THESIS APPROVAL

GRADUATE SCHOOL, KASETSART UNIVERSITY

Doctor of Philosophy (Tropical Agriculture)
DEGREE

Tropical Agriculture   Interdisciplinary Graduate Program
FIELD   **PROGRAM**

TITLE: Effect of Leaflet Size and Number on Agronomical and Physiological Characters of Mungbean (*Vigna radiata* (L.) Wilczek)

NAME: Miss Sukhumaporn Sriphadet

THIS THESIS HAS BEEN ACCEPTED BY

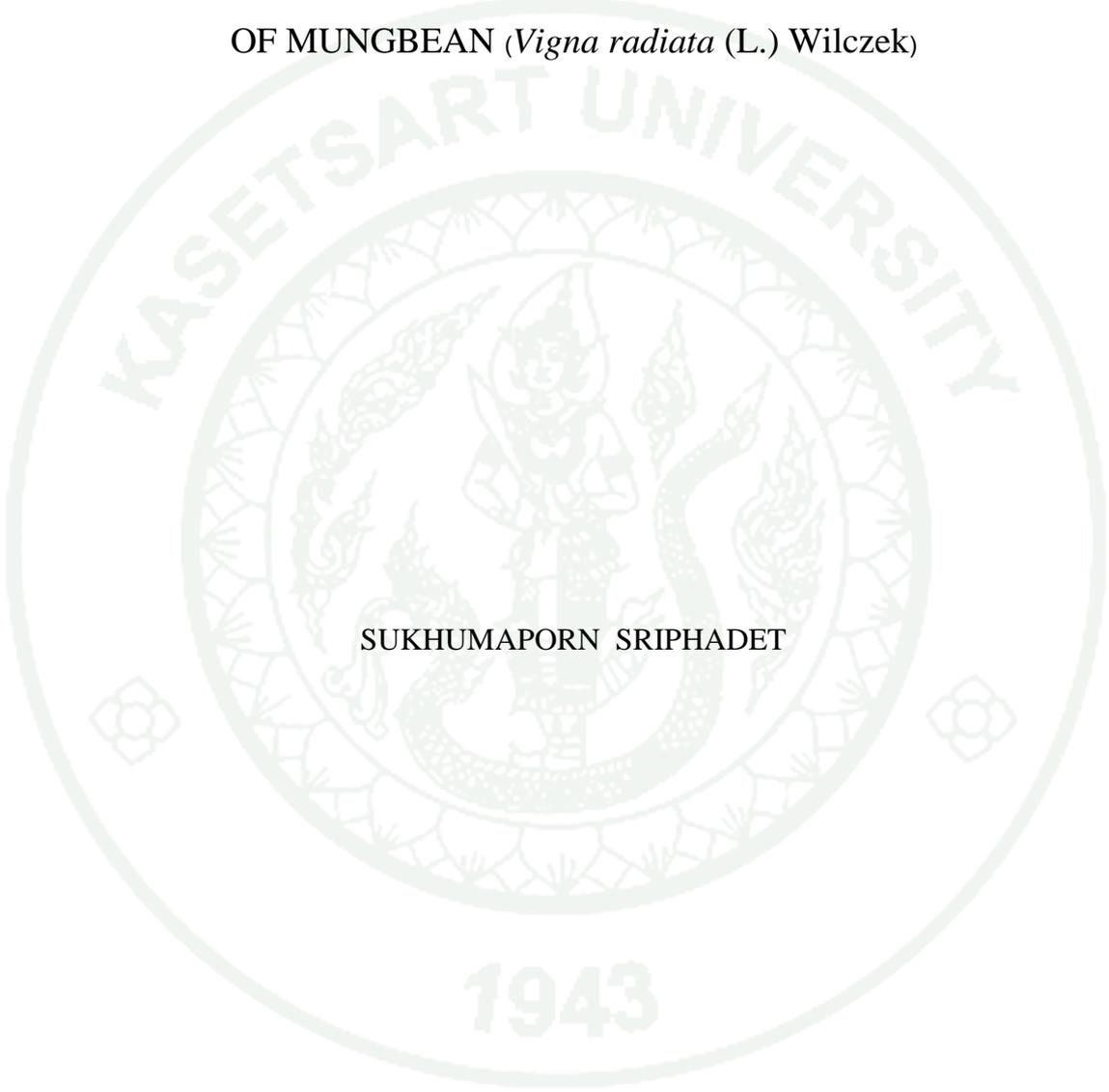|	
(Professor Peerasak Srinives, Ph.D.)	**THESIS ADVISOR**
(Associate Professor Poonpipope Kasemsap, Ph.D.)	**COMMITTEE MEMBER**
(Associate Professor Prasert Chatwachirawong, M.S.)	**COMMITTEE MEMBER**
(Associate Professor Somnuk Wongtong, Ph.D.)	**PROGRAM CHAIRMAN**

APPROVED BY THE GRADUATE SCHOOL ON

(Associate Professor Gunjana Theeragool, D.Agr.   )   **DEAN**

THESIS

EFFECT OF LEAFLET SIZE AND NUMBER ON AGRONOMICAL AND PHYSIOLOGICAL CHARACTERS OF MUNGBEAN (*Vigna radiata* (L.) Wilczek)

SUKHUMAPORN SRIPHADET

A Thesis Submitted in Partial Fulfillment of
the Requirements for the Degree of
Doctor of Philosophy (Tropical Agriculture)
Graduate School, Kasetsart University
2010

Sukhumaporn Sriphadet 2010: Effect of Leaflet Size and Number on Agronomical and Physiological Characters of Mungbean (*Vigna radiata* (L.) Wilczek). Doctor of Philosophy (Tropical Agriculture), Major Field: Tropical Agriculture, Interdisciplinary Graduate Program. Thesis Advisor: Professor Peerasak Srinives, Ph.D. 99 pages.

Mungbean average yield is still low due to indeterminate growth habit, photoperiod sensitivity, non-synchronous maturity, susceptibility to lodging, etc. Physiological studies revealed that mungbean yield bears a close relationship to the duration and rate of photosynthesis. Mungbean lines with more leaflets per leaf produce greater leaf area which can intercept more sunlight and thus possibly give greater yield. So this work was designed to compare agronomical and physiological characters among isogenic lines carrying different leaflet size and number. The population was derived from a cross between small- and large-multiple leaflet types. The parental lines were different in pod length, number of pods, clusters, and branches per plant, number of seeds per pod, 100 seed weight, seed yield and leaf area. While the isogenic lines were different in pod length, number of clusters, branches, and pods per plant, number of pods per cluster, number of seeds per pod, 100 seed weight, seed yield, LI, and leaf area. The isogenic lines carrying different leaf types in each family were significantly different in most traits. Seed weight showed positive correlation with number of pods per cluster, number of seeds per pod, pod size, and seed yield but showed negative correlation with number of leaflets, branches, clusters and pods per plant. Leaf area positively correlated with yield and pod length while LI positively correlated with plant height. Leaflet size correlated to more traits than number of leaflets did. Small-multiple leaflet lines gave higher number of clusters, branches, and pods per plant, and the extinction coefficient but less pods per cluster, seeds per pod, pod size, seed weight, seed yield, leaf area, leaf area index and light interception than large-multiple leaflet ones. Considering number of leaflets in each size, nine-small multiple leaflet lines produced more superior traits than five-, seven- and eleven-leaflet lines. Among the large-multiple leaflet lines, there was no different in agronomic characters. Leaflet size was more important trait than leaflet number in relation to agronomical and physiological characters.

_____   _____   ___ / ___ / ___
       Student's signature   Thesis Advisor's signature

ACKNOWLEDGEMENTS

Most importantly, I would like to thank my parents and two sisters for giving me the confidence and support to attain this goal through their constant love, understanding, and sacrifice given to me for the entire study period.

<div align="right">

Sukhumaporn Sriphadet

March 2010

</div>

TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

EFFECT OF LEAFLET SIZE AND NUMBER ON AGRONOMICAL AND PHYSIOLOGICAL CHARACTERS OF MUNGBEAN (*Vigna radiata* (L.) Wilczek)

INTRODUCTION

Mungbean (*Vigna radiata* (L.) Wilczek) is an important pulse crop in Asia and is widely cultivated in Thailand. In 2006, it occupied a planted area of 1,013,335 rai which produced 113,228 ton of grain (Office of Agricultural Economics, 2006). Mungbean can be sown up to three crops per year and it fits well into cropping systems. Mungbean seed has a high nutritive value. Dry seed has 6.6-11.6% moisture, 19.7-24.2% protein, 60.3-67.5% total carbohydrate, 4.2-4.4% crude fiber, 3.4-3.5% ash, 1-1.5% fat, 118-145 mg/100g Ca, 340-345 mg/100g P, 5.9-7.8 mg/100g Fe, and 1028 mg/100g K. Mungbean seed is used for bean sprouts, starch noodles, mungbean soup and deep-fried patties of different kinds. Seed that does not meet with human food standard is generally used as livestock feed due to its high protein content (Kay, 1979). Domestic and international demand of mungbean is still high. However, the average yield of mungbean is low due to indeterminate growth habit, photoperiod sensitivity, late and nonsynchronous maturity, susceptibility to lodging, pod shattering, and losses due to pests and diseases (Fernandez and Shanmugasundaram 1988). In order to raise the yield per unit area, new cultivars must be developed and cultural practices are improved. Physiological studies revealed that mungbean yield bears a close relationship to the duration and rate of photosynthesis (Kuo *et al.* 1978).

Mungbean plant generally has a relatively close canopy compare to the other grain legume species. The large amount of self-shading can reduce seed yield due to poor light penetration. Mungbean lines with more leaflets per leaf produce greater leaf area which can intercept more sunlight and thus possibly give greater yield. Adoms and Duarte (1961) reported the importance of additive gene action controlling leaf size and complete dominant controlling high leaf number in dry bean. The F_1 herosis

over the better parent for total leaf area, however, was caused by multiplicative effects of the two components. Sripisut and Srinives (1986) reported that the multiple leaflet character is controlled by a single recessive gene. This character can be transferred to other mungbean lines in which the gene can bear up to nine leaflets. AVRDC (1988) reported that, among F_2-segregants, the multiple leaflet plants tended to yield less than the normal trifoliate ones. However, AVRDC did not form isogenic lines to specifically assess the effect of the multiple leaflet genes. Wells *et al*., (1993) stated that greater photosynthesis per unit leaf area was related to a more uniform distribution of light in the canopy or a greater proportion of leaves actually involved in photosynthesis. Sung and Chen (1989) reported greater light penetration to lower canopy strata in narrow leaflet canopies of soybean. A new mungbean variety 'Samgang' in Korea with lobed leaflets that can intercept more sun light than the control variety 'Seonhwanogdu' reported releasing of a Lee *et al*. (2004). However, only a few studies have focused on leaf architecture influencing photosynthesis in mungbean, yet no study ever formed isogenic lines of leaflet size and number.

Thus the present work was designed to investigate possible benefits of the multiple leaflet characters as compared to the normal trifoliate ones and to compare between the large multiple leaflet and small multiple leaflet ones. To do so, the isogenic lines with different number and size of leaflets were evaluated for yield and yield components.

OBJECTIVE

The objective of this study was to compare agronomical and physiological traits among isogenic lines of mungbean carrying different leaflet size and number. The information can be used to determine the ideal leaf traits for the future mungbean breeding program.
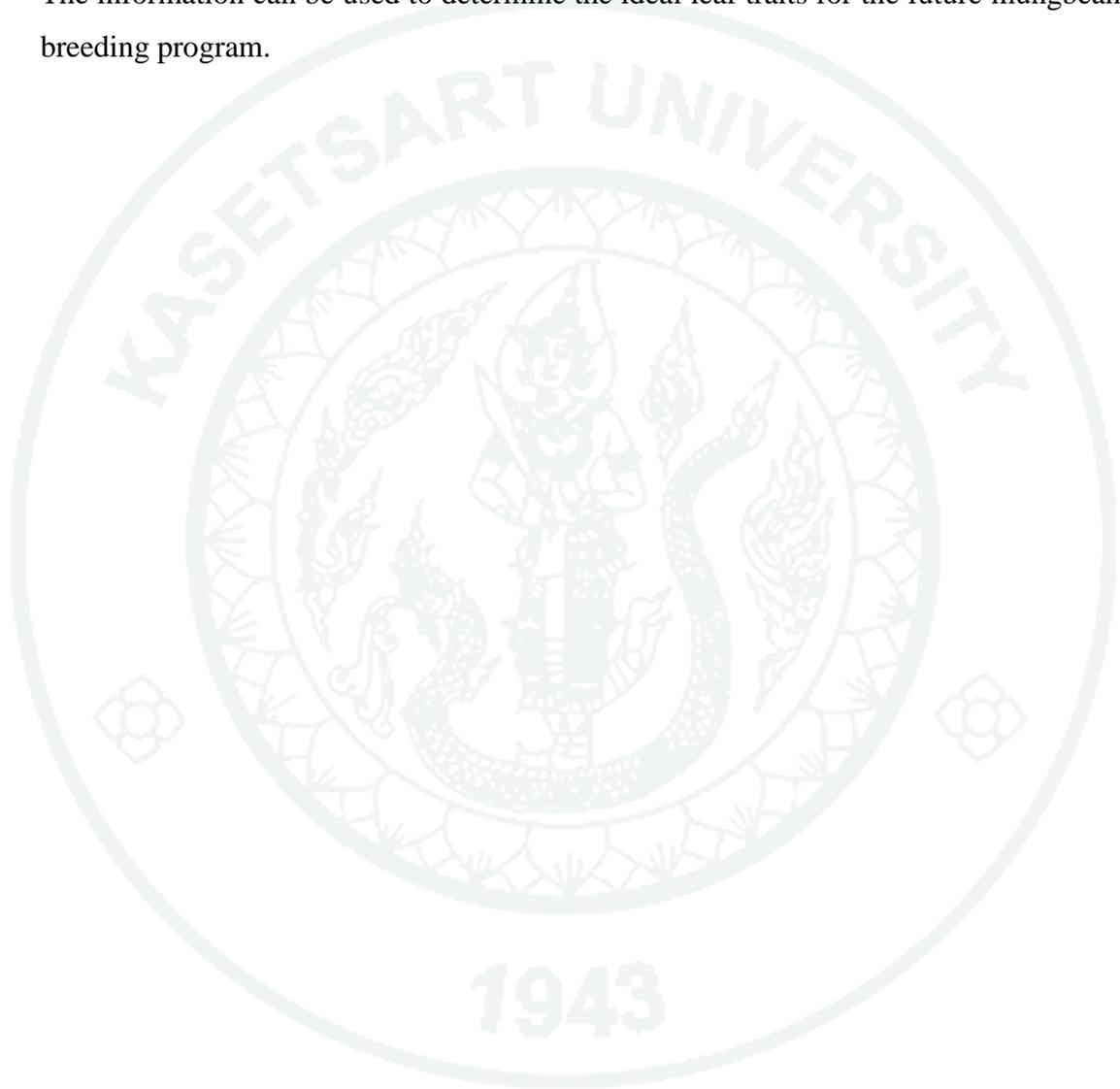
LITERATURE REVIEW

1. Inheritance of morpho-physiological traits in some food legumes

1.1 Multiple leaflets

Takahashi and Fukuyama (1919) found a single major gene controlling multifoliolate character in soybean. Later, Fehr (1972) observed a spontaneous mutation that gave rise to plant with multifoliolate leaves (mainly 7 leaflets). This character is controlled by a dominant Lf_2 gene, while the five-leaflet mutation was controlled by an incomplete dominant Lf_1 gene. Fu and Ehleringer (1991) presented a mutation with respect to multifoliolate leaves (4 - 7 leaflets) that derived from the seeds treated by gamma-rays whose genetic studies indicated that a pair of recessive alleles (lf_3lf_3) at a single locus led to this mutation and the dominant allele (Lf_3) controlled the normal trifoliolate leaves. Later, Wang *et al*. (2000) observed an inheritance of a five leaflet mutant in soybean from six crosses between "Five Leaf Bean" (carrying five leaflet trait) with 6 lines carrying normal leaves. F_2 plants from 5 crosses produced mainly three to five leaflet leaves with some showing four, six and seven multifoliolate leaves. There were two segregation ratios for major five leaflet (including other multifoliolate leaves) and trifoliolate characters in the F_2 progeny plants. Five crosses showed a goodness of fit to a 3:1 ratio, while one cross satisfied a 63:1 ratio. The cross analysis indicated that besides the Lf_1 gene controlling the five leaflet trait, other two newly found genes could also control this trait. These three genes were independent with incompletely dominant and effect-duplicated. The results also suggested that the "Five Leaf Bean" a donor of five leaflet genes acquired by random selection from a cross progenies ((cultivar1 x wild soybean) x cultivar2) showed heterogeneous genotypes at the three loci among individuals.

In mungbean, Veeraswamy and Kunjamma (1985) studied in a mutant with four or five leaflets and reported that it was probably dominant over the normal three leaflets. The mutation-induced unifoliate and the multifoliate leaflets were found governed by independent recessive gene over the normal trifoliate one (Santos, 1978).

Also Singh *et al.* (1982) reported that a pentafoliate was controlled by mono-recessive gene. Likewise, Chhabra (1990) reported that trifoliate leaves (normal) were monogenically dominant over pentafoliate. Whereas Bhadra (1991) reported that a nine-foliate leaflet character was monogenic recessive to normal trifoliate leaf. He proposed the symbols *tf* and *Tf* for the genes regulating these two characters. Satyanarayan *et al.* (1989) also reported that multiple leaflet mutants behaved as monogenic recessive to normal trifoliate leaves. Soehendi *et al.* (2006) reported that the genes controlling leaflet size and leaflet number were independent loci. The gene symbols *N1*, *n1* and *N2*, *n2* were proposed to control leaflet number. There was another locus with *S* and *s* alleles controlling the leaflet size. There were 3 AFLP markers linked to number of leaflets per leaf.

1.2 Leaf shape and color

Lamseejan (1978) reported a narrow-leaf mutation induced by fast neutron in the dry bean cv. "Seafare". It was characterized by short stature, branching, prolonged vegetative growth, and sterility. The whole complex was inherited as a single incomplete dominant gene. A spontaneous mutation of similar narrow lanceolate leaves was found in the cross FF336. According to Bassett (1981), the inheritance was controlled by a single dominant gene (*Lan*) which in homozygous dominant condition has deleterious effect that prevent reproduction. A crinkled lanceolate mutant governed by a single semidominant gene, lethal in homozygous condition was described by Singh and Saini (1983). Two trilobate mutants were each found to carry a dominant gene over normal monolobate trait. When crossed, an F_2 ratio of 15:1 was obtained (Shii *et al.,* 1985). Singh (1982) reported that lobed leaf was controlled by a single dominant gene. Grafton *et al.* (1983) reported a foliage color mutant in a dry edible bean breeding line was controlled by one recessive gene (*vir_t*).

Singh and Sharma (1993) isolated a few pentafoliate and tetafoliate mutants from the gamma rays- and EMS - treated mungbean. These mutants showed a significant increase in dry matter production, total chlorophyll content and yield.

Bahl and Gupta (1982) described the mutant characters and their inheritance in mungbean and reported that variegated, multifoliata, xantha, chlorina, albino, unifoliata were each controlled by a recessive gene.

Nagata and Basset (1984) reported nine mutations induced by gamma rays in *P. vulgaris*. They were round leaf (*rnd*), dark green savoy leaf (*dgs*), diamond leaf (*dia*), chlorotic cup (*cc*), stipule-less lanceolate leaf (*sl*), dwarf outcrossing (*do*), chlorotic stem (*sc*), silver leaf (*sil*) and progressive chlorosis (*pc*). Each was controlled by a different recessive gene. Later, Awuma and Bassett (1988) found that round leaf stipule-less lanceolate leaf, and dark green savoy leaf formed one linkage group, whereas diamond leaf and progressive chlorosis formed another group. Kilen (1977) found that brachytic stem in soybean was controlled by a single gene, *sb*. Later, Boerma and Jones (1978) identified a second gene and reported that both sb_1 and sb_2 were necessary for full expression of the trait. Dwivedi and Singh (1985) reported that narrow leaf character in mungbean is governed by two recessive genes symbolised by *nl1* and *nl2*. Frey (1980) described a crinkled lanceolate leaf mutation in mungbean and showed that the trait is conditioned by a single major factor (*N*), the gene was semi-dominant and lethal when it was in heterozygous condition. Sripisut and Srinives (1986) reported that lobed and trifoliate leaflets were dominant to normal and multiple leaflets. Each trait was governed by a single locus of gene on different chromosomes. Sangsiri *et al.* (2005) reported mutation in mungbean by gamma radiation found mutant characters were grouped as chlorophyll, leaf, flower, and pod mutants. Chlorophyll mutations included albino, coppery leaf, light-green leaf, variegated leaf, waxy leaf, white streak leaf, and xantha leaf. Leaf mutations were lanceolate leaf, narrow-rugose leaf, multiple leaflet, round-cuneate leaf, unifoliate leaf, and wrinkled leaf.

