Press.

Kaewmeechai, S., Sithipong, S., Srisombun, S., Pichitporn, S., Tumsan, S., Dangpradub, S., and Supapornhemin, P. (1997). Early maturity soybean: Line CM 8728 - B - 2. In **Proceedings National Soybean Research Conference VI** (pp. 23 - 35). Bangkok: Kasetsart University Press.

Kaw, R. N., and Menon, P. M. (1979). Heterosis in a ten parent diallel cross in soybean. **Indian J. Agric. Sci.** 49: 322 - 324.

Laosuwan, P. (2003). **Principle of plant breeding.** Nakhon Ratchasima: Suranaree University of Technology.

SAS Institute, Inc. (1985). **SAS user's guide: Statistics,** version 5 ed. Cary, NC. SAS Institute, Inc.

Shipe, E. R., Tomkins, J. P., and Hinson, K. (1994). Performance of long juvenile soybean genotypes in thesoutheastern USA. In **Proceedings: World Soybean Research Conference V** (pp. 15 - 17). Bangkok: Kasetsart University Press.

Smith, J. D., and Kinman, M. L. (1965). The use of parent off - spring regression as an estimater of heritability. **Crop Sci.** 5: 595 - 596.

Tomkins, J. P., and Shipe, E. R. (1996). Soybean growth and agronomic performance in response to the long juvenile traite. **Crop Sci.** 36: 1144 - 1149.

Weber, C. R., and Moorthy, B. R. (1952). Heritable and nonheritable relationships and variability of oil content and agronomic characters in the F_2 generation of soybean crosses. **Agron. J.** 44: 202 - 209.

Appendix

Table 1. Certain descriptions of the nine soybean varieties used in this study.

Group	Variety	Days to flowering	Days to maturity	Plant height	Reference
		.... no.	....	cm	
Early	CM2	29	79	40	Uthaida and Laosuwan, 2001
	NS1	29	78	50	Uthaida, 1999
	ST2	31	82	48	Uthaida, 1999
Medium	KKU67	36	95	65	Laosuwan et al., 1992
	SJ2	33	91	76	Uthaida, 1999
	KUSL20004	34	95	67	Uthaida, 1999
Late	LJ4	42	120	116	Pookpakdi et al., 1997
	KKU35	38	110	85	Laosuwan et al., 1992
	CB1	39	102	71	Uthaida and Laosuwan, 2001

Table 2. Means yield and other characters over locations of lines selected in the F_7 of CB1xNS1 cross.

Entry	Yield	DF†	DM‡	Seed size	Nodes	Branches	Pods	Seeds	Plant height
					plant^{-1}				
	kg ha^{-1}	—— no. ——		g 100 seeds^{-1}	——————no. ——————				cm
Conventional single seed descent									
1101	2,430	35.3	82.7	18.7	10.4	2.2	28.8	48	48
1102	2,882	33.8	84.0	16.7	12.0	1.8	35.3	69	76
1103	2,540	33.0	83.3	16.4	10.5	2.4	31.8	58	55
1104	2,535	34.5	80.7	15.2	10.2	2.2	28.9	49	40
1105	2,829	35.2	83.2	15.9	10.6	1.8	35.8	69	56
1106	2,650	34.8	81.7	16.9	9.6	1.8	27.0	51	48
1107	2,428	34.3	81.5	17.2	10.0	2.1	25.5	52	45
1108	2,635	34.5	82.7	17.8	10.2	1.9	31.0	56	43
1109	2,632	34.3	83.3	17.3	10.5	2.0	28.2	52	56
1110	2,822	35.3	82.7	16.7	10.5	2.2	30.5	59	60
1111	2,678	34.7	83.2	17.0	10.5	2.4	31.8	59	51
1112	2,757	33.3	82.7	15.8	10.2	2.3	26.9	49	51
1113	2,743	34.8	82.3	15.4	10.3	2.2	28.3	53	51
1114	2,621	34.8	83.5	15.1	10.8	3.2	33.4	58	58
1115	2,779	34.4	81.8	18.7	10.8	2.1	30.5	55	48
1116	2,649	33.3	83.2	17.4	10.7	2.8	32.1	60	62
1117	2,874	34.2	82.5	18.9	10.6	1.9	27.8	57	55
CM2	2,474	30.0	81.2	16.3	10.5	1.9	27.1	53	48
NW1	2,561	30.8	81.7	20.2	10.2	1.5	25.5	49	46
SJ5	2,757	36.0	99.0	17.5	13.0	2.6	34.8	72	68
$LSD_{0.05}$	159	1.0	1.0	1.1	0.9	0.8	6.1	9.9	8.4

Table 2. Continued.