1.3 Photosynthesis

Kemp (1979) reported that two pairs of gene were responsible for controlling of the temperature-modified photonastic movement of the unifoliolate leaf of bean. Probative carried the two recessive gene (*aabb*) whose photonastic reponse

was uninhibited by a temperature at 10°C. "GN 1140" and "Limelight" each carried one dominant allele, *A* and *B*, respectively. The intolerant reaction was due to either one or both of the dominant allele, one of which was epistatic to the second and similar in response. Bernard and Weiss (1983) reported that photoperiod insensitivity in soybean was dominant over photoperiod sensitivity. Swindell and Poehlman (1978) reported a dominant or partial dominant gene governs the sensitivity to photoperiod in PI1800311. The gene symbol *Ps* for photoperiod-sensitivity in mungbean was expressed in 14 to 16 hour photoperiod but not in 12 hour photoperiod. Ghai and Singh (1979) reported that photosensitivity was controlled by a single dominant gene in late flowering plants from variety ML1.

Bressan-Smith (1999) studied from cross between snap bean (cv HAB-52) and common bean (cv BAC-6) found that interval mapping identified 36 QTL associated with morphology, photosynthesis and yield, described as follows: one for plant height, three for canopy diameter, two for leaf width, one for leaf length, two for leaf width/length ratio, three for pod weight, two for pod length, one for total seed weight, two for number of seeds/pod, one for carbon dioxide assimilation rate, two for leaf temperature, five for stomatal conductance, one for internal CO_2 concentration, two for stomatal resistance, one for leaf chlorophyll *a* content, one for leaf chlorophyll *b* content, two for chlorophyll *a/b* ratio, one for total leaf chlorophyll content, one for carotenoid content, one for chlorophyll/carotenoid ratio and two for total soluble leaf protein content.

Tasma *et al.* (2004) studied in two single-cross populations, PI 317.336 $\times$ `Corsoy' and PI 317.334B $\times$ `Corsoy' and found that photoperiod insensitivity, flowering time, and maturity controlled by the same gene(s) in the same chromosomal region. In addition to the large effect QTL, minor QTL were also detected controlling the four traits in both populations. Thus, time of flowering, maturity, and photoperiod insensitivity in these soybean populations are proposed to be controlled by a major QTL with a large effect and modified by several minor QTL.

2. Effect of physio-morphological traits on yield and yield components in some food legumes

2.1 Effect of photosynthesis

Crop productivity and yield depend on many physiological processes and environmental factors such as environmental stresses (Van Kooten and Snel, 1990) high temperature (Costa *et al.*, 2002), air temperature and air vapor pressure different (Ribeiro *et al.,* 2004). Some photochemical reactions are also linked to the CO_2 fixation process by supplying ATP and NADPH (Cornic and Fresneau, 2002). Photosynthesis contributes about 90% of total dry matter accumulation. As a result, crop production aims to maximize photosynthesis. A plant must possess an efficient photosynthetic mechanism to be highly productive biologically. As an adaptation to maximize light interception, plants have developed different canopy architectures.

Mungbean yield bears a close relationship with the duration and rate of photosynthesis and light intensity (Kuo *et al*., 1978). Leaf photosynthesis depends on many factors such as leaf age, leaf position, and environmental factors such as light, temperature, nutrition, and available water (Lieth and Pasian, 1990). Leaf position and age also influence leaf area, gas exchange, leaf conductance, and saturated net photosynthetic rate (Constable and Rawson, 1980). Leaves are the main site of transpiration, which provides most of the energy necessary to draw water and minerals up from the roots of the plant. In addition, carbon dioxide for photosynthesis and oxygen for respiration are usually exchanged through the leaves. Then an erect leaf canopy could theoretically increase crop assimilation rate (Duncan, 1971; Sakamoto and Matsuoka, 2004). Similarly, Choomak (2002) reported that CN 36 mungbean had smaller proportion of sunlit leaf area and less light interception efficiencies of leaflet and canopy than the multiple leaflet near-isogenic line. However, CN36 had greater net canopy photosynthetic rate and canopy transpiration than the near-isogenic line. When leaves were older than 20 days, maximum photosynthetic rate of CN36 was less than the near-isogenic line, while dark respiration rate were not different. Later, Chidchenchey (2003) reported that CN36

leaflets were significantly greater in net photosynthesis rate but less leaf dark respiration rate than those of CN36 (BC$_9$) multiple leaflet line. Rungnoi *et al.* (2007) reported that the opaque leaf trait in mungbean was controlled by a single recessive *op* gene and this gene was independent from petiole color and growth habit ones. The chlorophyll content in opaque leaf was lower than the normal one, indicated that this trait was a chlorophyll-deficient mutant. The mutant was also lower in maximum quantum yield efficiency of photochemistry and PSII maximum compared to normal leaf.

Most of the highest yielding cultivars already have erect leaf canopies. It has been shown that leaf metabolism can adapt to different light intensities according to the position in the canopy. The upper leaves in a canopy may show elevated photo-protective responses. Photosynthesis also varies from time to time during periods of a day depending on the dynamics of light intensity, air temperature and relative humidity. A relationship between leaf net CO_2 assimilation rate, canopy photosynthesis, and seed yield has been reported in soybean and black gram (Harrison *et al.,* 1981; Babu *et al.,* 1985). Increasing of seed yield results from increasing of leaf area for photosynthesis, growth rate and supply assimilation after beginning of pod development (Gifford and Evans, 1981). However, correlation between leaf photosynthetic capacity and yield has been difficult to demonstrate and selection for greater photosynthesis "P$_{max}$" has not led to improved crop growth. This may be due to the negative correlation between "P$_{max}$" light saturating rate of leaf photosynthesis and leaf area (Wilson, 1984).

Bressan-Smith (1999) studied from a cross between a snap bean (cv HAB-52) and a common bean (cv BAC-6) and found that photosynthetic assimilation of CO_2 did not correlate with yield components, however, positive correlation was observed with stomatal conductance and leaf temperature. The combination of the characteristics cited above could allow the generation of lines, initiated from individuals of F$_2$ population, better adapted to environments which suffer from water deficits. A high correlation was found among chlorophyll *a*, chlorophyll *b* and carotenoids, further demonstrated by the identification of closely linked on linkage

group B. These results demonstrated that gene polymorphism affecting photosynthesis and yield.

2.2 Effect of leaf area

The leaf area of crop is a determinant factor in mechanisms such as radiation interception and water and energy exchange. Therefore, accurate measurement of leaf area index (LAI) is essential to understand the interaction between crop growth and environment. Watson (1947) reported that the analysis of crop growth should be based on unit of field area rather than per plant, and measurement of LAI based on the close coupling between radiation penetration and canopy structure was a good alternative to the direct LAI measurement techniques (Jesus *et al.*, 2001).

Egli *et al*. (1970) reported that a lanceolate leaflet isogenetic soybean line of Harosoy had 25% higher photosynthetic rate per unit leaf area than normal leaf, while no difference was apparent on a ground area basis. The greater photosynthesis per unit leaf area was due to two possibilities (i) a more uniform distribution of light in the canopy, or (ii) a greater proportion of leaves actually involved in photosynthesis. Sung and Chen (1989) studied in soybean and found that lanceolate leaflets possessed greater leaf photosynthetic capacity and more chloroplasts per unit area, thus suggesting an enhanced capacity to utilize greater available irradiance irrespective of position on the plant. In addition, Wallace (1985) reported that LAI increased with crop growth often reached a peak around the onset of rapid pod growth. The halt in leaf production presumably reflected in increased demand for nitrogen. LAI in determinate beans may stop increasing at a relatively early stage because of a lack of nodes for producing additional leaves. Kowsurat *et al*. (1999) reported that the LAI of the trifoliate parents was greater at the vegetative stage but lower at the flowering and young pod stages, due to the greater number of leaflets per plant of the multifoliate lines. After the beginning of the podding stage, the LAI of the multifoliate lines was less than that of the parents, as the number of leaflets per plant of these lines hardly changed while that of the trifoliate parents increased.

Leaf area and dry matter accumulation in blackgram were studied by Biswas *et al.* (2001). They found that leaf area increased slowly during pre-flowering but rapidly increased during post-flowering stage. The highest leaf area was recorded in pod filling stage and decreased sharply thereafter due to senescence of leaf. Similar trend of leaf area in blackgram was reported by Rahman *et al*. (1994). A positive correlation was found between photosynthesis and leaf area during flowering (r = 0.78) and pod filling (r = 0.97) stages. Similar results were reported by Mahon and Hobbs (1987) in pea. Blackgram showed rapid increase in dry matter during post-flowering than pre-flowering stage and the highest accumulation of dry matter was recorded at harvest. It showed significant correlation between leaf area and total dry matter accumulation at vegetative (r = 0.97), flowering (r = 0.96) and pod filling (r = 0.97) stages. Total dry matter accumulation also strongly correlated with leaf photosynthesis, both at flowering (r = 0.93) and pod filling (r = 0.91) stages of blackgram was reported by Rahman *et al*. (1994). Similar result in peas was also reported by Mahon (1982).

2.3 Effect of light interception

Egli (1988) reported a positive yield response in soybean at plant density greater than required for maximum light interception. Duncan (1986) suggested that soybean yield may respond to the LAI values greater than those considered critical. While the relationships between plant spacing and dry matter production and among plant spacing and canopy apparent photosynthesis (CAP) and yield have been examined, there have been no attempts to relate CAP, light interception, LAI, and plant spacing. Christy and Porter (1982) imposed defoliation treatments at R_2 and concluded that yield was directly related to light interception, and removal of the leaf area delayed the time to achieve a critical LAI. Halfield and Carlson (1978) found roughly 90% of light interception occurring in the top and peripheral section of the canopy. Similarly, Poehlman (1991) reported a greater concentration of LAI in the upper portions of field-grown plant canopies after canopy closure. Critical LAI during reproductive growth is a prerequisite for the attainment of maximum yield (Egli, 1988). Further, CAP and its duration during reproductive development are correlated

with yield and CAP difference was detected after reproductive stage R_5 (Ashley and Boerma, 1989). Well (1991) reported that LAI of soybean were curvilinear by related to percent light interception until canopy closure. After that, light interception did not decline at a rate commensurate with the loss of leaf area, indicating that abscission of leaves did not involve in light interception. Canopy photosynthesis was significantly different between R_1 and R_5 but not different after reproductive stage R_5. Canopy closure is one prerequisite for maximum seed yield (Shibles and Weber, 1966). In 1993, Well *et al.* reported that brachytic stem in soybean were 40% shorter at harvest than the normal genotype. Brachytic stem and lanceolate leaftets are canopy characteristics with potential effects on light interception. The combination of brachytic stem and narrow leaflets in a single background provides an interesting contrast of morphological type.

Higley (1992) demonstrated that there is a significant linear relationship between yield loss and reduction in canopy light interception after defoliation in soybean. If canopy light interception is reduced below the critical level of 95%, defoliation could lead to a significant yield reduction. Soybean genotypes differ in leaf photosynthetic rates usually differ in canopy apparent photosynthesis (Wells *et al.*, 1993). The extent to which the canopy absorbs the available radiation depends not only upon the leaf area index but also upon the characteristics such as leaf angle and the canopy architecture (Russell *et al.*, 989; Guiducci *et al.*, 1992). The absorbed radiation use efficiency can depend on rates of photosynthesis, photorespiration and respiration, or on a sink demand limitation. In other words, the conversion efficiency is the result of a complex interaction among photochemical and biochemical processes and transport of assimilates. A common way to measure it is to calculate the slope of the linear relationship between cumulative dry matter production and cumulative absorbed radiation by the crop canopy (Gosse *et al.*, 1986). The quantitative relationships for the allocation of dry matter among the leaves, roots, stems and storage organs are mostly empirical (Marcelis, 1993)

3. Relationship between yield and yield components

Yield is the net result of the production of assimilate by leaves (the source i.e. canopy photosynthesis) and translocation of these assimilates to the developing seed (sink) where they are used to synthesize starch, oil, and protein. The amount of photosynthesis is a function of the total leaf area and the solar radiation intercepted. Moreover, leaf starch is dynamic and responds quickly to the changes in photosynthesis and/or sink availability or activity. Soybean leaf starch levels typically increase during the day and decrease at night (Upmeyer and Koller, 1973; Huber *et al.,* 1984; Egli, 1999). Changes in crop growth rate can be used as an estimate of canopy photosynthesis (Ramseur *et al.*, 1985; Egli and Zen-wen, 1991), or environmental factors that affect photosynthesis, such as CO_2 levels (Hardman and Brun, 1971) or light (Schou *et al.,* 1978).

Board *et al.* (1996) reported that total dry matter and LAI at R_5 were positively correlated with seed yield. Furthermore, increasing in assimilate supply after beginning pod development increased seed yield. Sakamoto and Shaw (1967) reported that maximal Canopy apparent photosynthesis (CAP) rate occurred after canopy closure and during early reproductive growth, which is the period of ultimate importance for seed yield determination (Ashley and Boerma, 1989). Similarly, Kilen (1990) reported that plant height was significantly associated with photosynthetically active radiation (PAR) interaction during vegetative and reproductive growth in wide rows, while seed yield was positively related to PAR interception during reproductive growth in the wide row - low population combination. Brachytic genotype does not fully intercept available PAR in wide row and low population, especially when combined with lanceolate leaflets. Seed yield was significantly different when deposit 95% PAR interception (Fehr and Caviness, 1977). Kowsurat *et al.* (1999) studied on near-isogenic lines of mungbean cultivars KPS 1 and CN 36 carrying the multiple leaflet gene from the line V 5926. Seed yield, plant height, and number of pods per plant were greater in the trifoliate leaflet cultivars than in the multiple leaflet isogenic lines, whereas the number of seeds per pod and 1000-seed weight were not significantly different. Light saturation and photosynthetic rate were not different,

while light interception and dry matter accumulation were greater in the trifoliate leaflet cultivars than in the multifoliate lines.

Sriphadet *et al*. (2007) found positive correlation between seed yield with number of pods per plant and plant height. Khan *et al*. (2001) observed that grain yield production was due to many yield contributing traits that were positively correlated with yield. For example, grain yield was positively correlated with number of branches and thus Reddy *et al*. (1991) stated that the increase in number of branches enhanced the grain yield. Malik (1994) reported that seed yield was positively correlated with number of pods and number of branches per plant. As the branches bear pods, the number of pods per plant was positively correlated with the branches per plant. Khan *et al*. (2001) recorded that the cultivar produced highest number of branches per plant also produced highest number of pods per plant. Rubio *et al*. (2004) reported that, due to positive correlation between flowering date and seed yield, the latest flowering genotype would develop more branches, leading to higher seed yield. Yield production is positively correlated with the other yield contributing traits such as days to flowering, plant height, number of branches per plant, number of pods per plant and pod length.

MATERIALS AND METHODS

Materials

Plant Materials

The population used in this study was derived from a cross between five small multiple leaflet (5S) with purple petiole as the female parent and seven large multiple leaflet (7L) with green petiole as the male parent. The 5S parent is a new mutant line obtained from gamma-ray irradiation of F_2 seed from a cross between the cultivar 'Chai Nat 36' with 'TC 1966' (Srinives *et al.*, 2000). The 7L parent is a 'Kamphaeng Saen 1' isogenic line (BC_9) progeny having the large-multiple leaflet gene from the variety V 5926 (Kowsurat *et al.*, 1999). All the F_1 plants showed trifoliate leaves, as Soehendi *et al.* (2007) reported that this trait was controlled by two loci of gene, $N_1\_N_2\_$ segregating for leaflet number (3, 5 and 7) while leaflet size (large and small) is assigned as *Ss*. The *N* and *S* loci may also interact, giving some 9 and 11 leaflet plants. The F_2 seeds from individual F_1 plants were grown to generate F_2 populations. The F_2 progenies segregated for leaflet size and number in six characters, viz. small multiple leaflet with green petiole (SMG), small multiple leaflet with purple petiole (SMP), trifoliate leaf with green petiole (3NG), trifoliate leaf with purple petiole (3NP), large multiple leaflet with green petiole (LMG) and large multiple leaflet with purple petiole (LMP). Only the F_2 plants showing large trifoliate leaflets with purple petiole ($N_1\_N_2\_S\_$) were harvested and sown in plant-to-row to obtain F_3 plants. The same process was repeated from F_3 to F_6 generations, while the data were recorded on number of plants with different number of multiple leaflets and petiole color.

In the F_7 generation, the rows that showed no segregation in leaflet size and number, viz. trifoliate leaflet (3N), 5SM, 7SM, 7LM, 9SM, 9LM and 11SM were individually harvested. Up to 4 families of the above seven leaflet types were obtained. They were almost identical in genetic background (>95% similarity) but different in leaflet size, number and petiole color. Thus, the seeds from the F_7-derived lines were bulked in each leaflet trait, and finally, there were two sets each with green and purple petiole color. Each set had two families. Each family consisted of seven isogenic lines each of the above leaflet types. No other leaflet combinations were obtained in this study. The diagram of the overall steps in preparation of the F_9 isogenic lines is shown in Figure 1.
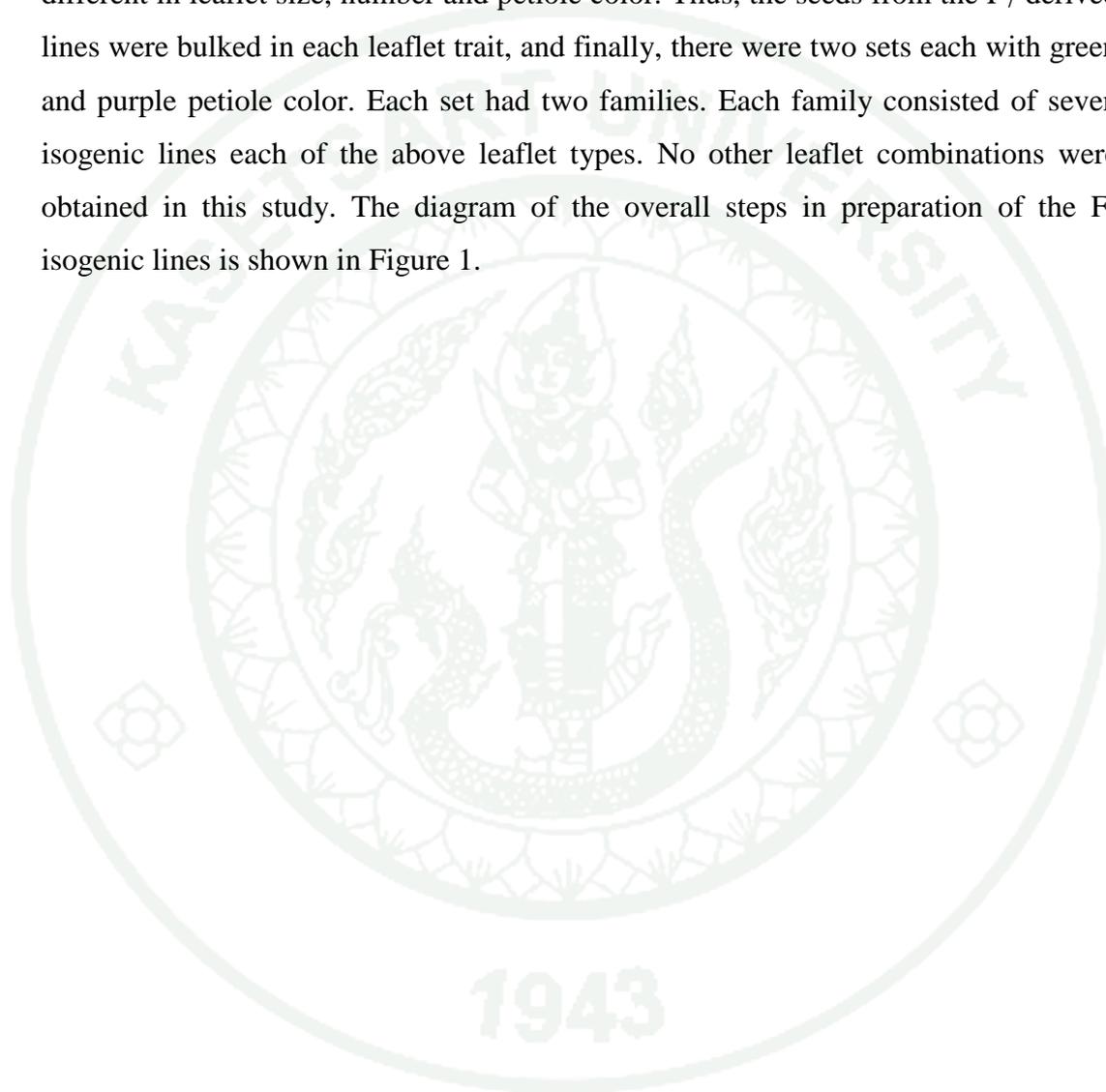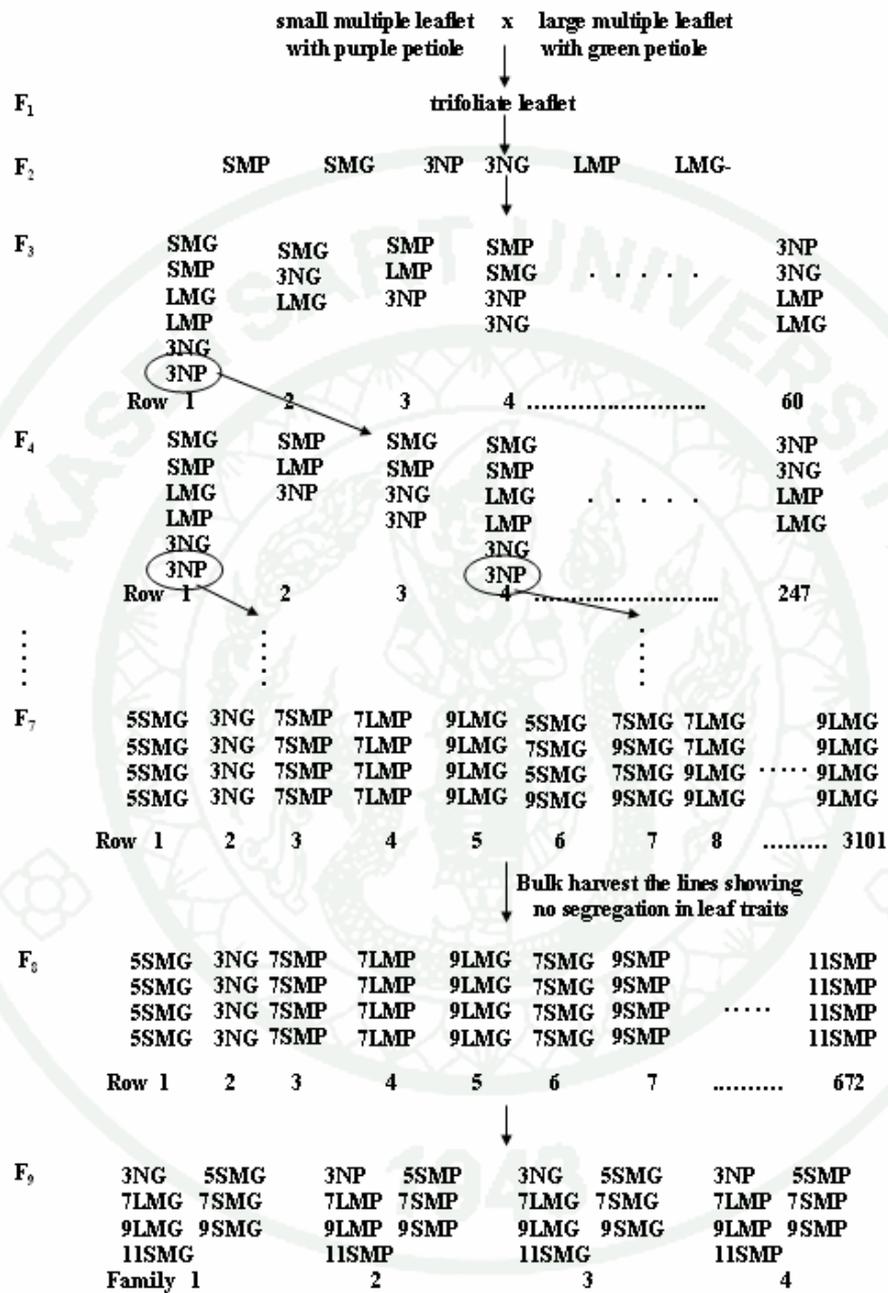
Figure 1 Diagram showing development of isogenic lines from the cross between

the mungbean parental line with five small multiple leaflet with purple

petiole (5SMP) and the one with seven large multiple leaflet with green

petiole (7LMG).

Methods

1. Statistical design

All four isogenic families, each with seven different leaflet size and number were tested with their parents in a randomized complete block design (RCBD) with three replicates. Thus there were altogether 30 treatments in the experiment. Each plot consisted of four rows, each with 5 m long. The spacing between rows and hills were 50 and 12.5 cm with one plant per hill. All the quantitative traits measured were analyzed in a RCBD analysis of variance with three replicates, having the isogenic lines of leaflet size and number nested in each family (Table 1). The analysis was performed by SAS version 6.12. Mean comparison was performed using non-orthogonal contrasts as well as Duncan's Multiple Range Test (DMRT) at $P \leq 0.05$. The trial was conducted at Kasertsart University, Kamphaeng Saen Campus during November 2006 to January 2007. The data were colleted on both agronomical and physiological characters.

The path coefficients showing direct and indirect relationship between effects of major agronomical and physiological traits on yield and yield components were also analyzed following Roy (2000).

Table 1 ANOVA of quantitative traits measured from the field trial of two parents and their four isogenic families each carrying seven leaflet types. Note that some contrasts are not orthogonal.

Source	df			
Replications	2			
Treatments	29			
Parents vs Lines	1			
P1 vs P2	1			
Between lines		27		
Between families			3	
Between leaflet types within family			24	
Between types across 4 families				6
Between 3N vs LM				1
Between 3N vs SM				1
Between LM vs SM				1
Between leaflet types residuals				3
Within families residuals				18
Error	58			
Total	89			

2. Data collection on agronomic traits

Seed yield and yield related characters were observed from each isogenic line in each replication as described below.

2.1 Days to 50 % flowering (number of days from planting to the day when 50 % of all plants in the plot are flowering).

2.2 Days to 50 % maturity (number of days from planting to the day when 50 % of pods in the plot attain maturity).

2.3 Plant height (cm) at days to 50% flowering (height of plant from soil level to the tip of central axis when 50 % of all plants in the plot are flowering, average plant height measured from six randomly selected plants).

2.4 Plant height (cm) at days to 50% maturity (height of plant from soil level to the tip of central axis when 50 % of pods in the plot attain maturity, average plant height measured from six randomly selected plants).

2.5 Number of branches per plant (average number of branches per plant counted on six randomly selected plants).

2.6 Number of pods per plant (average number of pods per plant counted on six randomly selected plants).

2.7 Number of pods per cluster (average number of pods per cluster counted on six randomly selected plants, each plant on six clusters bearing highest pod number).

2.8 Number of clusters per plant (average number of clusters per plant counted on six randomly selected plants).

2.9 Number of seeds per pod (average number of seeds counted on six randomly selected plants and each plant counted on six pods).

2.10 Pod length (cm) (average pod length from six randomly selected plants and each plant measured on six pods).

2.11 Pod width (mm) (average pod width from six randomly selected plants and each plant measured on six pods).

2.12 100-seed weight (g) (weight of one-hundred randomly selected seeds from six randomly selected plants).

2.13 Seed yield (g) per plant (average seed yield per plant from six randomly selected plants).

2.14 Total number of leaflets per plant (average total number of leaflets per plant from six randomly selected plants).

2.15 Total number of leaves per plant (average total number of leaves per plant from six randomly selected plants).

2.16 Harvest index (average harvest index from six randomly selected plants were harvested and dried at 65°C for 72 h in a hot air oven, then weighed in grams. The harvest index was calculated as seed weight/dry matter weight.)

3. Data collection on physiological traits

3.1 Light interception (LI)

Light interception was measured at 46-48 days after planting (DAP) using the LI-191 Line Quantum Sensor System (LI-COR, Lincoln, Nebraska, USA). The unit used was micromoles of quanta per square meter per second (μmol m^{-2}s^{-1}). The measurement was made on each 4-row plot, between row 2 and 3, from 11.00 – 13.00 h when the photosynthetic photon flux (PPF) was $\geq$ 1000 μmol m^{-2}s^{-1}. Light interception was measured once above a mungbean canopy, four times beneath the canopy, and finally once above the canopy (Figure 2). The PPF above and beneath the canopy were averaged and used for calculation of light interception as described by Board *et al.* (1992) as follows:

Percent light interception = [1 - (I/I_o)] x 100

When I = the PPF beneath the canopy

I_o = the PPF above the canopy

3.2 Leaf photosynthetic rate

The light response curves were measured at PPF of 0, 20, 50, 100, 200, 400, 800, 1200, 1600, 1800, 2200 and 2400 μmol m^{-2}s^{-1}. The 3N, 7L and 5S lines in replication one and two were chosen so that two plants per leaflet type per replication were measured. Then, leaf photosynthetic rate at the light saturation (P_{max}, at 2,200 μmol m^{-2}s^{-1}) of 3N, 7L, 9L, 5S, 7S, 9S and 11S lines were measured from two plants from each replication. The same process was done in all three replications.
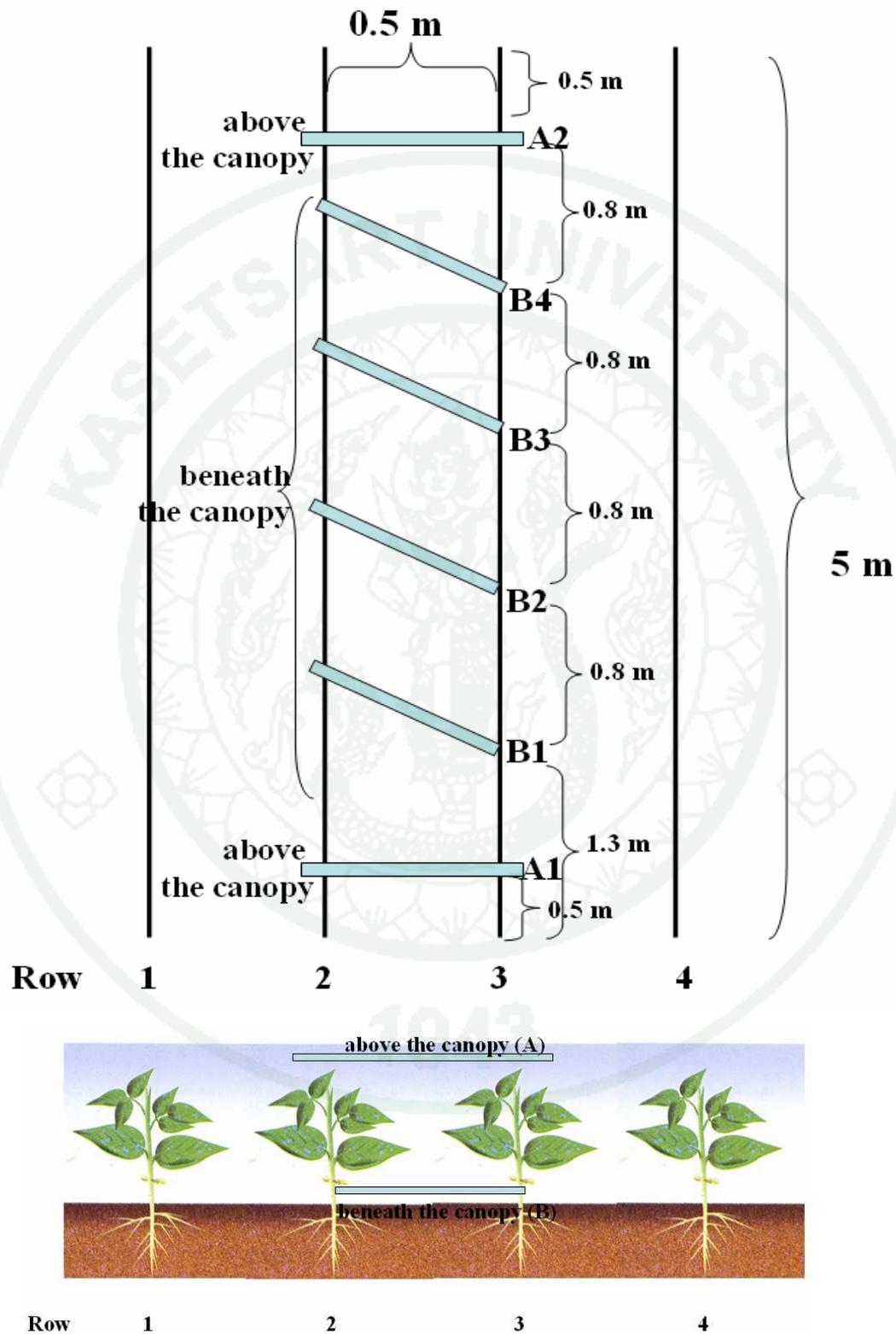
Figure 2 Light interception was measured by the LI-191 Line Quantum Sensor.

The light response curves and leaf photosynthetic rate at the light saturation (P_{max}) were measured using a LI-6400 Portable Photosynthesis System (LI-COR, Lincoln, Nebraska, USA) at 46-49 DAP. The red LEDs light source was used to provide light at the top part of leaf chamber. During measurement, the central leaflet of each line was enclosed in a six cm^2 leaf chamber. A measurement was recored when the leaf chamber attained the temperature between 27-33°C, 33-58% relative humidity, and CO_2 concentration of 358-363 ppm.

3.3 Leaf area (LA)

Leaf area was measured from six plants in row 2 and 3 of 3N, 7L, 9L, 5S, 7S, 9S and 11S lines. The measurement was done in all three replications. The measurement was performed during 42-44 DAP, using a LAI-3100 Area Meter (LI-COR, Lincoln, Nebraska, USA).

3.4 Leaf area index (LAI)

Leaf area index (LAI) was estimated from fisheye photographs, which were taken looking upwards from beneath the plant canopy, using a Nikon Fisheye lens with a Converter (FC-E8) and a high resolution digital camera (Nikon Coolpix 995). The best hemisphere photographs, with high contrast, can be obtained when taken under conditions with even backlighting: just sunrise, just sunset or under an evenly overcast sky (Diaci *et al.* 1999). We took the images in the early morning (9.00-10.00 h) to provide uniform lighting and illumination of the canopy. Images were saved in JPEG format. The Gap Light Analyzer (GLA) processing software Version 2.0 developed by Frazer *et al.* (1999) was used to process and analyzes the digital hemispheric canopy images. The simplified radiation model within GLA assumes that when the sun position is obstructed by the canopy, the direct radiation is zero, and when unobstructed, direct radiation is equal to the above-canopy value (Frazer *et al*., 2001). Beam enrichment by scattered and reflected radiation is not considered. The Leaf area index can be simply defined as the amount of leaf surface

area per unit of ground area. Here, we calculated effective leaf area index integrated over the zenith angles 0 to 75° (referred to as LAI 5 in the GLA software). The 3N, 7L, 9L, 5S, 7S, 9S and 11S lines chosen from four plots were measured. The fisheye photographs for each plot between row two and three.

3.5 The light extinction coefficient (k)

The light extinction coefficient (k) is the coefficient relating leaf angle to the ability of unit leaf are to intercept radiation (Loomis and Connor, 1992). Light extinction coefficient depends upon the architecture of a canopy and transmission of radiation through individual leaves (Sczcies, 1974; Pozo and Dennett, 1999). The leaf area index was estimated from fisheye photographs, the light interception was measured by LI-191 Line Quantum Sensor System (LI-COR, Lincoln, Nebraska, USA). Then, the light extinction coefficient was estimated with the light interception and the leaf area index using Beer's Law (Monsi and Saeki, 1953).

$$LI = [1-e^{-(k \times LAI)}]$$

When LAI = the leaf area index

k = the light extinction coefficient

LI = the light interception ($0 < LI < 1$, unit less)

RESULTS

1. Effect of leaflet types on agronomical traits

All agronomical traits were significantly different among the lines carrying different leaflet size and number (Table 1). Most traits were also different among parents, except days to 50% flowering (DF), plant height at days to 50% flowering (PF), harvest index (HI) and number of pods per cluster (PC). The average of the progenies and the parents were not different in most traits, except in total number of leaflets per plant (LP), since most of the progenies were multiple leaflets and had higher number of leaflets per plant than the parental average. They were not different among the four families, except in number of pods per plant (PP) and leaf area (LA). The recombinant inbred lines averaged across four families showed that there were different between 3N and LM group, i.e. PP, LP, number of branches per plant (BP), number of seeds per pod (SP), number of clusters per plant (CP) and total number of leaves per plant (LC). On the past of 3N was different from SM in most agronomical traits, i.e. seed yield per plant (Y), one-hundred seed weight (SW), pod length (PL), leaf area (LA), SP, PP, PC, CP, BP, LP, LC and DF. Similarly, LM was different from SM in most agronomical traits, i.e. Y, SW, SP, PL, PP, CP, BP, LP, LC, LA, HI, DF, plant height at maturity (PM), and light interception (LI).

Range, mean and standard deviation of some agronomical and physiological traits of progenies and their parents are presented in Table 2. Mean comparison of recombinant inbred lines averaged across 4 families were presented in Table 3. Most agronomical and physiological traits of recombinant inbred lines fall between their parents, except only LP was higher than their parents. This is because the progenies have more leaflets (5 to 11) and thus have higher leaflet number than their parents. 3N was not different from LM in most traits except LP, and expressed more similar traits to 7L than to 9L.

After harvesting, 3N had more PW, SW, DF and PM, but less Y, SP, PL, BP, PC, CP, PP than LM. Among the LM lines, 7L had higher SW, SP, PL, PW, PC, PP, BP, DF, PF and PM than 9L. While, 3N and LM were higher in Y, SW, PW, PL SP and PC, but lower in CP, PP and BP than SM. Among the SM, 5S was different from 7S in SP, Y, LP, LI and PR. Both 5S and 7S showed less CP, PP, SP and LP but more BP and DF than 9S and 11S (Table 3).

Yield and yield components between isogenic lines carrying different leaflet size and number from each of the four families indicated that Y and SW of 3N were more similar to LM than to SM due to yield was highly related to seed weight. In the SM group, there was not different within group in both traits (Figure 3). 3N and LM produced longer pod and larger seed than SM. SM produced more but smaller seed and thus gave less yield than LM. 9L showed similar in pod size between four families (Figure 4). Whereas, 3N and LM gave higher number of seeds per pod, but less pods per plant than SM, owing to 3N and LM had longer pod than SM. SM had higher number of pods per plant than 3N and LM (Figure 5). Similarly, number of clusters per plant was higher in SM than 3N and LM, while number of pods per cluster was higher in LM and 3N than SM due to 3N and LM had less branches (Figure 6).

2. Effect of leaflet type on physiological traits

2.1 Light interception

Light interception (LI) was different between parents, and between the progenies carrying different leaflet size and number. The recombinant inbred lines were different between leaflet types within family, largely as the result of difference between LM and SM families (Table 1). On the average, the progenies had higher light interception than their parents (Table 2). Light interception of the progenies from four families indicated that 3N was nearer to 9L than to 7L. Among the SM, 7S and 11S were the lowest and highest LI, respectively (Figure 7). When averaged across four families, 3N gave the highest LI. 3N and LM were taller and bigger in canopy than SM due to the relationship between LI and canopy. While, LI of SM was lower than 3N and LM and varied within SM, i.e. 7S was not different form 9S but different from 5S and 11S, while 9S was different from only 11S (Table 3).

2.2 Leaf photosynthetic rate

On the same day that LI was recorded. The light response curves of 3N, 7L and 5S were measured at the photosynthetic photon flux (PPF) 0, 20, 50, 100, 200, 400, 800, 1200, 1600, 1800, 2200 and 2400 μmol m^{-2}s^{-1} for leaf photosynthetic rate until at the light saturation (P_{max}). Mungbean plants started photosynthesis when PPF was approximately 100 μmol m^{-2}s^{-1} and the initial slope of light response function increased until 2400 μmol m^{-2}s^{-1}, which was the light saturation point (P_{max}). This trait tended to be the same in 3N, 5S and 7L (Figure 8). 3N, 5S and 7L were different in photosynthetic rate at PPF 400 μmol m^{-2}s^{-1} until the highest rate of PPF at 2400 μmol m^{-2}s^{-1}. On the average, 5S and 3N were the lowest and highest of photosynthetic rate from PPF 0 to 2400 μmol m^{-2}s^{-1}, respectively. 3N and 7L were different from 5S in photosynthetic rate at PPF 400 to 1200 μmol m^{-2}s^{-1}. Whereas from PPF 1600 to 2400 μmol m^{-2}s^{-1}, 3N had higher photosynthetic rate than 5S and 7L (Table 4).

The photosynthetic rate at the light saturation (P_{max}) at the PPF 2,200 µmol m^{-2}s^{-1} was measured in 3N, 7L, 9L, 5S, 7S, 9S and 11S. When averaged across four families, 5S and 11S gave the highest and lowest photosynthesis rate a compared to the other leaflet size and number, respectively. 5S and 9S were higher photosynthetic rate, but 7S and 11S were lower than 3N and LM. 3N showed higher leaf photosynthetic rate than LM, whereas LM group was not different between 7L and 9L (Table 3).

2.3 Leaf area (LA)

Leaf area was different among the parents, while the progenies were diverse among lines carrying different leaflet size and number. The recombinant inbred lines were difference between family and between leaflet types within family. The progenies were averaged across four families, comparison between 3N and SM groups and between LM and SM groups revealed significant difference (Table 1). On the average, the progeny lines, 7L and 5S parents had LA of 783, 568 and 784 cm^2 per plant, respectively. Averaged LA of the progenies lines fell between the parents and nearer to 5S than to 7L parent (Table 2). The isogenic lines in each of the four families indicated that 3N was nearer to 9L than to 7L, whereas 3N and LM were higher in leaf area than SM. 7S showed more uniform leaf area across families than 5S, 9S and 11S (Figure 7). The lines with different leaflet number were similar in mot traits. While 3N gave lower leaf area than LM, and both leaflet types were different from SM. 9L had higher than 7L. Within SM group, 9S was highest and following by 11S, 5S and 7S, respectively (Table 3). This study indicated that the difference in leaf area depended on leaflet size rather than on leaflet number.