Entry	Yield	DF†	DM‡	Seed size	Nodes	Branches	Pods	Seeds	Plant height
					plant^{-1}				
	kg ha^{-1}	no.		g 100 seeds^{-1}	no.				cm
Modified single seed descent									
1201	2,528	35.8	83.7	16.6	10.7	2.0	26.1	45	57
1202	2,615	32.8	81.7	16.9	10.2	2.5	29.5	52	56
1203	2,617	33.5	82.8	17.1	10.5	2.6	30.3	57	58
1204	2,489	33.2	80.7	15.3	9.6	2.1	24.8	47	40
1205	2,415	32.2	82.7	17.1	10.4	2.2	41.1	70	47
1206	2,532	33.0	81.8	18.1	10.8	3.2	26.1	50	58
1207	2,524	32.7	81.3	18.3	10.1	4.2	30.3	52	53
1208	2,454	32.7	84.3	16.7	10.1	3.0	29.8	54	59
1209	2,557	34.0	82.5	16.3	10.3	2.8	29.9	56	58
1210	2,554	33.7	82.7	16.0	10.8	2.7	27.2	52	57
1211	2,663	33.7	82.2	17.6	10.6	2.4	29.8	54	57
1212	2,559	35.0	81.5	16.4	10.3	2.1	26.0	49	57
1213	2,510	34.8	82.9	15.8	11.0	2.3	28.7	57	51
1214	2,444	32.8	81.7	19.3	10.8	2.2	33.7	66	57
1215	2,610	34.2	82.3	18.9	10.2	2.4	30.4	57	59
1216	2,742	33.7	84.2	16.7	10.6	2.0	34.3	63	61
1217	2,356	34.8	82.8	17.9	10.6	2.2	30.4	54	46
CM2	2,526	30.0	81.0	16.3	10.0	1.9	27.1	51	46
NW1	2,559	30.5	81.8	18.7	10.0	1.5	27.3	50	48
SJ5	2,777	36.0	100.2	16.7	13.0	3.0	32.7	66	71
LSD $_{0.05}$	174	1.1	1.0	1.3	0.9	1.4	5.3	7.4	7.2

† Days to flowering ‡ Days to maturity

Table 3. Means yield and other characters over locations of lines selected in the F_7 of LJ4 x NS1 cross.

Entry	Yield	DF†	DM‡	Seed size	Nodes	Branches	Pods plant^{-1}	Seeds	Plant height
	kg ha^{-1}	no.		g 100 seeds^{-1}			no.		cm
Conventional single seed descent									
2101	2,682	34.3	81.2	18.0	9.9	2.3	30.2	50	59
2102	2,612	32.2	81.8	21.9	10.2	2.4	27.1	60	54
2103	2,594	34.0	83.7	19.1	10.7	1.4	25.2	54	64
2104	2,976	32.7	80.5	20.0	10.2	1.9	30.5	58	57
2105	2,775	32.7	82.0	21.4	11.1	2.0	35.1	68	51
2106	2,585	32.8	83.3	20.2	10.7	2.8	25.2	51	52
2107	2,639	34.2	82.0	16.5	11.4	3.1	34.0	70	60
2108	2,941	36.2	83.3	18.3	10.0	2.0	29.9	64	56
2109	2,903	33.8	80.8	19.2	10.1	1.7	28.8	56	60
2110	2,722	33.5	82.7	21.4	10.8	1.3	29.0	54	55
2111	2,773	32.8	81.2	20.9	10.0	1.6	22.9	45	48
2112	2,732	32.3	82.7	17.6	10.4	2.6	34.6	70	63
2113	2,759	32.5	81.8	17.7	11.0	2.7	27.7	48	61
2114	2,426	33.2	80.5	18.9	10.0	2.0	24.6	46	55
2115	2,527	37.3	83.2	18.2	10.1	2.4	26.6	47	61
2116	2,922	36.2	84.0	22.2	10.6	1.3	25.0	48	70
2117	2,866	37.5	84.2	17.9	11.5	2.7	33.4	59	61
CM2	2,559	31.0	81.0	15.7	10.0	2.1	30.8	57	42
NS1	2,570	30.8	81.5	20.0	10.0	2.1	26.3	51	46
SJ5	2,703	36.0	99.0	17.2	13.0	2.7	32.5	65	67
$LSD_{0.05}$	168	1.4	1.0	1.3	1.0	0.7	5.1	9.1	8.3

Table 3. Continued.