2.4 Leaf area index (LAI)

LAI was estimated from fisheye photographs were observed in 3N, 7L, 9L, 5S, 7S, 9S and 11S lines indicated that all lines were different between lines (Table 5). Moreover, all lines were different between plot within leaflet types such as 3N was different LAI between plots were measured and tended to be same in 7L, 9L,

5S, 7S, 9S and 11S lines. On the average, 3N was higher LAI than LM and SM. Within LM group, 9L was higher than 7L. Within SM group, 5S was the highest and following by 11S, 7S and 9S, respectively. The progenies were different within each leaflet size and number, i.e. plot one and three of 3N were different from plot two and four. While, plot three of 7L was different from plot one, two and four, but 9L, 5S and 7S were different between plots (Table 6).

2.5 The extinction coefficient (K)

The average of light extinction coefficient (k) from seven RILs was 0.29. 3N and 9S had the lowest and highest k values, respectively. The higher LAI and LI resulted from greater leaf area and that was associated with higher degree of foliage clumping. The low the light extinction coefficient may be associated with the relatively large leaf area. Among small multiple leaflets lines, 5S and 11S had smaller the light extinction coefficient than 7S and 9S because 7S and 9S had more LAI than 5S and 11S. The light extinction coefficient of RILs differed because of difference in canopy architecture (Table 7).

3. Correlation between yield and yield components

Correlation between yield and yield components of mungbean recombinant inbred lines averaged across four families were shown in Table 8. Yield was found positively correlated with seed weight (r = 0.68), pod length (r = 0.73), number of seeds per pod (r = 0.60), and number of pods per cluster (r = 0.53). However, it was negatively correlated with total number of leaves per plant (r = -0.56) and total number of leaflets per plant (r = -0.53), owing to the fact that seed weight, pod length and number of pods per cluster were subset of yield components, while total number of leaves and leaflets per plant were physiological traits. Plants with high total number of leaves per plant may use up carbohydrate to produce leaves and thus had less carbohydrate left for yield components in reproductive stage, according to source-sink relationship.

Seed weight was positively correlated with pod length (r = 0.90), pod width (r = 0.52), and number of seeds per pod (r = 0.59) but negatively correlated with number of pods per plant (r = -0.53), number of clusters per plant (r = -0.56), number of branches per plant (r = -0.58), total number of leaves per plant (r = -0.66) and total number of leaflets per plant (r = -0.73). Pod size is related to seed weight, i.e. plants with large pod should produce large seeds.

Number of pods per plant was positively correlated with number of branches per plant (r = 0.70), number of clusters per plant (r = 0.77), total number of leaflets per plant (r = 0.77), and total number of leaves per plant (r = 0.71). While number of seeds per pod was positively correlated with number of pods per cluster (r = 0.61) and pod length (r = 0.77), but negatively correlated with number of clusters per plant (r = -0.59), number of branches per plant (r = -0.60), total number of leaflets per plant (r = -0.72) and total number of leaves per plant (r = -0.67). Pod length was positively correlated with only number of pods per clusters (r = 0.67), while negatively correlated with number of branches per plant (r = -0.66), number of clusters per plant (r = -0.64), total number of leaflets per plant (r = -0.75), and total number of leaves

per plant (r = -0.82). Plant bearing more pods per plant normally had shorter pods because both traits were yield components and thus can compensate each others.

Plants with more branches and clusters per plant usually bore more pods because number of clusters per plant showed a strong correlation with number of branches per plant (r = 0.87). Plants with more branches tended to set more clusters. Number of pods per cluster was correlated with total number of leaves per plant (r = -0.53), while number of branches per plant was correlated with total number of leaflets per plant (r = 0.83), and total number of leaves per plant (r = 0.85). Plant height at maturity was positively correlated with LI (r = 0.66), and leaf area (r = 0.58). There was also a correlation between total number of leaflets per plant with total number of leaves per plant (r = 0.92).

The partitioning of correlation coefficients into direct and indirect effects by path-coefficient analysis was shown in Figure 9. It is then easy to determine specific yield components substantially influencing the yield. Pod length had highest positive direct effect on yield, followed by seed weight. Both traits also showed indirect effects to yield through number of pods per plant and number of seeds per pod. In the case of number of pods per plant, it is positively correlated with number of pods per cluster and number of branches per plant. On the other hand, number of clusters per plant showed negative direct effect with number of pods per plant. While number of branches and clusters per plant showed direct effect to number of pods per plant.

Table 1 ANOVA of some agronomical and physiological traits of isogenic mungbean lines carrying different leaflet types.

Source	df	CP[1]	PC	PL	PP	BP	SP	SW	Y
Replications	2	30.68	0.62	0.12	144.38	1.65	0.01	0.41	4.05
Treatments	29	85.74**	0.53**	12.68**	177.61**	4.26**	3.47**	2.58**	14.56**
Parents vs Lines	1	5.45	0.002	1.64	1.30	0.01	1.08	0.68	4.37
P1 vs P2	1	79.64**	0.04	23.25**	83.10*	4.40*	6.81*	5.75*	14.98*
Between lines	27	91.27**	0.57**	12.70**	183.26**	4.48**	3.43**	2.53**	14.92**
Between families	3	65.47	0.05	0.29	242.28*	1.13	0.39	0.02	4.89
Between leaflet types within family	24	94.50**	0.63**	14.25**	175.88**	4.90**	3.82**	2.85**	16.17**
Between types across 4 families	6	76.67**	0.53**	14.17**	113.79**	3.62**	3.43**	2.65**	14.50**
Between 3N vs LM	1	14.05*	0.05	0.06	113.10**	1.20*	0.21*	0.003	0.24
Between 3N vs SM	1	57.17**	0.34**	9.33**	110.89**	3.20**	6.81**	1.09**	14.53**
Between LM vs SM	1	91.26**	0.14	12.54**	293.55**	5.80**	7.30**	1.21**	14.67**
Between leaflet types residuals	3	99.18	0.88	21.03	55.06	3.84	2.08	4.53	19.18
Within families residuals	18	100.44	0.66	14.27	196.57	5.33	3.95	2.91	16.72
Error	58	20.32	0.15	0.11	39.48	0.89	0.43	0.22	4.02

Table 1 (Continued)

Source	df	DF	PF	PM	LP	LC	LI	LA	HI
Replications	2	8.18	67.77	216.94*	1334	36.64	394.09*	11807	0.01
Treatments	29	7.89	41.63	140.05**	12958**	199.15**	384.55**	107106**	0.01
Parents vs Lines	1	0.67	12.97	30.27	19281*	0.55	2.81	46448	0.01
P1 vs P2	1	16.67	11.2	247.68*	558**	534.12**	369.11*	58819*	0.01
Between lines	27	8.31	43.98	142.80**	13728**	207.27**	393.78**	10790**	0.01
Between families	3	10.52	38.46	206.58	5684	109.145	80.02	259228**	0.01
Between leaflet types within family	24	6.79	32.64	134.83**	14734**	219.53**	432.99**	88995**	0.01
Between types across 4 families	6	3.96	24.62	109.68**	13245	3.62**	164.45**	51973*	0.03
Between 3N vs LM	1	0.001	0.11	34.83	12813**	1.02**	77.79	1507	0.004
Between 3N vs SM	1	14.26*	27.19	0.86	11188**	5.08**	43.25	54184*	0.01*
Between LM vs SM	1	11.92*	51.91	91.11*	31188**	3.2**	439.46*	57576*	0.02**
Between leaflet types residuals	3	0.81	22.83	177.09	8093	4.14	142.06	66190	0.04
Within families residuals	18	7.73	35.31	143.21	15230	291.5	522.50	101335	0.003
Error	58	5.71	32.42	40.22	624	12.68	117.76	33781	0.01

[1]: CP = number of clusters per plant, PC = number of pods per clusters, PL = pod length in cm, PP = number of pods per plant, BP = number of branches per plant, SP = number of seeds per pod, SW = one-hundred seed weight, Y = seed yield per plant, DF = days to 50 % flowering, PF = plant height at 50 % flowering, PM = plant height at maturity, LP = total number of leaflets per plant, LC = total number of leaves per plant, LI = Light interception, LA = Leaf area and HI = Harvest index.

*,** = significantly different at 0.05 and 0.01 level of probability, respectively.

Table 2 Range and mean±SD of some agronomical and physiological traits of mungbean RILs and their parents.

Traits[1]	RILs		Parents			
			7GL		5PS	
	Range	Mean±SD	Range	Mean±SD	Range	Mean±SD
Agronomical traits						
PL	4.58-10.92	7.74±2.07	9.95-10.43	10.25±0.26	6.03-6.52	6.31±0.25
PW	3.96-5.92	4.88+±0.27	4.83-5.35	5.14±0.27	4.81-5.06	4.95±0.13
PC	3.00-5.50	3.87±0.55	3.67-4.22	3.96±0.28	3.22-4.56	3.80±0.69
CP	5.00-25.17	14.62±6.53	8.50-10.00	9.20±0.75	15.75-17.50	16.45±0.91
PP	19.67- 65.00	32.25± 9.47	25.39-29.83	28.33±2.55	31.94-39.83	35.78±3.95
SP	7.89-13.06	10.87±1.19	10.89-12.42	10.92±0.81	9.08-9.78	9.38±0.36
BP	0.750-5.67	3.59±1.46	2.17-3.11	2.57±0.48	4.11-4.42	4.29±0.16
SW	2.52-6.65	4.13± 0.99	4.43-6.13	5.46±0.91	3.13-3.73	3.50±0.33
Y	5.66-18.62	10.54±2.80	12.48-13.89	13.01±0.77	8.64-10.96	9.85±1.16
Physiological traits						
DF	34.00-45.00	38.32±2.60	39.00-42.00	40.33±1.53	36.00-38.00	37.00±1.00
PF	21.17-51.00	32.62± 6.24	33.89-36.94	35.33±1.54	30.83-33.94	32.59±1.59
PM	36.50-76.17	47.56±8.91	53.39-59.67	56.67±3.149	41.00-45.67	43.82±2.48
LP	19.50- 285.00	109.51±68.74	48.61-59.83	54.15±5.611	45.83-49.67	47.94±1.95
LC	5.67- 38.33	16.94±8.59	6.72-8.33	7.54±0.805	25.61-27.00	26.41±0.72
LI	79.34- 90.97	82.11±14.7	66.92-74.50	71.45±3.99	57.74-77.71	68.76±5.55
LA	403-1388	783±242	525-679	586±81	706-856	784±75
HI	0.44-0.89	0.70±0.08	0.69-0.730	0.71±0.02	0.65-0.68	0.66±0.01

Traits[1]: PL = pod length in cm, PW = pod width in mm, PC = number of pods per clusters, CP = number of clusters per plant, PP = number of pods per plant, SP = number of seeds per pod, BP = number of branches per plant, SW = one-hundred seed weight in g, Y = seed yield per plant in g, DF = days to 50 % flowering, PF = plant height in cm at 50 % flowering, PM = plant height in cm at maturity, LP = total number of leaflets per plant, LC = total number of leaves per plant, LI = Light interception, LA = Leaf area and HI = Harvest index.

Table 3 Mean comparisons of some agronomical and physiological traits of mungbean recombinant inbred lines averaged across four families.

Traits	3N	7L	9L	5S	7S	9S	11S	Mean	CV
PL[1]	10.01 a[2]	10.13 a	10.02 a	5.95 b	6.10 b	6.145 b	5.81 b	7.74	2.92
PW	5.02 a	5.01 a	4.96 a	4.75 b	4.74 b	4.824 b	4.83 b	4.87	1.58
PC	4.13 b	4.51 a	4.28 ab	3.56 c	3.45 c	3.59 c	3.58 c	3.87	5.34
CP	8.83 c	8.96 c	8.99 c	16.46 b	15.47 b	21.26 a	20.56 a	14.36	15.32
PP	22.84 d	27.87 cd	27.33 cd	30.78 bc	34.02 b	43.00 a	39.92 a	32.25	11.94
SP	11.77 a	12.07 a	11.95 a	10.82 b	10.18 c	10.02 c	9.37 d	10.88	3.86
BP	2.02 b	2.72 b	2.32 b	4.31 a	4.15 a	4.76 a	4.86 a	3.59	14.12
SW	5.20 a	5.12 a	5.06 a	3.30 b	3.24 b	3.47 b	3.52 b	4.13	7.54
Y	12.45 a	12.54 a	13.52 a	9.70 b	8.21 c	9.13 bc	8.36 c	10.55	8.20
DF	38.92 abc	38.25 bcd	38.00 bcd	37.34 dc	37.08 d	39.08 ab	40.16 a	38.32	3.04
PF	36.46 a	36.75 a	29.33 de	33.74 bc	31.46 cd	28.41 e	35.54 ab	33.10	5.13
PM	55.56 a	53.85 a	47.36 b	44.43 cb	40.60 c	44.06 bc	47.07 b	47.56	5.42
LP	28.49 d	53.35 c	65.17 c	83.10 c	153.43 b	192.63 a	190.42 a	109.51	19.35
LC	8.97 c	7.50 c	8.57 c	22.11 ab	21.56 b	25.88 a	24.01 ab	16.94	14.94

Table 3 (Continued)

Traits	3N	7L	9L	5S	7S	9S	11S	Mean	CV
LI	88.05 a	71.39 b	83.28 a	68.62 bc	58.57 d	61.93 cd	72.92 b	72.11	10.39
LA	891.04 a	916.91 a	936.11 a	654.81 b	620.10 b	669.56 b	658.95 b	763.92	9.64
PR	25.67 bc	23.56 bc	23.30 bc	30.25 a	24.71 bc	28.53 ab	22.40 c	25.49	8.22

[1]: PL = pod length in cm, PW = pod width in mm, PC = number of pods per clusters, CP = number of clusters per plant, PP = number of pods per plant,

SP = number of seeds per pod, BP = number of branches per plant, SW = 100-seed weight in g, Y = seed yield per plant in g, DF = days to 50 % flowering,

PF = plant height in cm at 50 % flowering, PM = plant height in cm at maturity, LP = total number of leaflets per plant, LC = total number of leaves per plant,

LI = light interception, LA = Leaf area in cm^2, and PR = photosynthetic rate.

[2]: Means of each trait followed by the same letter are not significantly different among the RILs as tested by Duncan's Multiple Range Test (DMRT) at $P \leq 0.05$.
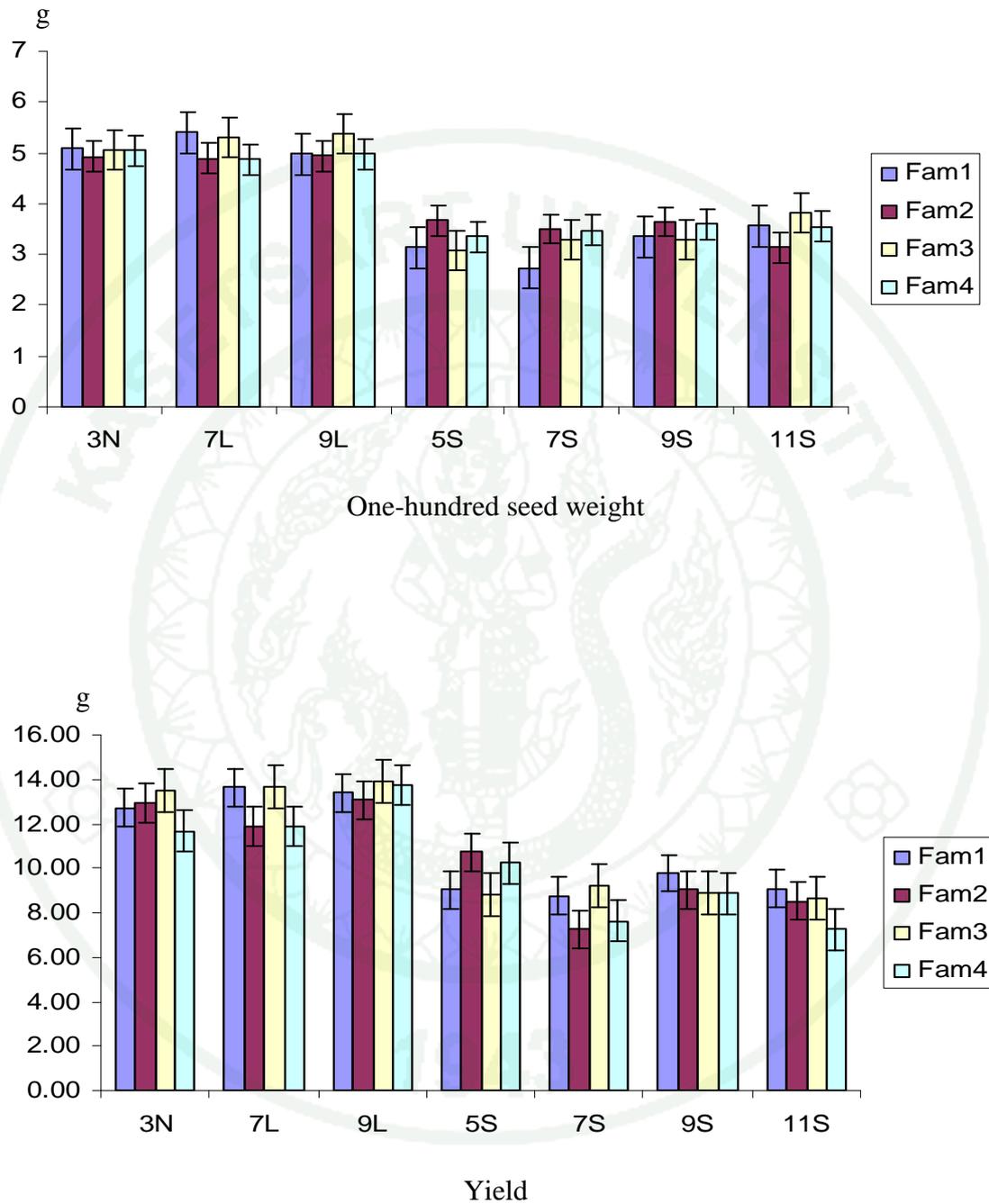
Figure 3 One-hundred seed weight (g) and yield (g) of mungbean isogenic lines
carrying different leaflet size and number from each of the four families
(I = standard error of mean (SE)).
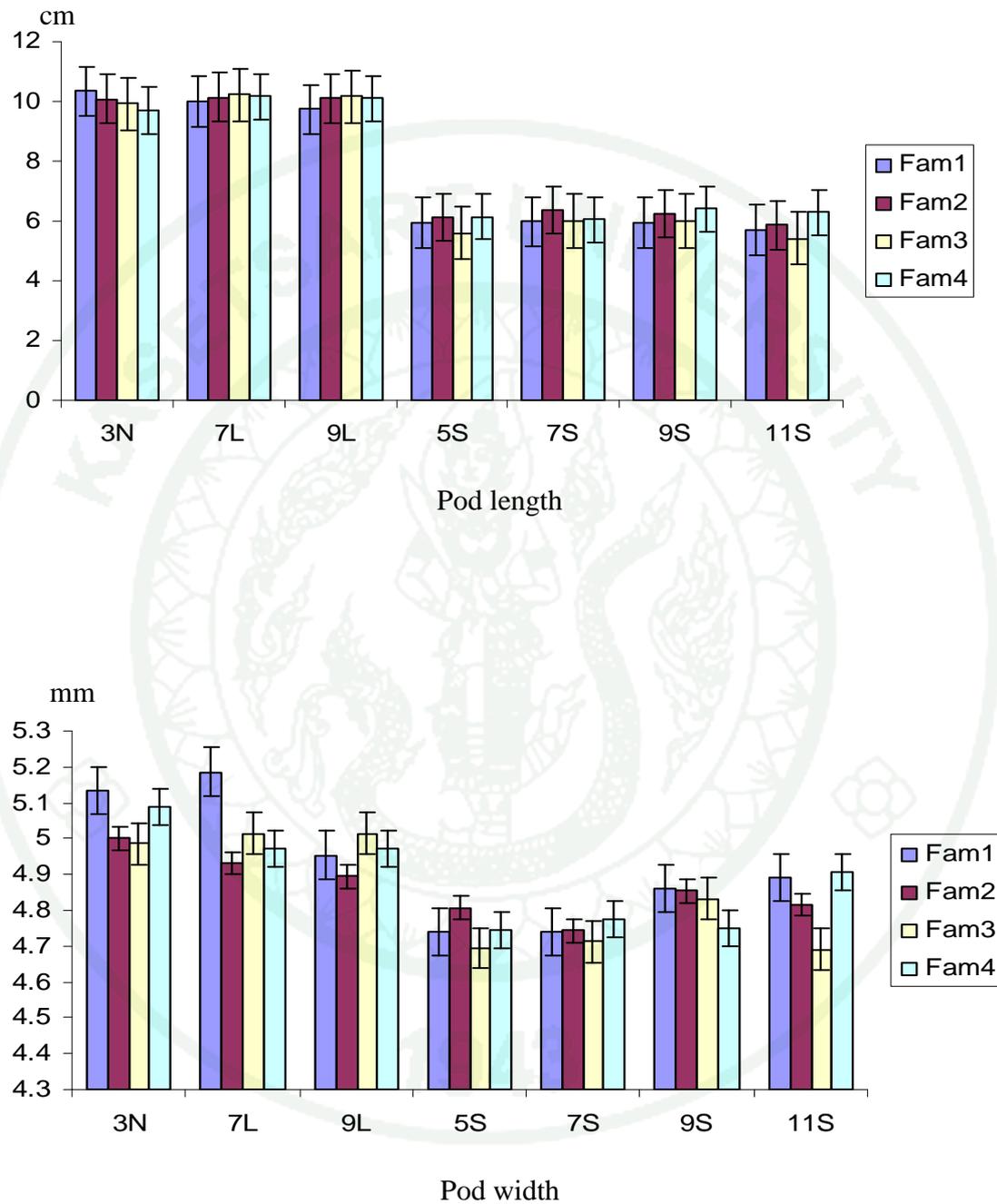
Figure 4 Pod length (cm) and pod width (mm) of mungbean isogenic lines carrying
different leaflet size and number from each of the four families (I = standard
error of mean (SE)).

Number of seeds per pod

Number of pods per plant
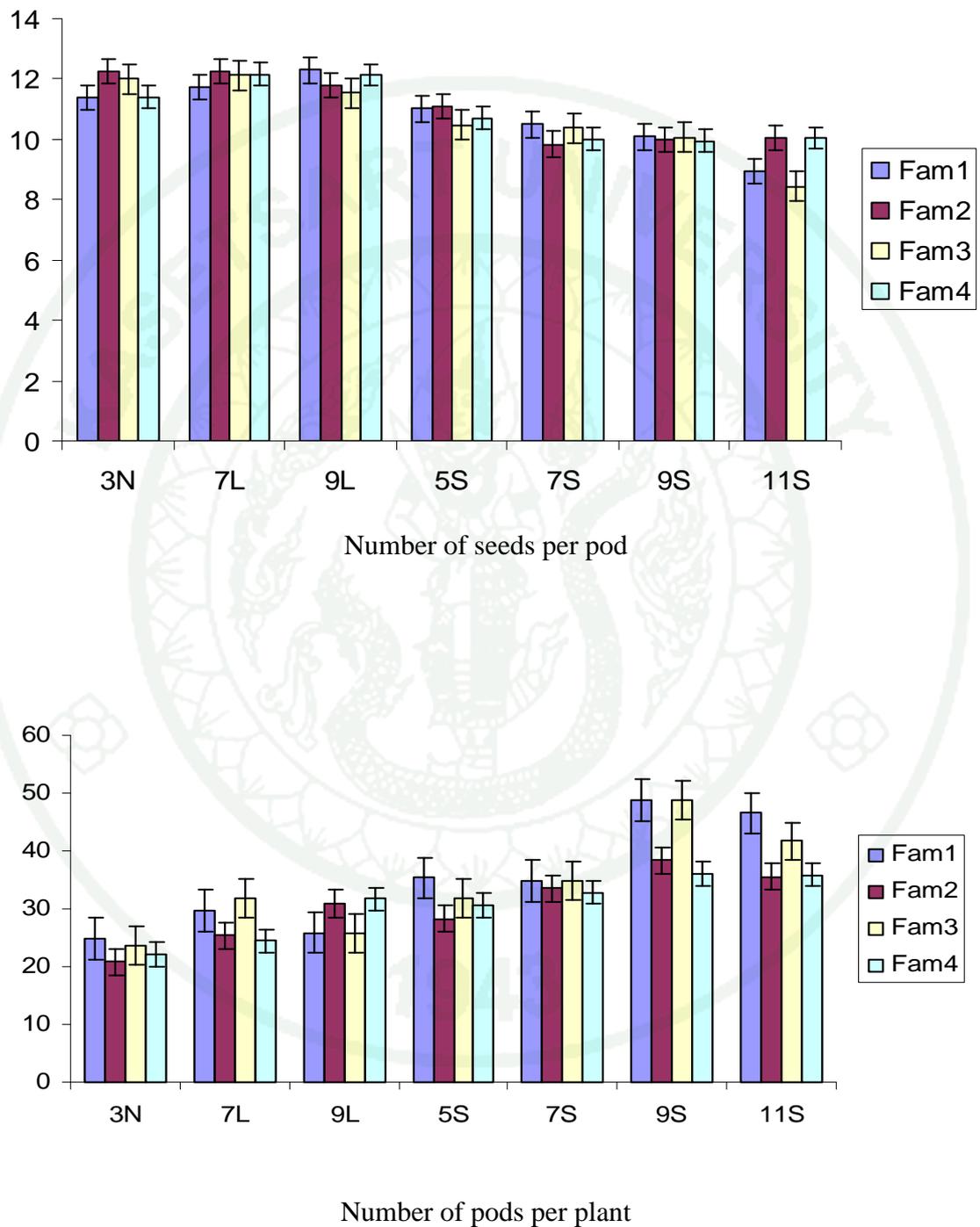
Figure 5 Number of seeds per pod and number of pods per plant of mungbean
isogenic lines carrying different leaflet size and number from each of the
four families (I = standard error of mean (SE)).
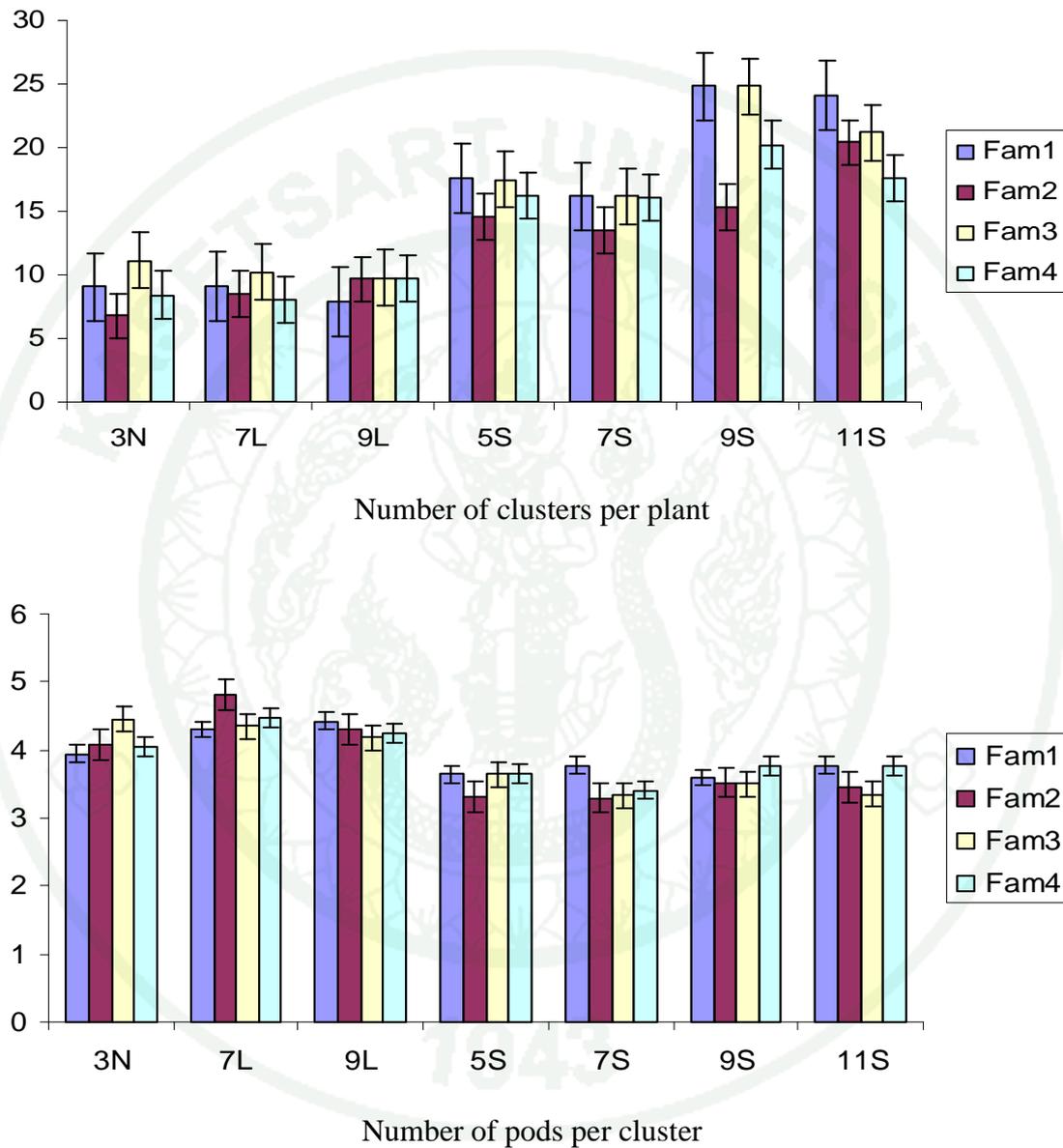
Figure 6 Number of clusters per plant and number of pods per cluster of mungbean
isogenic lines carrying different leaflet size and number from each of the
four families (I = standard error of mean (SE)).

% Light interception

Light interception

cm^2
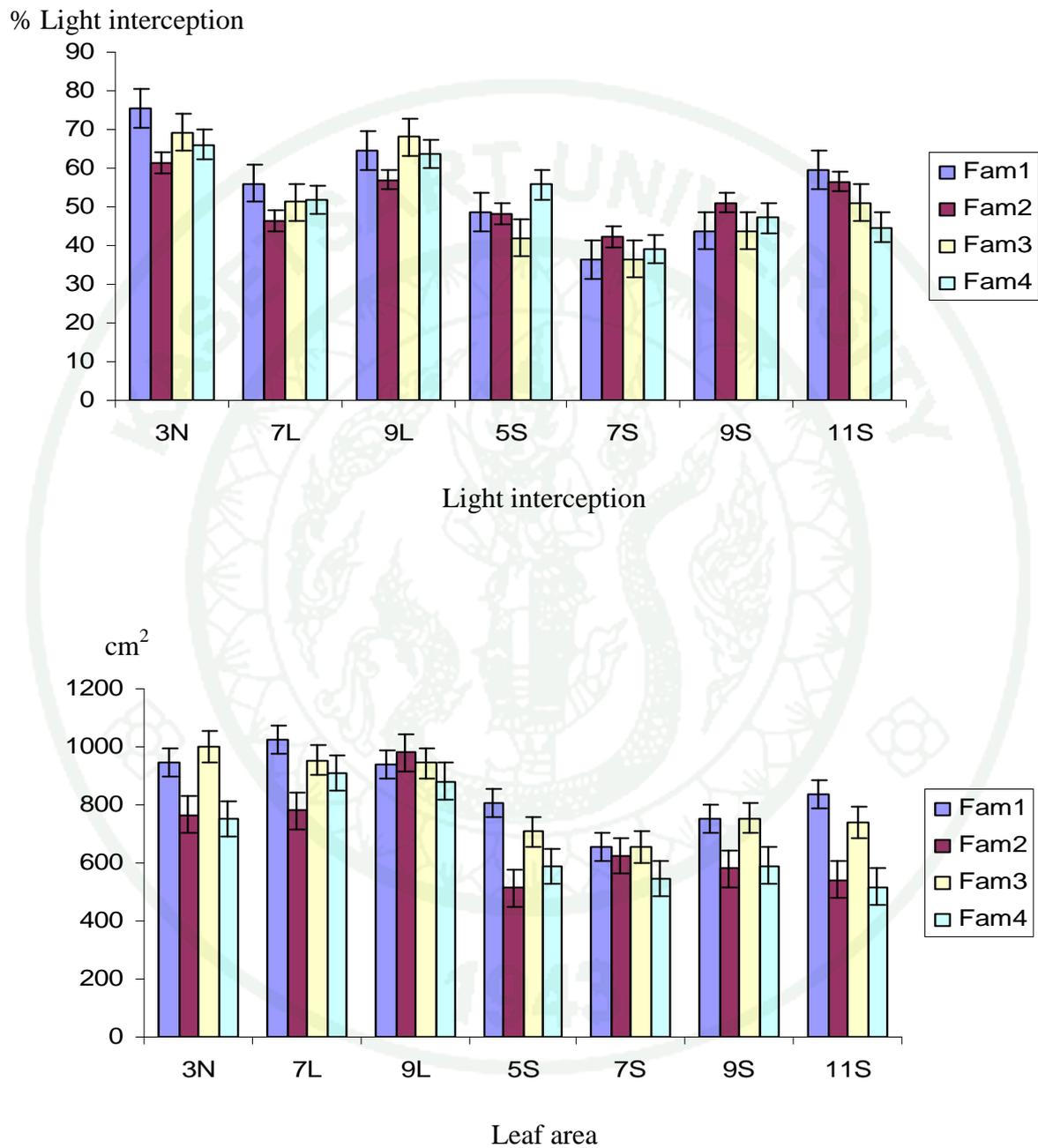
Leaf area

Figure 7 Light interception (%) and leaf area (cm^2) of mungbean isogenic lines
carrying different leaflet size and number from each of the four families
(I = standard error of mean (SE)).

Photosynthetic rate (µmol m^{-2}s^{-1})
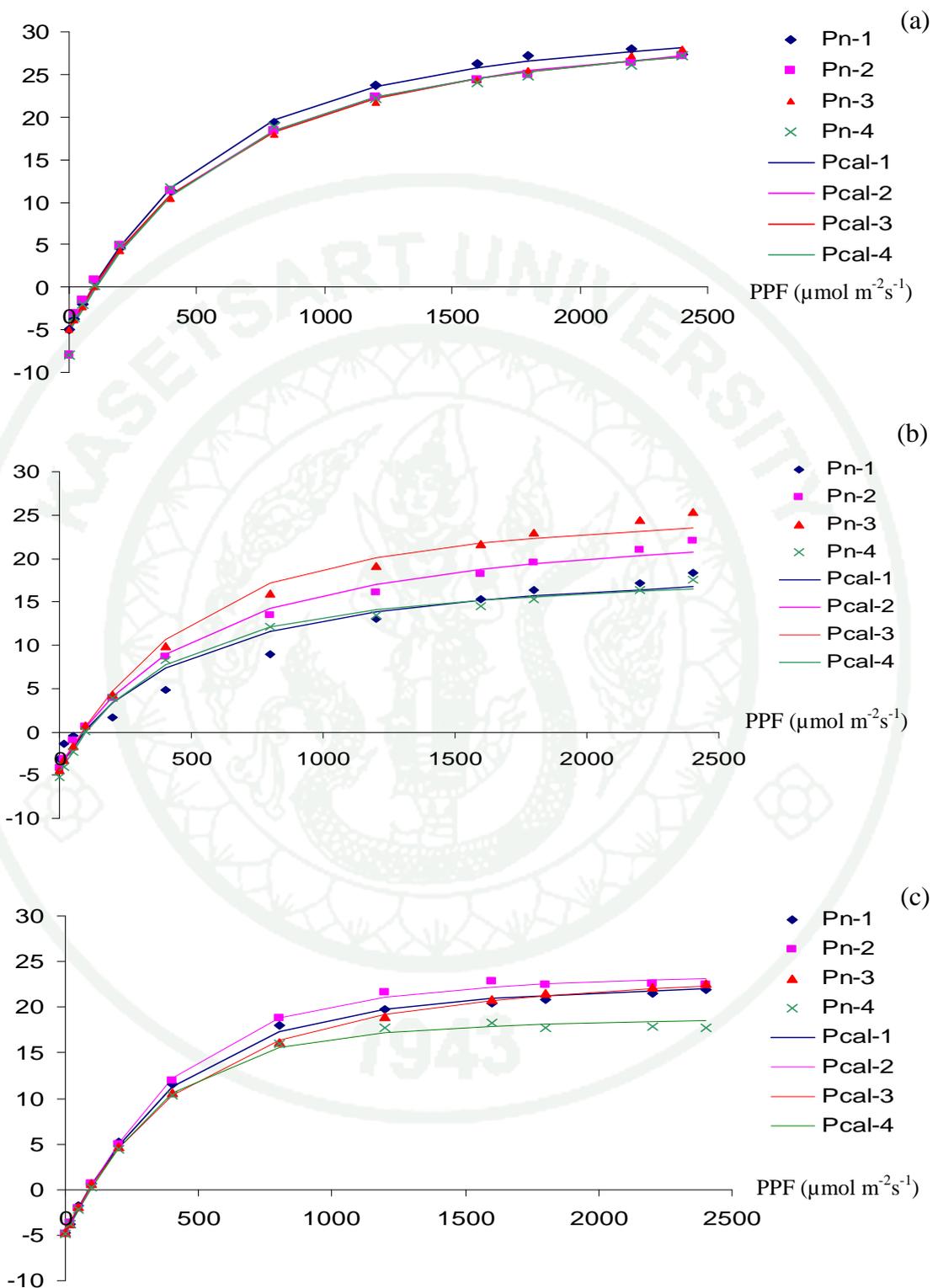
Figure 8 Light response curves of trifoliate leaflet (3N) (a), five-small multiple
leaflet (5S) (b) and seven-large multiple leaflet (7L) (c) from the four plants
of each isogenic lines.

Table 4 Mean comparisons of photosynthetic rate at the range of PPF from 0 to 2,400 µmol m^{-2}s^{-1} in 3N, 7L and 5S lines.

Leaflet types	Photosynthetic photon flux (PPF)											
	0	20	50	100	200	400	800	1200	1600	1800	2200	2400
3N	-5.67 a[1]	-3.61 a	-1.94 a	0.41 a	4.69 a	11.18 a	18.65 a	22.48 a	24.73 a	25.63 a	26.88 a	27.40 a
7L	-4.81 a	-3.77 a	-1.97 a	0.53 a	4.82 a	11.10 a	17.23 a	19.55 a	20.60 b	20.60 b	21.05 b	21.18 b
5S	-4.26 a	-2.92 a	-1.38 a	0.52 a	3.44 a	7.92 b	12.62 b	15.45 b	17.43 b	18.55 b	19.78 b	20.83 b
Mean	-4.91	-3.43	-1.77	0.49	4.31	10.01	16.11	19.16	20.92	21.59	22.57	23.13
CV(%)	20.28	18.93	28.98	44.19	17.94	13.61	10.79	10.27	10.75	10.14	10.21	10.71
F-test	ns	ns	ns	ns	ns	*	**	**	**	**	**	**

[1] = means of photosynthetic rate in each PPF followed by the same letter are not significantly different as tested by Duncan's Multiple Range Test (DMRT)
 at P $\leq$ 0.05.

*,** = significantly different at 0.05 and 0.01 level of probability, respectively.

ns = not significant.

44

Table 5 ANOVA of LAI of leaflet types in the recombinant inbred lines from
fisheye photographs.

SOV	df	MS
		Fisheye photographs
Lines	6	0.81*
Error	21	0.20

[*] = significantly different at 0.05 level of probability.

Table 6 Mean comparison of LAI of the recombinant inbred lines from fisheye photographs.

LAI	3N	7L	9L	5S	7S	9S	11S
Plot 1	2.44 a[1]	1.28 a	2.80 a	1.93 a	1.18 c	1.41 a	1.47 a
Plot 2	1.76 b	1.28 a	2.07 b	0.75 c	1.26 b	0.78 b	1.21 b
Plot 3	2.74 a	1.06 b	1.07 d	1.96 a	1.13 d	0.70 c	1.34 ab
Plot 4	2.05 b	1.27 a	1.38 c	0.83 b	1.39 a	0.70 c	1.30 ab
Mean	2.25 a	1.22 cd	1.83 b	1.36 c	1.24 cd	0.90 d	1.33 c
CV (%)	7.79	1.08	7.52	1.82	1.73	1.07	6.03

[1] = means of each trait followed by the same letter are not significantly different as tested by Duncan's Multiple Range Test (DMRT) at $P \leq 0.05$.

Table 7 The leafarea index (LAI), light interception (LI) and estimated the light extinction coefficient (k) of the recombinant inbred lines at 46 DAP.

Leaf characters	LAI	LI	k
3N	2.25	0.88	0.15
7L	1.34	0.71	0.26
9L	1.83	0.83	0.22
5S	1.36	0.68	0.28
7S	1.24	0.57	0.44
9S	1.10	0.61	0.45
11S	1.33	0.72	0.25
mean	1.45	0.72	0.29

Table 8 Correlation between agronomical and physiological traits of mungbean recombinant inbred lines averaged across 4 families.

Traits[1]	PF	PM	LI	LA	LP	LC	HI	BP	PC	CP	PW	PL	SP	PP	SW	Y
DF	0.28*	0.25*	0.27*	0.21*	0.33*	0.30**	-0.15	0.37**	0.06	0.37**	-0.03	-0.08	-0.22*	0.35**	0.01	-0.04
PF		0.53**	0.43**	0.10	-0.13	-0.07	-0.07	-0.07	0.12	-0.05	0.02	0.08	0.01	0.02	0.12	-0.01
PM			0.66**	0.58**	-0.33**	-0.31**	0.09	-0.19	0.46**	-0.12	0.27*	0.49**	0.29**	-0.04	0.49**	0.50**
LI				0.45**	-0.06**	-0.32**	0.07	-0.26*	0.38**	-0.18	0.30**	0.47**	0.27*	-0.24*	0.48**	0.33**
LA					-0.17	-0.18	0.17	-0.06	0.42**	-0.01	0.12	0.51**	0.36**	0.01	0.47**	0.57**
LP						0.92**	-0.17	0.83**	-0.47**	0.83**	-0.28*	-0.75**	-0.72**	0.77**	-0.65	-0.53**
LC							-0.01	0.85**	-0.53**	0.85**	-0.27*	-0.82**	-0.67**	0.71**	-0.73**	-0.56**
HI								-0.09	0.34**	-0.04	0.07	0.17	0.37**	-0.09	0.03	0.03
BP									-0.39**	0.87**	-0.32**	-0.66**	-0.60**	0.70**	-0.58**	0.35
PC										-0.41**	0.11	0.67**	0.61**	-0.26*	0.48**	0.53**
CP											-0.24*	-0.64**	-0.59**	0.77**	-0.56**	-0.37**
PW												0.37**	0.12	-0.31**	0.52**	0.26*
PL													0.77**	-0.55**	0.90**	0.73**
SP														-0.47**	0.60**	0.60**
PP															-0.53**	0.40**
SW																0.68**

*,** = significantly different at 0.05 and 0.01 level of probability, respectively.