Entry	Yield	DF[†]	DM[‡]	Seed size	Nodes	Branches	Pods	Seeds	Plant height
						plant^{-1}			
	kg ha^{-1}	no.		g 100 seeds^{-1}	no.				cm
Modified single seed descent									
2201	2,683	34.0	81.8	16.4	10.7	2.5	30.6	56	49
2202	2,493	32.8	83.3	16.7	10.7	1.2	24.9	51	40
2203	2,588	34.5	82.8	19.6	10.9	1.5	30.9	63	61
2204	2,677	33.8	82.0	16.6	11.7	1.6	34.1	71	59
2205	2,510	32.0	83.0	20.0	10.6	1.9	30.1	60	55
2206	2,807	34.3	82.2	19.8	9.7	1.9	27.3	57	53
2207	2,702	33.7	81.7	17.7	10.1	2.2	32.1	52	55
2208	2,822	32.5	82.8	17.3	10.9	2.1	35.5	78	74
2209	2,740	34.8	81.7	16.4	10.7	2.1	29.0	49	46
2210	2,523	31.8	82.8	18.8	10.2	2.3	32.8	60	55
2211	2,561	32.2	81.7	17.0	9.5	1.9	27.1	58	41
2212	2,721	33.2	84.5	19.5	10.9	2.0	28.3	53	56
2213	2,633	34.2	84.5	15.5	10.7	1.7	30.2	61	58
2214	2,586	32.7	82.7	16.1	10.4	2.3	30.9	63	44
2215	2,799	33.8	83.3	16.1	10.7	2.1	31.4	61	65
2216	2,692	34.3	83.3	22.8	11.0	1.6	30.2	57	68
2217	2,529	34.5	83.7	20.1	11.6	2.0	35.7	74	64
CM2	2,568	30.0	80.8	16.8	10.0	2.1	34.3	58	45
NS1	2,608	31.0	81.0	19.8	10.0	1.6	24.1	45	46
SJ5	2,737	36.0	98.0	16.5	12.8	3.2	38.5	74	62
$LSD_{0.05}$	162	1.0	1.3	1.2	0.9	0.7	4.4	8.3	7.1

[†] Days to flowering [‡] Days to maturity

Table 4. Means yield and other characters over locations of lines selected in F_7 of LJ4 x CM2 cross.

Entry	Yield	DF†	DM‡	Seed size	Nodes	Branches	Pods	Seeds	Plant height
					plant^{-1}				
	kg ha^{-1}	no.		g 100 seeds^{-1}	no.				cm
Conventional single seed descent									
3101	2,703	33.3	83.0	13.8	11.6	2.5	33.3	62	64
3102	2,650	34.8	80.6	16.7	11.0	1.8	32.0	69	57
3103	2,753	34.8	83.2	18.8	10.2	1.8	26.5	52	51
3104	2,851	33.0	82.1	16.9	10.9	2.0	30.8	65	70
3105	2,818	33.7	81.2	15.6	10.9	1.7	27.8	55	65
3106	2,703	33.2	82.7	15.5	10.5	1.7	28.2	50	62
3107	2,755	32.7	82.1	16.8	11.7	2.3	37.4	71	64
3108	2,870	33.3	80.3	17.9	11.0	1.7	30.7	59	69
3109	2,580	36.2	83.6	20.1	10.9	2.0	29.7	55	64
3110	2,857	36.5	82.2	16.2	10.8	1.9	36.1	68	55
3111	2,798	34.8	82.9	16.7	10.6	2.3	34.0	66	52
3112	2,944	34.5	83.1	16.4	10.3	1.9	37.3	74	50
3113	2,488	36.0	83.2	17.8	10.7	1.5	27.3	55	67
3114	2,728	35.2	80.4	16.9	11.1	2.0	29.1	61	56
3115	2,670	35.3	81.4	15.9	10.5	1.8	28.0	58	60
3116	2,758	36.3	82.6	16.1	10.8	2.2	32.1	58	47
3117	2,458	35.2	83.6	16.0	10.4	1.8	27.2	44	56
CM2	2,572	30.0	80.3	16.7	10.5	1.9	26.2	52	42
NS1	2,589	30.4	81.3	19.5	10.2	1.3	25.5	43	48
SJ5	2,730	36.1	100.0	17.6	12.9	3.0	37.6	72	63
$LSD_{0.05}$	165	1.1	1.0	1.2	1.2	0.7	4.3	6.7	7.5

Table 4. Continued.