[1]: DF = days to 50 % flowering, PF = plant height in cm at 50 % flowering, PM = plant height in cm at maturity, LI =light interception, LA = Leaf area, LP = total number of leaflets per plant, LC = total number of leaves per plant, HI = Harvest index, BP = number of branches per plant, PC = number of pods per clusters, CP = number of clusters per plant, PW = pod width in mm, PL = pod length in cm, SP = number of seeds per pod, PP = number of pods per plant,   SW = 100-seed weight and Y = seed yield per plant
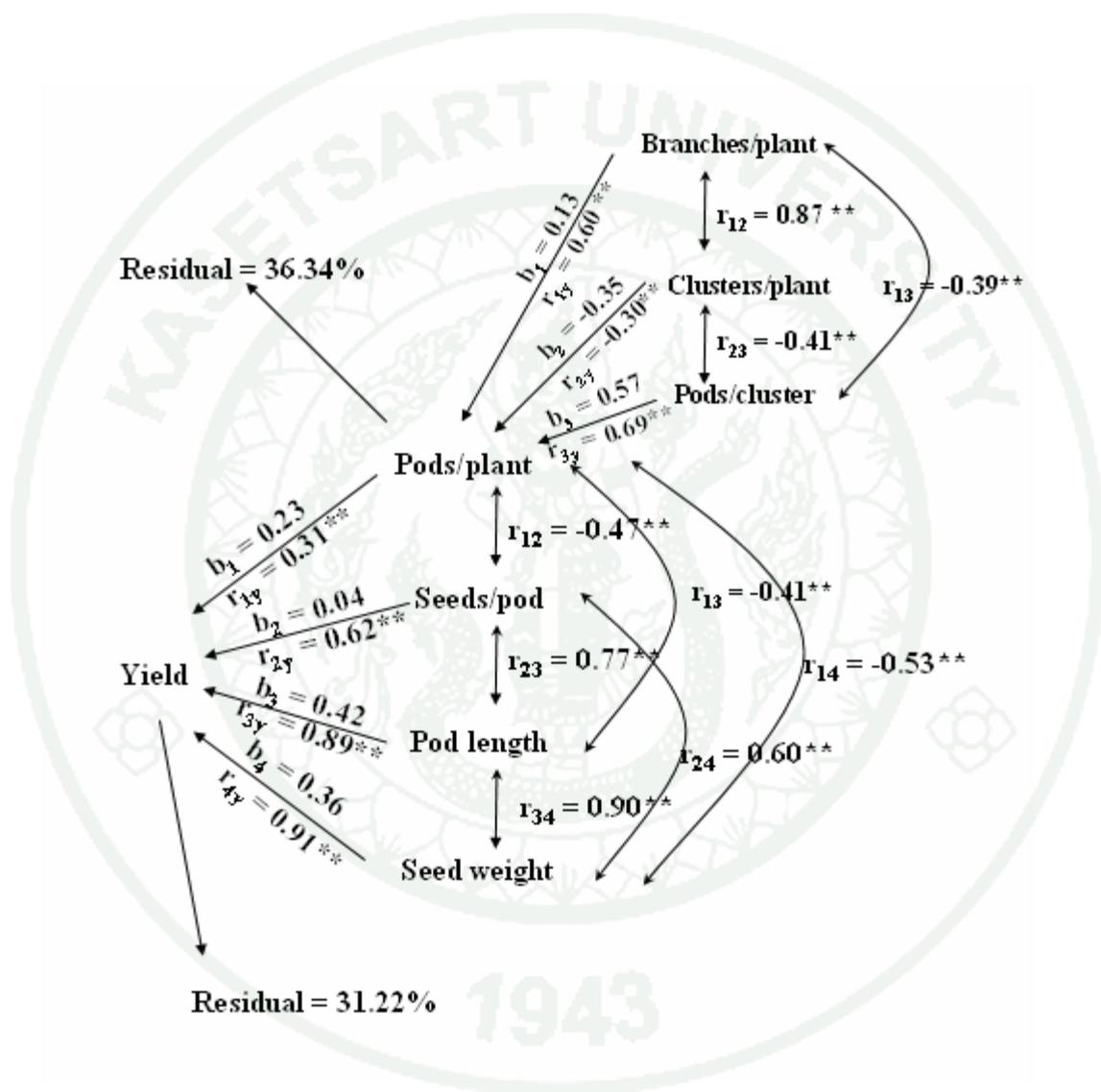
Figure 9 Path coefficients between yield and yield components of some agronomical traits of mungbean recombinant inbred lines averaged across four families.

DISCUSSION

1. Effect of leaflet size and number on agronomic traits

3N and LM gave higher yield than SM, owing mainly to their larger seed size, although LM produced larger seed as compared to 3N. Kowsurat *et al*. (1999) found no difference in 1000-seed weight between normal trifoliate leaflet and large multiple leaflet lines (7L), whereas seed yield, plant height, and number of pods per plant were greater in 3N than in 7L. This study indicated that the leaflet type significantly influenced seed yield, although the genetic background is up to 93.75% homozygous among lines within the same family. Thus difference between lines within each family is clearly affected by genes controlling the leaflet size and number. Seed size seemed to be the most important yield component and directly proportional to seed yield per plant. Seed size of the SM lines was generally smaller than 3N and LM (Table 1), which implied that the gene(s) controlling seed size is linked with that controlling leaflet size as the number of leaflets per plant of all lines hardly changed. LM had higher number of seeds per pod, number of pods per cluster with larger and longer pods, but less number of branches per plant, number of pods per plant and number of cluster per plant than the SM ones. Difference between RILs of the same leaflet size was not significant, regardless of leaflet number. Thus, leaflet size seemed to be more important in controlling agronomic characters. Similarly, Kowsurat *et al*. (1999) reported that number of seeds per pod was not different between normal trifoliate leaflet and large heptafoliate leaflets (7L), while dry matter accumulation was greater in the trifoliate leaflet cultivars than in the 7L lines. Later, Soehendi *et al.* (2007) reported that trifoliate and 7L gave similar pod length but significantly longer than those of 5S and 7S lines. Increasing in assimilate supply after beginning pod development may increase seed yield.

During this study, mungbean grew slowly in the early vegetative stage until 30 days after planting due to low temperature. They later grew faster when the temperature became warmer. 7S and 5S showed earlier flowering than the other

leaflet types, however the pattern was not clear whether leaflet size and number affected days to flowering due to the fact that 3N was not different from LM. These traits are also dependent of available nutrition, temperature and genetic make-up of the cultivars. However, 3N and LM were taller than SM in both vegetative and reproductive stages. 3N and 7S were the tallest and shortest, respectively. Plant height showed positive association with days to flowering. Similar result was reported by Rohman *et al.* (2003). Tickoo *et al.* (1996) found that both characters were not different among multiple leaflet line although flowering came in different flushes. Rubio *et al.* (2004) reported that the latest flowering genotype would develop more branches, leading to higher seed yield in white lupin.

2. Effect of leaflet size and number on physiological traits

2.1 Light interception (LI)

LI was different between the progeny lines due to leaflet size and number. 3N had higher LI than LM and SM. Kowsurat *et al.* (1999) reported that trifoliate leaflet was higher in light interception than 7L. 3N and LM had larger leaf and canopy, so the plants grew faster to cover inter-row spaces and lead to a higher LI. LM has higher LI than SM, as large leaflet plants tended to intercept more light than the small leaflet one, since LM had higher LA than SM and LA was positively associated with LI. While 9S and 7S were different from 5S and 11S, indicating that leaf area was curvilinear in relation to percent light interception. As an adaptation to maximize light interception, plants have developed different canopy architectures. Odabas *et al.* (2008) stated that LI had an important relationship with growth rate through PAR, so plant height which related to leaf canopy and growth rate are also important in affecting LI of leaf. Additionally, Sung and Chen (1989) reported greater light penetration to lower canopy strata in narrow leaflet canopies of soybean. Idinoba *et al* (2002) reported that LI was highly correlated with leaf area in groundnut, and in cowpea showed that leaf area orientation and distribution showed a considerable influence on intercepted PAR.

2.2 Leaf photosynthetic rate (PR)

3N was higher in photosynthetic rate than LM, but 3N was not different from LM. 5S was the highest. 5S and 9S had higher photosynthetic rate, but 7S and 11S less rate than 3N. Photosynthesis per unit leaf area in crop plants is an important physiological attribute controlling whole plant photosynthesis. Increasing photosynthesis and growth rate should increase grain yield because photosynthetic carbon assimilation is the major source of dry matter. These results agreed with Choomak (2002) and Chidchenchey (2003) who reported that net photosynthetic rate in trifoliate leaflets was greater than in multiple leaflet line (7L). However, Kowsurat *et al*. (1999) reported that light saturation and photosynthetic rate were not different between normal and multiple leaflet line.

2.3 Leaf area (LA)

3N and LM gave higher leaf area than SM because large leaf area that intercepts maximum light is required to obtain high seed yield, and LA was positively related with yield. Jahan and Hamid (2006) reported that leaf area was an important component having a large bearing on the physiological processes controlling yield and dry matter production. Eventhough SM had numerous leaflets distributing evenly in the canopy, each leaflet is comparatively much smaller in leaf area than 3N and LM, and consequently they absorb less sun light. It was clear from our study that leaf area was dependent on leaflet size more than leaflet number. Soehendi *et al.* (2007) showed that leaf area of the trifoliate leaflet and 7L lines was higher than that of 5S and 7S.

2.4 Leaf area index (LAI)

LAI was provided by fisheye photographs in 3N, 7L, 9L, 5S, 7S, 9S and 11S lines indicated that 3N was higher LAI than LM and SM. Within LM group showed that 9L was higher than 7L this resulted were agree with LAI were calculated by LI, while SM group found that 5S was the highest and following by 11S, 9S and

7S, respectively. Kowsurat *et al*. (1999) reported that LAI of the multifoliate lines (7L) was less than that of the trifoliate ones, as the number of leaflets per plant of 7L hardly changed while that of the trifoliate parents increased. Well (1991) reported that LAI of soybean was curvilinearly related to percent light interception until canopy closure due to leaf area index was positively associated with seed yield (Board *et al.*, 1996).

2.5 The light extinction coefficient (k)

Among large multiple leaflets lines, 3N had taller and bigger canopy, hence, 3N had high LI and LAI than 7L and 9L. 3N had lowest light extinction coefficient because the light extinction coefficient was related to LAI and LI. While 9L had greater number of leaves and leaf area per plant than 7L that resulted in higher LI and LAI, it had lower the light extinction coefficient than 7L because LI was positively correlated with LAI. The large multiple leaflets showed a trend of decreasing k with increasing canopy. De Costa (1992) reported an inverse relationship between the light extinction coefficient and LAI. The light extinction coefficient was changed with time of the day and it was the lowest at noon (Wang *et al.*, 2001). Comparison between small multiple leaflets lines found that the light extinction coefficient of 5S and 11S were smaller than 7S and 9S. Common bean and mungbean had light extinction coefficients of 0.34 and 0.45, respectively (Alimadadi *et al.*, 2006). Whereas, the extinction coefficient of chickpea was 0.55 (Robertson, 2002; Hughes *et al.,* 1987), mungbean was 0.40 (Robertson, 2001; Muchow and Charles-Edwards, 1982), Peanut was from 0.37-0.45 (Hammer *et al.,* 1995; Kiniry *et al.,* 2005) Lucerne was 0.45 (Sato, 1971) and Faba bean was 0.36 (Husain, 1990). Generally, canopies with rather horizontal leaves tend to have high light extinction coefficient values and can only be of advantage early in the season when LAI is low and light interception is limited by the size of the canopy (Squire, 1990).

3. Correlation between yield and yield components

Yield was positively correlated with seed weight, number of seeds per pod, number of pods per cluster, pod length and leaf area. This study found that yield depended on pod length more than the other characters. LM produced higher yield per plant than SM due to its larger seed size, although SM produced more pods per plant than LM. This indicated that seed size increment was essential for yield improvement. Thus increasing in seed yield is resulted from increasing in leaf area for photosynthesis, growth and assimilation. These results were in accordance with the finding of Khan *et al.* (2001), Upadhayaya *et al.* (2002) and Afzal *et al.* (2003) who reported that grain yield production was due to many yield contributing traits such as number of pods per plant, plant height, and leaf area index. Grain yield was positively correlated with number of branches per plant, thus plants with higher number of branches tended to give higher yield. In this study, yield was negatively correlated with total number of leaflets per plant, implying that plants producing higher number of leaves have less carbohydrate to produce yield components in the reproductive stage according to source-sink relationship. Yield was varied among different leaflet size and number because it was dependent on many factors such as leaf area, LI, seeds per pod, branches per plant, and pods per plant, pod length and seed weight. Yield was more dependent on number of pods per plant than on number of seeds per pod, because the latter characteristic was rather stable. Vasic *et al.* (1997) worked on common bean and Egli (1999) worked on soybean and both reported that number of seeds per pod depended largely on genetic control. Whereas, Khan *et al.* (2001) reported that number of pods per plant was positively correlated with branches and clusters per plant because increasing in number of leaves affected high photosynthesis and accumulation of carbohydrate which consequently increased number of pods and clusters.

One-hundred seed weight was positively correlated with number of seeds per pod, pod length and pod width but negatively correlated with number of clusters per plant, number of branches per plant, number of pods per plant and total number of leaflets per plant. The plant with large seed size produced large pods but less number

of clusters per plant due to limitation of source from photosynthetic process and sink existed at the same time. These results were in accordance with the finding of Reddy *et al.* (1991) who reported a positive association between pod length and seed weight in mungbean.

Number of seeds per pod was positively correlated with pod length and number of pods per cluster, but negatively correlated with number of branches per plant, number of clusters per plant, and number of leaflets per plant. This implied that long pod had more seeds per pod. At vegetative stage, the plants used carbohydrate for increasing branches, clusters, and leaves and thus had not enough carbohydrate for use at the beginning and full pod stages. This finding is in agreement with Tewari and Gautam (1989) and Malik (1994) who reported that number of pods per plant was positively correlated with number of branches per plant and number of clusters per plant. Reddy *et al.* (1991) stated that the increase in number of branches enhanced pod number and grain yield. In this study, number of clusters per plant was positively correlated with number of branches per plant and number of leaflets per plant. Rubio *et al.* (2004) observed that various genotypes of mungbean produced different number of branches and pods per plant. Khan *et al.* (2001) recorded that the cultivar produced highest number of branches per plant also produced highest number of pods per plant.

Pod length was positively correlated with number of pods per clusters, leaf area and LI, and plant height at maturity stage, but negatively correlated with number of leaflets per plant, number of branches per plant and number of clusters per plant. Clearly, yield components can compensate each others. For example, although SM set more pods per plant, it also had smaller seed and less seed number per plant, thus it might be used as a source to increase pod number and improve seed yield. Miah and Bhadra (1989) studied the relationship between agronomic characters of mungbean and found that pod length showed positive correlation with number of pods per cluster and plant height. However, this study showed that plant height at maturity was positively correlated with LI and leaf area. This result was in agreement with the experiment in cowpea (Peksen, 2004), and dry bean (Mirja, 2005). Naidu *et al.* (1991) reported that plant height associated with PAR interaction during growth in rows.

Vigorous growth before flowering was required to encourage assimilate production in order to be translocated into the seed after flowering (Tickoo *et al*., 1996).

Number of leaflets per plant was positively correlated with number of branches per plant, number of clusters per plant, number of pods per plant, but negatively correlated with leaf area, pod length, number of seeds per pod, number of pods per cluster, seed weight and yield. Photosynthesis varies from time to time in a day depending on light intensity and relative humidity. An erect leaf canopy could theoretically increase crop assimilation rate (Sakamoto and Matsuoka, 2004).

The path-coefficient analysis revealed that seed yield was positively associated with seed weight and pod length owing to high positive direct effects. Khan and Qureshi (2001) reported that 100-seed weight had positive direct effect on grain yield in chickpea, while Yucel (2004) reported this relationship in narbon bean. However, yield can be indirectly affected by number of pods per plant and seeds per pod. Ghafoor *et al*. (1990) found a direct effect of number of pods per plant and seeds per pod on yield in mashbean while Malik *et al*. (1987) found in mungbean. This research indicated that above four yield component traits had high effect on yield with $R^2 = 69.78$. It can be concluded that the most important characters related to seed yield, considering through correlation as well as path analysis were seed weight and pod length.

When number of pods per plant was focused and analyzed for path coefficient, number of pods per cluster showed a maximum genetic correlation and positive direct contribution, followed by number of branches and clusters per plant, respectively, owing to number of pods per plant showed highly positive correlation with number of branches and clusters per plant. Similarly, Kutty *et al.* (2003) found that number of branches per plant had positive direct effect on number of pods per plant in cowpea while Yaqoob (1990) reported the same result in chickpea. Also from this study, number of branches per plant showed negative direct effect on number of pods per plant. Kumar *et al.* (2002) reported that the direct effect of number of branches per

plant on number of pods per plant was negative and low in mungbean, while Bakheit and Mahdy (1988) reported a similar result in faba bean

In this study, number of branches and clusters per plant also showed indirect effects on number of pods per plant. Khan and Qureshi (2001) reported that number of branches per plant had indirect effects on number of pods per plant. This research indicated that branches per plant, clusters per plant and pod per cluster had high effect on number of pods per plant with $R^2 = 63.66$.
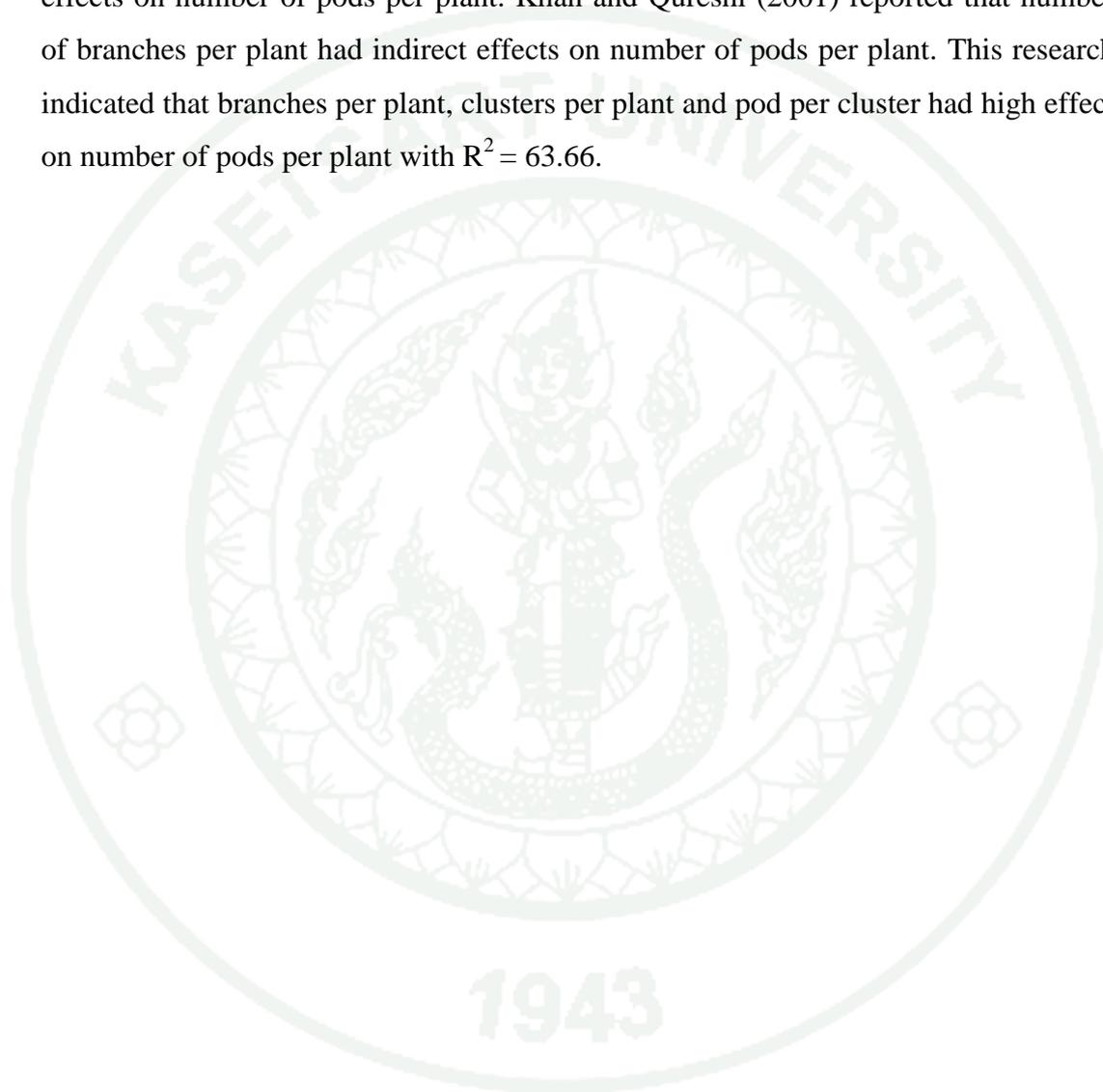
CONCLUSION

1. Small multiple leaflet lines gave higher number of leaflets, leaves, clusters, branches, and pods per plant, and the extinction coefficient but less number of pods per cluster, number of seeds per pod, pod size, seed weight, seed yield, leaf area, leaf area index and light interception than large multiple leaflet ones.

2. Nine small multiple leaflet lines produced more superior traits than five, seven and eleven leaflet lines.

3. Leaflet size was more important than leaflet number in causing variation in agronomical and physiological traits.

4. Seed yield was positively associated with seed weight and pod length owing to high positive direct effects. Number of pods per plant and number of seeds per pod had indirect effect on yield.

LITERATURE CITED

Adoms, M.W. and R. Duarte. 1961. The nature of heterosis for a complex trait in a field bean cross. **Crop Sci**. 1: 380-385.

Afzal, M.A., M.M. Bashir, N.K. Luna, M.A. Bakr and M.M. Haque. 2003. Relationship between seed size, protein content and cooking time of mungbean (*Vigna radiata* (L.) Wilczek) seeds. **Asian J. Plant Sci.** 2: 1008-1009.

Alimadadi, A., M. Rostamza, M.R.Jahansooz, A. Ahmadi and R.T. Afshari. 2006. Cowpea, common bean and mungbean radiation use efficiency, light extinction coefficient and radiation interception in double cropping. **Agronomy and horticulture.** 71: 67-75.

Ashley, D.A. and H.R. Boerma. 1989. Canopy photosynthesis and its association with seed yield in advanced generation of soybean cross. **Crop Sci.** 29: 1042-1045.

AVRDC. 1988. Effect of leaflet shape and number on mungbean yield. p. 354. *In* **1987 Progress Report, Shanhua**, Tainan, Taiwan.

Awuma W. and M. Bassett. 1988. Addition of gene for dwarf seed (*ds*) and spindly branch (*sb*) to the linkage map of common bean. **J. Am. Soc. Hortic. Sci** 113: 464-467.

Babu, R.C., P.S. Srinivasan, N. N. Ratnam and S.R.S. Rangasamy. 1985. Relationship between leaf photosynthetic rate and yield in blackgram (*Vigna mungo* L. Hepper) genotypes. **Photosynthetica** 19: 195-1630.

Bahl, J.R. and P.K. Gupta. 1982. Inheritance of two induced lethal chlorophyll mutations in mungbean. **Curr. Sci.** 53: 147-148.

Bakheit, B.R. and E.E. Mahdy. 1988. Variation correlations and pathcoefficient analysis for some characters in collections of faba bean. **Information Serv**. 20: 9-14.

Bassett, M.J. 1981. Inheritance of lanceolate leaf mutation in common bean. **J. Hered.** 72: 431-432.

Bernard, A.L. and M.G. Weiss. 1983. Qualitative genetic. pp. 117-154. *In* B.E. Caldwell (ed.). **Soybeans: improvement, production and uses.** 1st ed Agron. Monogr. 16 ASA, CSSA and SSSA, Madison, WJ.

Biswas, D.K., M.M. Haque, A. Hamid and M.A. Rahman. 2001. Photosynthetic gas exchange characteristics, leaf area and dry matter accumulation of two blackgram cultivars. **J. Biol. Sci.** 10: 951-954.

Bhadra, S.K. 1991. Inheritance of nine-foliate leaf in mungbean (*Vigna radiata* (L.)Wilczek). **SABRAO J.** 23: 71-73.

Board, J.E., M. Karmal, and B.G. Harville. 1992. Temporal importance of greater light interception to increased yield in narrow row soybean. **Agron. J.** 84:575–579.

Board, J.E., W. Zhang and B.G. Harville. 1996. Yield rankings for soybean cultivars grown in narrow and wide rows with late planting date. **Agron. J.** 88: 540-245.

Boerma, H.R. and B.J. Jones. 1978. Inheritance of a second gene for brachytic stem in soybean. **Crop Sci.** 18: 559-560.

Bressan-Smith, R.E. 1999. Genetic mapping of quantitative trait loci associated with morphology, photosynthesis and yield in the bean (*Phaseolus vulgaris* L.). **Genet. Mol. Biol.** 22: 117-119.

Chhabra, A.K. 1990. Inheritance to lobed and pentafoliate leaf in mungbean. **Indian J. Pulses Res.** 3: 69-72.

Christy, A.L. and C.A. Porter. 1982. Canopy photosynthesis and yield in soybean, pp. 499-516. *In* Govindjee (ed.). **Photosynthesis: development, carbon metabolism and plant production. Vol. 2**. Academic Press, New York.

Chidchenchey, S. 2003. **Canopy, structure, leaflet photosynthesis and pod respiration in mungbean (*Vigna radiata* (L.)Wilczek).** M.S. thesis, Kasetsart University, Bangkok. (in Thai)

Choomak, R. 2002. **Study on plant architecture and relationship between light, leaf age and photosynthesis of mungbean**. M.S. thesis, Kasertsart University, Bangkok. (in Thai)

Constable, G.A. and H.M. Rawson. 1980. Effect of leaf position, expansion and age on photosynthesis, transpiration and water use of cotton. **Aus. J. Plant Physiol.** 7: 89-100.

Cornic G. and C. Fresneau. 2002. Photosynthetic carbon reduction and carbon oxidation cycles are the main electro skins for photosystem II activity during a mild drought. **Ann. Bot.** 89: 887-894.

Costa, E.S., R. Bressan-Smith, J.G. Oliveira, E. Campostrini and C. Pimentel. 2002. Photochemical efficiency in bean plants (*Phaseolus vulgaris* L. and *Vigna unguiculata* L.Walp) during recovery from high temperature stress. **Brazilian J. Plant Physiology.** 14: 105-110.

Diaci, J., D. Roženbergar, U. Kolar, R. Pisek, T. Nagel and D. Hladnik. 1999. Methodologies for monitoring forest development in strict forest reserves. pp. 25-33. *In* **Management of forest ecosystems in national parks and other protected areas.** Zbornik radova, Jahorina - NP. Sutjeska.

De Costa, W. A. J. M. 1992. **Effects of contrasting water regimes on dry matter production, radiation and water use and stomatal conductance of determinate and indeterminate faba beans (Vicia fababL.).** PhD Thesis, University of Reading, Whiteknights.

Duncan, W.G. 1971. Leaf angle, leaf area and canopy photosynthesis. **Crop Sci.** 11: 482-485.

Duncan, W.G. 1986. Planting patterns and soybean yield. **Crop Sci.** 26: 584-588.

Dwivedi, S. and D.P. Singh. 1985. Inheritance of narrow trifoliate leaf in mungbean (*Vigna radiata* (L.) Wilczek). **SABRAO J.** 17: 177-180.

Egli, D.B. 1988. Plant density and soybean yield. **Crop Sci.** 28: 977-981.

Egli, D.B. 1999. Variation in leaf starch and sink limitations during seed filling in soybean. **Crop Sci.** 39: 1361-1368.

Egli, D.B., and Y. Zhen-wen. 1991. Crop Growth rate and seed number per unit area in soybean. **Crop Sci.** 31: 439-442.

Egli, D.B., J.W. Pendleton and D.B. Peters. 1970. Photosynthesis rate of three soybean communities as related to carbon dioxide level and solar radiation. **Agron J.** 62: 411-414.

Frazer, G.W., R.A. Fournier, J.A. Trofymow and R.J. Hall. 2001. A comparison of digital and film fisheye photography for analysis of forest canopy structure and gap light transmission. **Agric. For. Meteor.** 109: 249–263.

Frazer, G.W., C.D. Canham and K.P. Lertzman. 1999. **Gap Light Analyzer (GLA) Version 2.0: Imaging software to extract canopy structure and gap light transmission indices from true-colour fisheye photographs: users manual**

and program documentation. Simon Fraser University, Burnaby, British Columbia, and the Institute of Ecosystems Studies, Millbrook, New York. Available Source http://www.ecostudies.org/gla/, June, 29, 2008.

Fernandez, G.C.J. and S. Shanmugasundaram. 1988. The AVRDC mungbean improvement program: the past present and future. pp. 58-70. *In* **Proceedings of the 2nd International Mungbean Symposium**. Shanhua, Tainan, Taiwan: Asian Vegetable Research and Development Center.

Fehr, W.R. 1972. Genetic control of leaflet number in soybean. **Crop Sci.** 12: 211-224.

Fehr, W.R. and C.E. Caviness. 1977. Stages of soybean development. **Special report 80**. Cooperative Extension Service, Agriculture and Home Economic Experiment Station. Ames, Iowa: Iowa State University.

Frey, R.L. 1980. Genetics of *Vigna*. **Hort. Rev.** 2:311-394.

Fu, Q.A. and J.R. Ehleringer. 1991. Modification of paraheliotropic leaf movement in *Phaseolus vulgaris* by photon flux density. **Plant Cell Environ.** 14: 339-343.

Ghafoor, A., M. Zubair and B.A. Malik. 1990. Path analysis in mashbean (*Vigna mungo*). **Pak. J. Bot.** 22: 160-167.

Ghai, B.S. and T.P. Singh. 1979. Inheritance of photosensitivity in greengram (*Vigna radiata*). **Indian J. Ecology.** 6: 143-144.

Gifford, R.M. and L.T. Evans. 1981. Photosynthesis, carbon partioning and yield**. Ann Rev Plant Physiol.** 32:485-509.

Grafton, K.F., J.E. Wyatt and G.C. Welser. 1983. Genetics of a virescent foliage mutant in beans. **Heredity.** 74: 385-385.

Gosse G., C. Varlet-Grancher, R. Bonhomme, M. Chartier, J.M. Allirand, G. Lemaire. 1986. Production maximale de matiere seche et rayonnement solaire intercepte par un covert vegetal. **Agronomie** 6: 47-56.

Guiducci M., A. Antognoni, P. Benincasa. 1992. Effect of water availability on leaf movement, light interception and light utilization efficiency in several field crops. **Ri. ista di Agronomia** 27: 392-397.

Hammer, G.L., T.R. Sinclair, K.J. Boote, G.C. Wright, H. Meinke and M.J. Bell. 1995. A peanut simulation model: I. Model development and testing. **Agron J.** 87: 1085–1093.

Hardman, L.L. and W.A. Brun. 1971. Effects of atmospheric carbon dioxide enrichment at different development stages on growth and yield components of soybeans. **Crop Sci.** 11: 886–888.

Harrison, S.A., H.R. Boerma and D.A. Ashley. 1981. Heritability of canopy apparent photosynthesis and its relationship to seed yield in soybeans. **Crop Sci.** 21: 222-226.

Hatfield J.L. and R.E. Carlson. 1978. Photosynthetically active radiation, CO_2 uptake, and stomatal diffusive resistance profiles within soybean canopies. **Agron. J.** 70:592-596.

Higley, L.G. 1992. New understandings of soybean defoliation and their implications for pest management. p. 56–65. *In* L.G. Copping *et al.* (ed.) **Pest management in soybean.** Elsevier Sci. Publ., London

Huber, S.C., H. Rogers and F.L. Mowry. 1984. Effects of water stress on photosynthesis and carbon partitioning in soybean plants grown in the field at different CO_2 levels. **Plant Physiol.** 76: 244–249.

Hughes G., J.D.H. Keatinge, P.J.M. Cooper and N.F. Dee. 1987. Solar radiation interception and utilization by chickpea (*Cicer arietinum* L.) crops in northern Syria. **Agri. Science.** 108: 419–424.

Husain, M.M., J.B. Reid, H. Othman and J.N Gallagher. 1990. Growth and water use of fababeans (*Vicia faba*) in a sub-humid climate. 1. Root and shoot adaptations to drought stress. **Field Crops Research** 23: 1–17.

Idinoba, M.E., P.A. Idinoba and A.S. Gbadegesin. 2002. Radiation interception and its efficiency for dry matter production in three crop species in the transitional humid zone of Nigeria. **Agronomic.** 22: 273-281.

Jahan, S. Md. and A. Hamid. 2006. Effect of Population Density and Planting Configuration on Canopy Development and Reproductive Effort in Mungbean (*Vigna radiata* (L.) Wilczek). **Res. J. Agric. & Biol. Sci.** 2: 122-126.

Jesus, W.C., F.X.R. Vale, R.R. Coelho and L.C. Coata. 2001. Comparison of two method for estimating leaf area index on common bean. **Agron. J.** 93: 989-991.

Kay, D.E. 1979. **Crop and Product Digest: Food Legume No. 3**, Tropical Products Institute, London.

Kemp, G.A. 1979. Interaction and inheritance of suboptimal temperature interference with photonastic response of leaves of *Phaseolus vulgaris* L. **Euphytica** 28: 425-433.

Khan, M.R. and A.S. Qureshi. 2001. Path coefficient and correlation analysis studies on the variation induced by gamma irradiation in M_1 generation of chickpea (*Cicer arietinum* L.). **J. Bio. Sci**. 1: 108-110.

Khan, M.R., K. Nawab, A. Khan and M.S. Baloch. 2001. Genetic variability and correlation studies in mungbean. **J. Bio. Sci**. 1: 117-119.

Kilen, T.C. 1977. Inheritance of the brachytic character in soybean. **Crop Sci.** 17:853-854.

Kilen, T.C. 1990. Brachytic stem and narrow leaflet effects on soybean seed composition and yield. **Crop Sci.** 30: 1006-1008.

Kiniry, J.R., C.E. Simpson, A.M. Schubert and J.D. Reed. 2005. Reed Peanut leaf area index, light interception, radiation use efficiency, and harvest index at three sites in Texas. **Field Crops Res.** 91: 297-306.

Kowsurat S., P. Sinives, P. Kasemsap and S. Lamseejan. 1999. Effect of the multiple leaflet gene on agronomical and physiological characters of mungbean (*Vigna radiata*) **J. Agri. Sci.** 133: 321-324

Kumar, J., H. Singh, T. Singh., D.S. Tonk and R. Lal. 2002. Correlationand path coefficient analysis of yield and its components in summer moong (*Vigna radiata* (L.) Wilczek). **Crop Res**. 24 : 374-377.

Kuo, C.G., L.T. Wang, A.C. Cheng and M.H. Chou. 1978. Physiological basis for mungbean yield improvement. pp. 205-209. *In* **Proceedings of the 1st International Mungbean Symposium**. Shanhua, Tainan, Taiwan: Asian Vegetable Research and Development Center.

Kutty, C.N., R. Mili and U. Jaikumaran, 2003. Correlation and path coefficient analysis in vegetable cowpea (*Vigna unguiculata* (L.) Walp.). **Indian. J. Hort.** 60: 257-261.

Lamseejan, S. 1978. Genetic, physiological and anatomical studies of narrow-leaflet mutant in dry bean (*Phaseolus vulgaris* L.). **Diss Abstr.** 39: 1126B.

Lee, Y.S., J.Y. Lee, D.K. Kim, C.Y. Yoon, G.C. Bak, I.J. Park, G.P. Bang, J.K. Moon, Y.J. Oh and K.S. Min. 2004. A new high-yielding mungbean cultivar, "Samgang" with lobed leaflet. **Korean J. Breed.** 36: 183-184.

Lieth, J.H. and C.C. Pasian. 1990. A model for photosynthesis of rose leaves as a function of photosynthetically active radiation, leaf temperature, and leaf age. **J. Amer. Soc. Hort. Sci.** 115: 486-491.

Loomis, R.S. and D.J. Connor. 1992. **Crop ecology: productivity and management in agricultural systems.** Cambridge University Press, new York.USA.

Mahon, J.D. 1982. Field evaluation in growth and nitrogen fixation in peas selected for high and low photosynthetic CO_2 exchange. **Can. J. Plant Sci.** 62: 5-17.

Mahon, J.D. and L.A. Hobbs. 1987. Genetic control of photosynthesis in relation to growth of pea (*Pisum sativm* L.) plant. pp. 385-391. *In* J. Biggins, ed. **Progress in Photosynthesis Research**. Martinus Nijhoff Publ., Dordrecht, The Netherlands.

Malik, B.A. 1994. Grain legume. pp. 277-328. *In* E. Bashir and R. Bantel Eds. **Crop Production**. National Book Foundation, Islamabad Pakistan.

Malik, B.A., M. Tahir, I.A. Khan, M. Zubair and A.H. Haqqani. 1987. Genetic variability, character correlation and path-co-efficient analysis of yield components in mungbean (*Vigna radiata*) **Pak. J.Bot.** 19: 1-89-97.

Marcelis, L.F.M. 1993. Simulation of biomass allocation in greenhouse crops: a review. **Acta Hortic.** 328: 49–67.

Miah, A.J. and S.K. Bhadra. 1989. Genetic variability in the F_2 generation of mungbean. **Bangladesh J. Agric. Res.** 14 : 72-75.

Mirja, V. 2005. Correlations in dry bean breeding collection. **Annual report of the bean improvement cooperative**. 48: 18-19.

Monsi, M., and T. Saeki. 1953. Uber den lichtfaktor in den pflanzenges selschaften und seine bedeutung fur die stoff produktion. **Jpn. J. Bot**. 14:22–52.

Muchow, R.C. and D.A. Charles-Edwards. 1982. An analysis of the growth of mungbean at a range of plant densities in tropical Australia. I. Dry matter production. **Aust. J. Agric. Res** 33: 41–51.

Mythili, J.B. and T.V.R. Nair. 1996. Relationship between photosynthetic carbon exchange rate, specific leaf mass and other leaf characteristics in chickpea genotypes. **Australian J. Plant Physio.** 23: 617 – 622.

Nagata, R.T. and M.J. Basset. 1984. Characterization and inheritance of gamma rays induced mutation in common bean. **J. Am. Soc. Hortic. Sci.** 109: 513-516.

Naidu, N.V., A. Satyanarana and A.R.L. Gunter. 1991. Studies on estimation of genetic parameters under different environments in green bean. **Indian J. Pulses Res.** 4: 19-22.

Norman, J. M. 1979. Modeling the complete crop canopy. p. 249-277. *In* **Modification of the Aerial Environment of Plants,** B. J. Bardield and J. F. Gerber (eds.) ASAE, St. Joseph, Michigan.

Odabas, M.S., S. Uzun and A. Gülümser. 2008. The Effect of Light Interception and Light Use Efficiency with Different Sowing Time of Faba Bean (*Vicia Faba* L.). **IJNES.** 2: 87-91.

Office of Agricultural Economics. 2006. Mungbean. **Department of Agricultural Extension**. Available Source: http://www.oae.go.th/statistic/yearbook49/, June, 22, 2007.

Peksen, A. 2004. Fresh pod yield and some pod characteristics of cowpea (*Vigna unguiculata* L. Walp) genotypes from Turkey. **Asian J. Plant Sci.** 3: 269-273.

Poehlman, J.M. 1991. **The mungbean.** Oxford & IBH publishing Co. PVT. Ltd, New Delhi, India.

Pozo, A.D. and M.D. Dennett. 1999. Analysis of the distribution of light, leaf nitrogen, and photosynthesis within the canopy of *Vicia faba* L. at two contrasting plant densities. **Aust. J. Agric. Res**. 50: 183-189.

Rahman, M.M., A.A. Miah, A.K.M.M. Rahma, A.F.M. Maniruzzaman and K. Khan. 1994. Growth analysis of blackgram (*Vigna mungo* L. Hepper) under varying levels of population densities and its agronomic appraisal. **Bangladesh J. Bot.** 23: 155-159.

Ramseur, E.L., S.U. Wallace and V.L. Quisenberry. 1985. Growth of 'Braxton' soybeans as influenced by irrigation and intrarow spacing. **Agron. J.** 77:163–168.

Reddy, T.D., R.K. Mishra and R.K. Yadav. 1991. Genetic variability and correlation coefficient related to yield and other quantitatives and use of path coefficient in mungbean. **Indian J. Pulses Res.** 4: 100-104.

Ribeiro, R.V., M.G. Santos, G.M. Souza, E.C. Machado, R.F. Oliveira, L.R. Angelocci and C. Pimentel. 2004. Environmental effects on photosynthesis capacity of bean genotypes. **Pesq. Agropec. Bras.** 39: 615-623.

Robertson, M. J., P. S. Carberry, N. I. Huth, J. E. Turpin, M. E. Probert, P. L. Poulton, M. Bell, G. C. Wright, S. J. Yeates, and R. B. Brinsmead. 2002. Simulation of growth and development of diverse legume species in APSIM. **Aust. J. Agric. Res.** 53: 429–446

Rohman, M.M., A.S.M. Iqbal Hussain, Md.S. Arifin, Z. Akhter and M. Hasanuzzaman. 2003. Genetic variability, correlation and path analysis in mungbean. **Asian J. Plant Sci.** 2: 1209-1211.

Roy, D. 2000. **Plant breeding: Analysis and exploitation of variation**. Alpha Science International Lid. Pangbourne, UK.