Entry	Yield	DF†	DM‡	Seed size	Nodes	Branches	Pods	Seeds	Plant height
					plant^{-1}				
	kg ha^{-1}	no.		g 100 seeds^{-1}	no.				cm
Modified single seed descent									
3201	2,641	35.8	82.5	16.3	10.4	1.8	31.6	60	49
3202	2,754	33.7	82.5	15.7	11.4	1.8	29.9	60	44
3203	2,615	34.8	82.6	14.8	10.7	1.7	31.2	68	49
3204	2,407	33.2	82.5	14.6	10.2	2.2	28.8	59	44
3205	2,570	33.0	81.6	16.7	11.7	1.6	27.9	51	50
3206	2,733	35.3	82.3	18.5	10.5	1.6	29.0	57	61
3207	2,620	33.5	81.8	14.7	11.5	2.3	32.7	62	61
3208	2,667	34.3	82.5	14.9	10.5	2.0	30.5	56	48
3209	2,548	33.3	84.1	18.8	11.1	1.9	29.4	56	65
3210	2,690	33.5	83.0	17.2	11.0	2.0	26.9	54	54
3211	2,818	32.7	82.6	17.9	10.4	2.0	26.5	57	58
3212	2,544	34.0	82.5	15.9	11.6	2.5	29.3	53	69
3213	2,712	34.6	83.5	14.6	12.2	2.1	34.6	65	72
3214	2,520	34.7	84.0	15.8	9.8	1.8	27.6	51	41
3215	2,750	34.7	83.2	16.4	11.5	2.3	35.7	64	57
3216	2,511	35.6	82.1	16.0	11.7	2.7	30.6	61	62
3217	2,888	33.3	81.6	16.8	11.3	2.5	29.4	56	66
CM2	2,549	30.0	80.5	16.4	10.0	1.6	24.4	45	41
NS1	2,658	31.0	81.2	19.7	10.0	1.9	30.1	54	47
SJ5	2,669	36.0	98.0	17.2	12.5	3.0	43.5	81	67
$LSD_{0.05}$	156	1.1	1.0	1.3	0.8	0.8	5.0	7.5	82

† Days to flowering ‡ Days to maturity

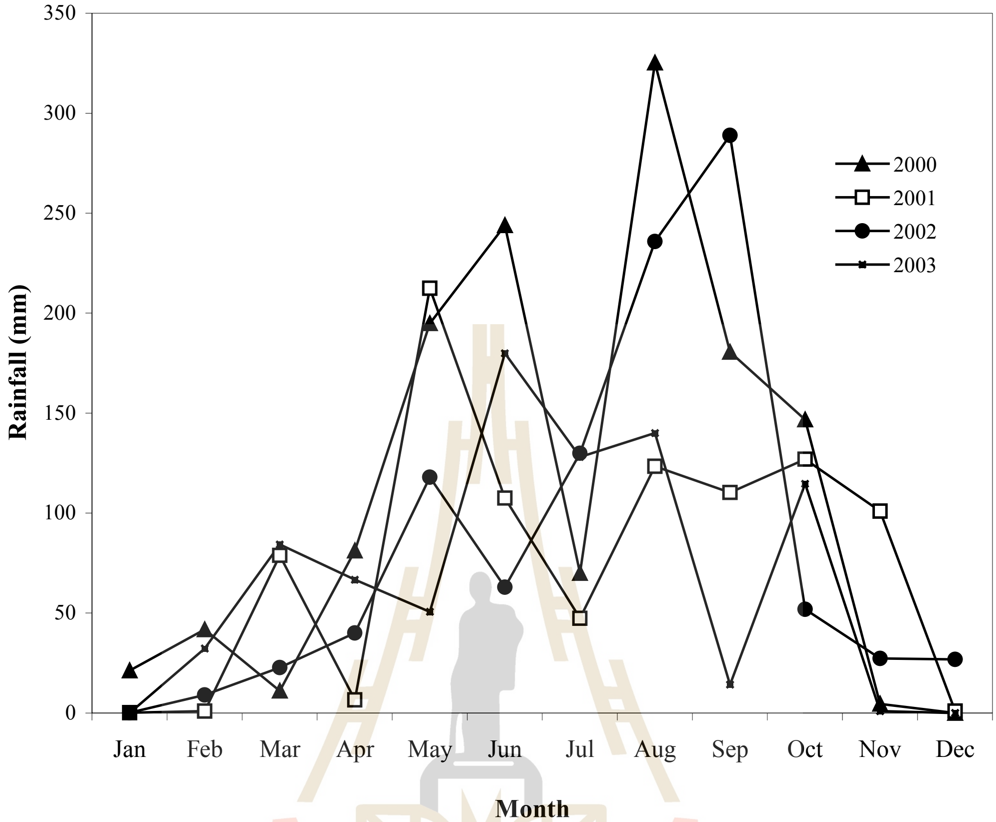


Fig. 1. Rainfall at Nakhon Ratchasima from January 2000 to December 2003.

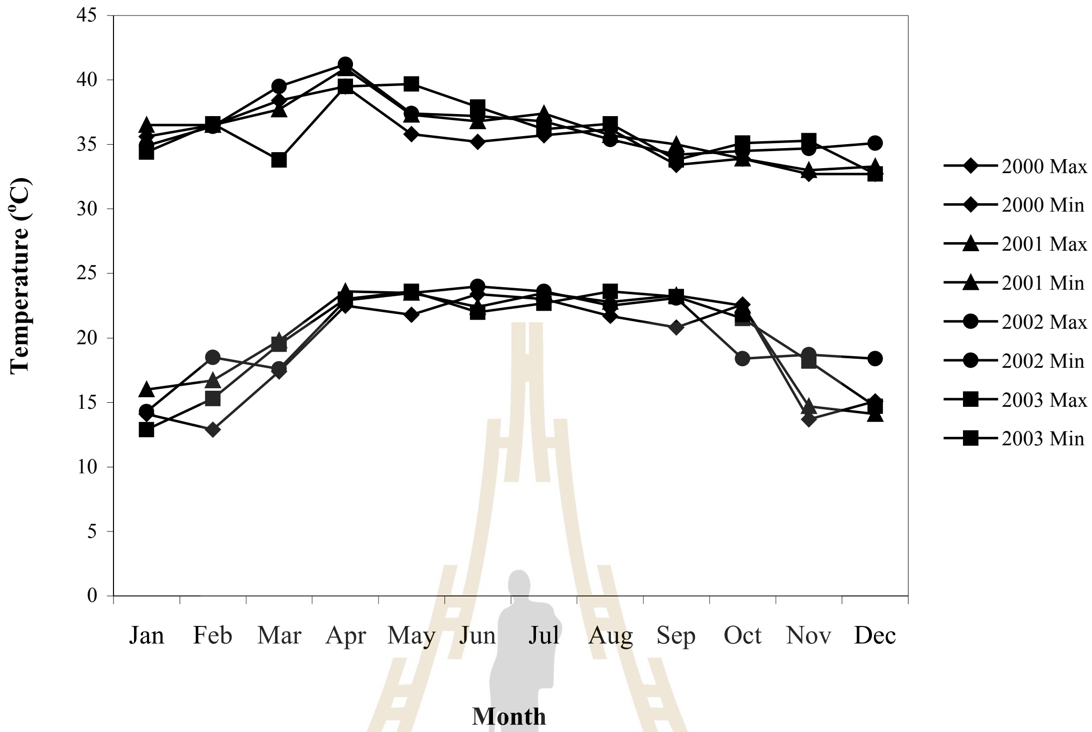


Fig. 2. Temperature at Nakhon Ratchasima from January 2000 to December 2003.

BIBLIOGRAPHY

My name is Thitiporn Machikowa. I was born on October 26, 1976 in Buriram. I graduated high school in 1995 from Khumaung Wittayakom School, Buriram and I received Bachelors degree in B.Sc. (Crop Production Technology) in 1998 from School of Crop Production Technology, Institute of Agricultural Technology, Suranaree University of Technology, Nakhon Ratchasima, Thailand. In the same year, I have got the Royal Jubilee Scholarship fellowship from Thailand Research Fund (TRF) to study for Ph.D. at the same university. My advisor is Prof. Dr. Paisan Laosuwan. The research topic for the dissertation was "Characters Associated with Yield Potential of Early Maturing Soybeans: Expression and Inheritance".

The results of this research were presented as poster presentation at RGJ -Ph.D. meeting, poster presentation at the 3rd National Symposium on Graduate Research and poster presentation at 2003 Annual Meetings of American Society of Agronomy, Crop Science Society of America and Soil Science of America at Denver, Colorado, USA.