Rubio, J., J.I. Cubero, L.M. Suso and F. Flores. 2004. Biplot analysis of trait relation of white lupin in spain. **Euphytica.** 135: 217-224.

Rungnoi, O., P. Srinives, S. Chanprame and T. Toojinda. 2007. Inheritance, chlorophyll content and maximun quantum yield of opaque leaf mutant of mungbean. **Agricultural Sci. J.** 38: 271-277. (in thai)

Russell G., Jarvis P.G. and J.L. Monteith. 1989. Absorption of radiation by canopies and stand growth. pp. 21-39. *In* Russell G, Marshall B, Jarvis PG (eds). **Plant canopies.** Society for Experimental Biology Seminar Series, No. 31, Cambridge: Cambridge University Press.

Sakamoto, T. and M. Matsuoka. 2004. Generation high-yield varieties by genetic manipulation of plant architecture. **Curr. Opin. Biotechnol.** 15: 144-147.

Sakamoto, C.M. and R.H. Shaw. 1967. Light distribution in field soybean canopies. **Agron. J.** 59: 7-9.

Sangsiri, C., W. Sorajjapinun, and P. Srinives. 2005. Gamma radiation induced mutations in mungbean. **SciAsia.** 31: 251-255.

Santos, I.S. 1978. Induction of mutation in mungbean and genetic studies of some of the mutant. pp. 167-179. *In* E. Doyle, Ed. **Induced Mutation in Plant**. International Atomic Energy Agency, Vienna.

SAS Institute. 1990. **SAS System for Windows**, Release 6.12, SAS Institute. Cary, NC, USA.

Sato, K. 1971. Growth and development of lucerne plants in a controlled environment. I. Effects of daylength and temperature before and after cutting on growth and chemical composition. **Crop Science Society of Japan** 40: 120–126.

Satyanarayana, A., Y.K. Rao, P. Seeaniah and D. Kondadaramaiah. 1989. Multifoliate leaf mutant of mungbean and urdbean. **Mutantion Breed. Newsletter**. 33: 17-19

Schou, J.B., D.L. Jeffers, and J.G. Streeter. 1978. Effects of reflectors, black boards, or shades applied at different stages of plant development on yield of soybeans. **Crop Sci.** 18:29–34.

Sczcies,G .1974. Solar radiation in crop canopies. **J. Appl. Ecol.** 11: 1117-1156.

Shibles, R.M. and C.R. Weber. 1966. Interception of solar radiation and dry matter production by various soybean planting patterns. **Crop Sci.** 6: 55-59.

Shii, C.T., M.C. Mok and D.S.W. Mok. 1981. Developmental Controls of morphological mutant of *Phaseolus vulgaris* L.: differential expression of mutant loci in plant organs. **Dev. Gene.** 2: 279-220.

Singh, S.P. 1982. A key for identification of different growth habits of *Phaseolus vulgaris* **L. Annu. Pep. Bean Improve. Coop.** 25: 92-95.

Singh, A.K. and S.S. Saini. 1983. Heterosis and combining ability studies in bean. **SABRAO J**. 15: 17-22.

Singh, V.P. and R. Sharma. 1993. γ-Rays-and EMS induced leaf mutants in mungbean (*Vigna radiata* (L)Wilczek). **Curr. Sci**. 65: 636-638.

Singh, V.P., R.C. Yadav and R.K. Singh. 1981. A pentafoliate leaf mutant in mungbean. **Pulse Crops Newletter.** 1: 25.

Soehendi, R., S. Chanprame, T. Toojinda and P. Srinives. 2006. Inheritance and AFLP tagging of leaflet mutants in mungbean (*Vigna radiata* (L.) Wilczek) **Kasetsart J. (Nat. Sci.)** 40: 566 - 572

Soehendi, R., S. Chanprame, T. Toojinda, S. Ngampongsai and P. Srinives. 2007. Genetics, agronomic and molecular study of leaflet mutant in mungbean (*Vigna radiata* (L.) Wilczek). **J. Crop Sci. Biotech.** 10: 193-200.

Squire, GR. 1990. **The physiology of tropical crop production.** CAB International, Wallingford, UK.

Sriphadet S., C.J. Lambrides and P. Srinives. 2007. Inheritance of agronomic traits and their interrelationship in mungbean (*Vigna radiata*(L.) Wilczek). **J. Crop Sci. Biotech.** 10: 123-132.

Srinives, P., N. Hual-alai, S. Saengchot and S. Ngampongsai. 2000. The use of wild relatives and gamma radiation in mungbean and blackgram breeding. pp.205-218. *In* **Proc. 7**[th] **MAFF Inter. Workshop on Genetic Resources Part 1. Wild Legumes.** October 21-25, 1999, Tsukuba, Japan. National Institute of Agrobiological Resources, Tsukuba.

Sripisut, W. and P. Srinives. 1986. Inheritance of lobed leaflets and multiple leaflets in mungbean. **Thai Agri. Res. J**. 4: 192-199.

Steel, R.G.D. and J.H. Torrie. 1960. **Principles and procedures of statistics.** McGraw-Hill Book Co., Inc., New York.

Sung, F.J.M. and J.J. Chen. 1989. Changes in photosynthesis and other chloroplast traits in lanceolate leaflet isoline of soybean. **Plant Physiol.** 90: 773-777.

Swindell, R.E. and J.M. Poehlman. 1978. Heterosis in mungbean. **Trop. Agric.** 53: 25-30.

Szeics, G. 1974. Solar radiation for plant growth. **J. Applied Ecology 11:** 617-619.

Takahashi Y. and J. Fukuyama. 1919. Morphological and genetic studies on soybean. **Hokkaido Agr. Exp. Stn. Rep**. 10: 1–10.

Tasma, I.M., L.L. Lorenzen, D.E. Green and R.C. Shoemaker. 2004. Mapping genetic loci for flowering time, maturity, and photoperiod insensitivity in soybean. **Molecular Breeding** 8: 25-35.

Tewari, A.K. and N.C. Gautam, 1989. Correlation and path coefficient analysis in cowpea (*Vigna unguiculata* L. Walp.). **Indian J. Hort**. 46: 516-521.

Tickoo, J., L. Gajraj, R. Mahto and C. Manji. 1996. Plant type in mungbean (*Vigna radiata* (L.) Wilczek). pp. 197-213. *In* A.N. Asthana and D.H. Kim, eds. **Advances in mungbean research**. Indian Society of plulses research, IIPR, Kanpur, India.

Upadhayaya, H.D., R. Ortiz, P.J. Bramel and S. Singh. 2002. Phenotypic diversity for morphological and agronomical characteristics in chickpea core collection. **Euphytica.** 123: 333-342.

Upmeyer, D.J. and H.R. Koller. 1973. Diurnal trends in net photosynthesis rate and carbohydrate levels of soybean leaves. **Plant Physiol.** 51: 871–874.

Van Kooten, O. and J.F.H. Snel. 1990. The use of chlorophyll fluorescence nomenclature in plant stress physiology. **Photosynthesis Res.** 25: 147-150.

Vasic, M., J. Gvozdanovic-Varga and J. Cervenski. 1997. The interdependence of
morphological characters in Yugoslavian bean varieties (*Phaseolus vulgaris* L.).
Acta Horticulturae. 462: 235-239.

Veeraswamy, R. and V.K. Kunjamma. 1985. A note on foliar variation in greengram
or mungbean. **Madras. Agric. J.** 43: 151-152.

Wallace, D.H. 1985. Physiological genetics of plant maturity, adaptation, and yield.
Plant Breed. Rev. 3: 21-67.

Wang, D., M.C. Shannon and C.M. Grieve. 2001. Salinity reduces radiation
absorption and use efficiency in soybean. **Field Crops Research** 69: 267-277.

Wang, K.J., F.S. Li, T. Zhou and Z.Y. Xu. 2000. Inheritance of a five leaflet character
arising from wild soybean (*Glycine soja* Sieb. et Zucc.) in soybeans (*G. max*
(L.) Merr.). **Soybean Genetics Newsletter 27.** Available Source: http://www.
soygenetics.org/articles/sgn2000-005.htm, December 17, 2004.

Watson, D.J. 1947. Comparative physiological studied on the growth of field crops: I
Variation in net assimilation rate and leaf area between species and varieties and
within and between years. **Ann Bot.** 11: 41-76.

Well, R. 1991. Soybean growth response to plant density: relationship among canopy
photosynthesis, leaf area and light interception. **Crop Sci.** 31: 755-761.

Well, R., J.W. Burton and T.C. Kilen. 1993. Soybean growth and light interception:
response to differing leaf and stem morphology. **Crop Sci.** 33: 520-524.

Wilson, D. 1984. Identifying and exploiting genetic variation on the physiological
components of production. **Ann. Appl. Biol.** 104: 527-532.

Yaqoob, M., H. Jan and M.B. Ahmad, 1990. Interrelationship between grain yield and other important characters in gram (*Cicer arietinum* L.). **Sarhad J. Agric.** 4: 87-91

Yucel, C. 2004. Correlation and path coefficient analyses of seed yield components in the narbon bean (*Vicia narbonensis* L.) **Turk. J. Agric.** 28: 371-376.
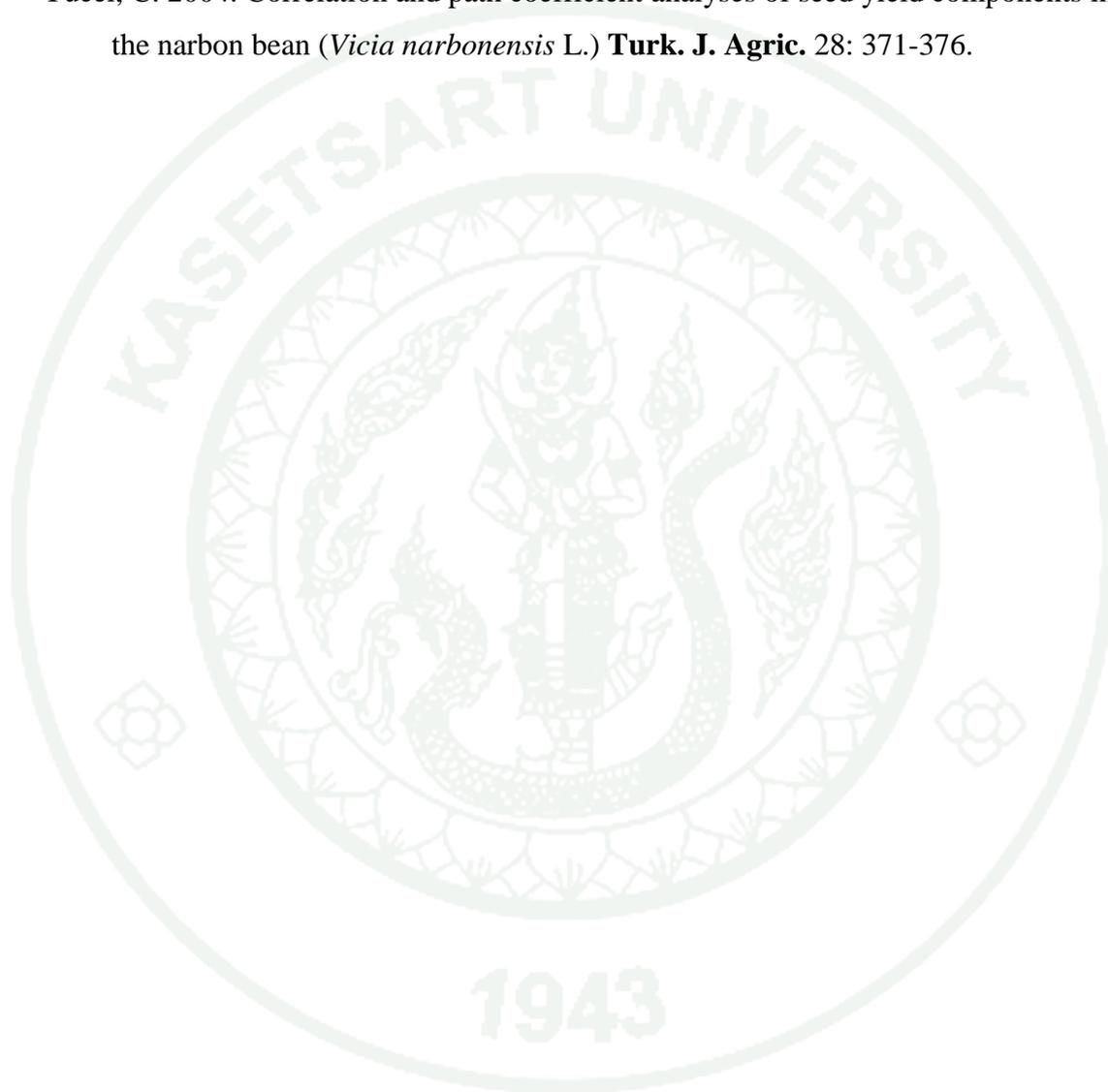
APPENDIX

Appendix Table 1 ANOVA of some agronomical and physiological traits of
mungbean lines.

Source	df	CP	PC	PL	PP
Replications	2	30.68	0.62	0.12	144.38
Treatments	29	85.74**	0.53**	12.68**	177.61**
Parents vs Lines	1	5.45	0.002	1.64	1.30
P1 vs P2	1	79.64**	0.04	23.25**	83.10*
Between lines	27	91.27**	0.57**	12.70**	183.26**
Between families	3	65.47	0.05	0.29	242.28*
Between leaflet types	24	94.50**	0.63**	14.25**	175.88**
Types within family 1	6	169.99**	0.31*	14.71**	297.68**
3N vs LM	1	2.14	0.35	0.45*	5.71
3N vs SM	1	338.20**	0.15	47.40**	661.48**
LM vs SM	1	666.07**	1.78*	62.96**	889.43**
Residuals	3	4.51	0.13	52.89**	76.46
Types within family 2	6	31.46*	1.10**	13.58**	67.82**
3N vs LM	1	10.64	0.55**	0.56	108.98**
3N vs SM	1	122.61**	1.10**	37.33**	140.91**
LM vs SM	1	93.73**	5.80**	63.49**	0.32
Residuals	3	12.74	0.01	6.43	52.45
Types within family 3	6	109.61**	0.70**	16.46**	250.80**
3N vs LM	1	2.73	0.07	0.14	32.29
3N vs SM	1	121.04*	2.39**	42.02**	585.31**
LM vs SM	1	273.68**	2.62**	79.24**	538.09**
Residuals	3	86.74	0.29	7.57	116.38
Types within family 4	6	66.92*	0.40*	12.24**	87.19*
3N vs LM	1	0.44	0.17	0.38	71.12
3N vs SM	1	178.61**	0.41	28.95**	331.02**
LM vs SM	1	266.12**	2.00*	61.10**	133.67*
Residuals	3	14.54	0.06	5.66*	4.22
Error	58	20.32	0.51	0.11	39.48

Appendix Table 1 (Continued)

Source	df	BP	SP	SW	Y
Replications	2	1.65	0.01	0.41	4.05
Treatments	29	4.26**	3.47**	2.58**	14.56**
Parents vs Lines	1	0.01	1.08	0.68	4.37
P1 vs P2	1	4.40*	6.81*	5.75*	14.98*
Between lines	27	4.48**	3.43**	2.53**	14.92**
Between families	3	1.13	0.39	0.02	4.89
Between leaflet types	24	4.90**	3.82**	2.85**	16.17**
Types within family 1	6	8.10**	3.76**	4.47**	14.86*
3N vs LM	1	0.01	0.76	0.73	1.30
3N vs SM	1	20.79**	3.82*	16.14**	30.30*
LM vs SM	1	35.32**	14.10**	15.84**	75.98**
Residuals	3	2.52	0.29	1.96	15.23
Types within family 2	6	1.90**	3.55**	1.85**	14.90*
3N vs LM	1	4.00*	0.10	0.01	1.12
3N vs SM	1	9.84**	9.70**	4.99**	39.58**
LM vs SM	1	11.50**	12.85**	8.18**	43.89**
Residuals	3	0.81	0.45	0.68	1.60
Types within family 3	6	6.29**	5.06**	3.21**	19.84*
3N vs LM	1	0.01	0.06	0.16	0.22
3N vs SM	1	8.76**	11.28**	6.83**	50.27**
LM vs SM	1	13.78**	16.00**	15.56**	96.23**
Residuals	3	5.07	1.01	1.10	9.23
Types within family 4	6	3.31**	2.90**	1.87**	15.08**
3N vs LM	1	0.62	1.08	0.03	6.14
3N vs SM	1	12.22**	3.64**	5.76**	11.48
LM vs SM	1	11.56**	15.47**	8.18**	62.04**
Residuals	3	1.51	0.93	0.90	3.61
Error	58	0.89	0.43	0.22	4.02

Appendix Table 1 (Continued)

Source	df	DF	PF	PM	LP
Replications	2	8.18	67.77	216.94*	1334
Treatments	29	7.89	41.63	140.05**	12958**
Parents vs Lines	1	0.67	12.97	30.27	19281*
P1 vs P2	1	16.67	11.2	247.68*	558**
Between lines	27	8.31	43.98	142.80**	13728**
Between families	3	10.52	38.46	206.58	5684
Between leaflet types	24	6.79	32.64	134.83**	14734**
Types within family 1	6	13.44	55.12	260.69**	22593**
3N vs LM	1	0.05	32.92	458.04**	1206
3N vs SM	1	0.02	79.74	1259.87**	64901**
LM vs SM	1	0.25	11.66	242.01*	78275**
Residuals	3	2.69	41.21	131.93	2942
Types within family 2	6	0.78	30.35	60.21*	7023**
3N vs LM	1	0.50	25.23	0.23	2384**
3N vs SM	1	0.27	25.48	127.02*	24839**
LM vs SM	1	0.11	0.34	192.56**	18069**
Residuals	3	1.26	43.76	25.80	1051
Types within family 3	6	11.97	35.50	119.71*	19845**
3N vs LM	1	34.72	0.10	55.69	1624
3N vs SM	1	11.27	48.08	351.24*	39537**
LM vs SM	1	16.0	72.22	186.10*	39880**
Residuals	3	3.28	30.86	41.75	1678
Types within family 4	6	5.93	57.70	92.71*	9475**
3N vs LM	1	2.0	23.87	162.96	2520
3N vs SM	1	4.27	67.42	453.31**	30422**
LM vs SM	1	0.44	122.82	88.99	23771**
Residuals	3	9.64	26.37	49.65	47
Error	58	5.71	32.42	40.22	624

Appendix Table 1 (Continued)

Source	df	LC	PAR	LA	HI
Replications	2	36.64	394.09*	11807	0.01
Treatments	29	199.15**	384.55**	107106**	0.01
Parents vs Lines	1	0.55	2.81	46448	0.01
P1 vs P2	1	534.12**	369.11	58819*	0.01
Between lines	27	207.27**	393.78**	10790**	0.01
Between families	3	109.145	80.02	259228**	0.01
Between leaflet types	24	219.53**	432.99**	88995**	0.01
Types within family 1	6	377.58**	757.54**	60320*	0.01
3N vs LM	1	14.80	469.10	2330	0.01
3N vs SM	1	818.96**	1908.58**	22285	0.01
LM vs SM	1	1796.49**	664.09	68119*	0
Residuals	3	121.58	501.16	26916	0.02
Types within family 2	6	102.95**	84.22	117960**	0.01
3N vs LM	1	0.10	188.37	54085	0
3N vs SM	1	266.92**	210.86*	96967	0.01
LM vs SM	1	463.61**	0.44	543219*	0.01
Residuals	3	37.33	35.21	7498	0.02
Types within family 3	6	234.84**	585.46*	80792**	0.01
3N vs LM	1	2.98	181.45	46156	0
3N vs SM	1	396.14**	1897.76**	360142*	0.01
LM vs SM	1	791.77**	1383.10*	221765*	0
Residuals	3	72.73	17.56	47770	0.03
Types within family 4	6	162.75**	304.76*	96904*	0.01
3N vs LM	1	0.35	138.89	42178	0
3N vs SM	1	457.22**	863.44*	109523**	0
LM vs SM	1	716.90**	452.34	515078**	0
Residuals	3	65.99	124.64	28450	0.02
Error	58	12.68	117.76	33781	0.01

Appendix Table 2 ANOVA of photosynthetic rate at range of PAR from 0 to 2,400 $\mu molm^{-2}s^{-1}$ in 3N, 5S and 7L lines.

Source	df	MS											
		PAR 0	PAR 20	PAR 50	PAR 100	PAR 200	PAR 400	PAR 800	PAR 1200	PAR 1600	PAR 1800	PAR 2200	PAR 2400
Lines	2	2.03	0.82	0.44	0.02	2.34	13.83*	39.77**	49.81**	53.59**	53.01**	57.31**	54.74**
Error	9	0.99	0.42	0.26	0.10	0.60	1.88	3.64	3.88	5.06	5.79	6.40	6.15

Appendix Figure 1 LI-191 Line Quantum Sensor and LI-250A Light Meter

Appendix Figure 2 LI-6400 Portable Photosynthesis System.

Appendix Figure 3 LAI-3100 Area Meter.

Appendix Figure 4 Fisheye photographs of mungbean

7SM   **5SM**   **3N**   **7LM**

7LM   **3N**   **11SM**

Appendix Figure 5   Leaflet size and number of isogenetic lines
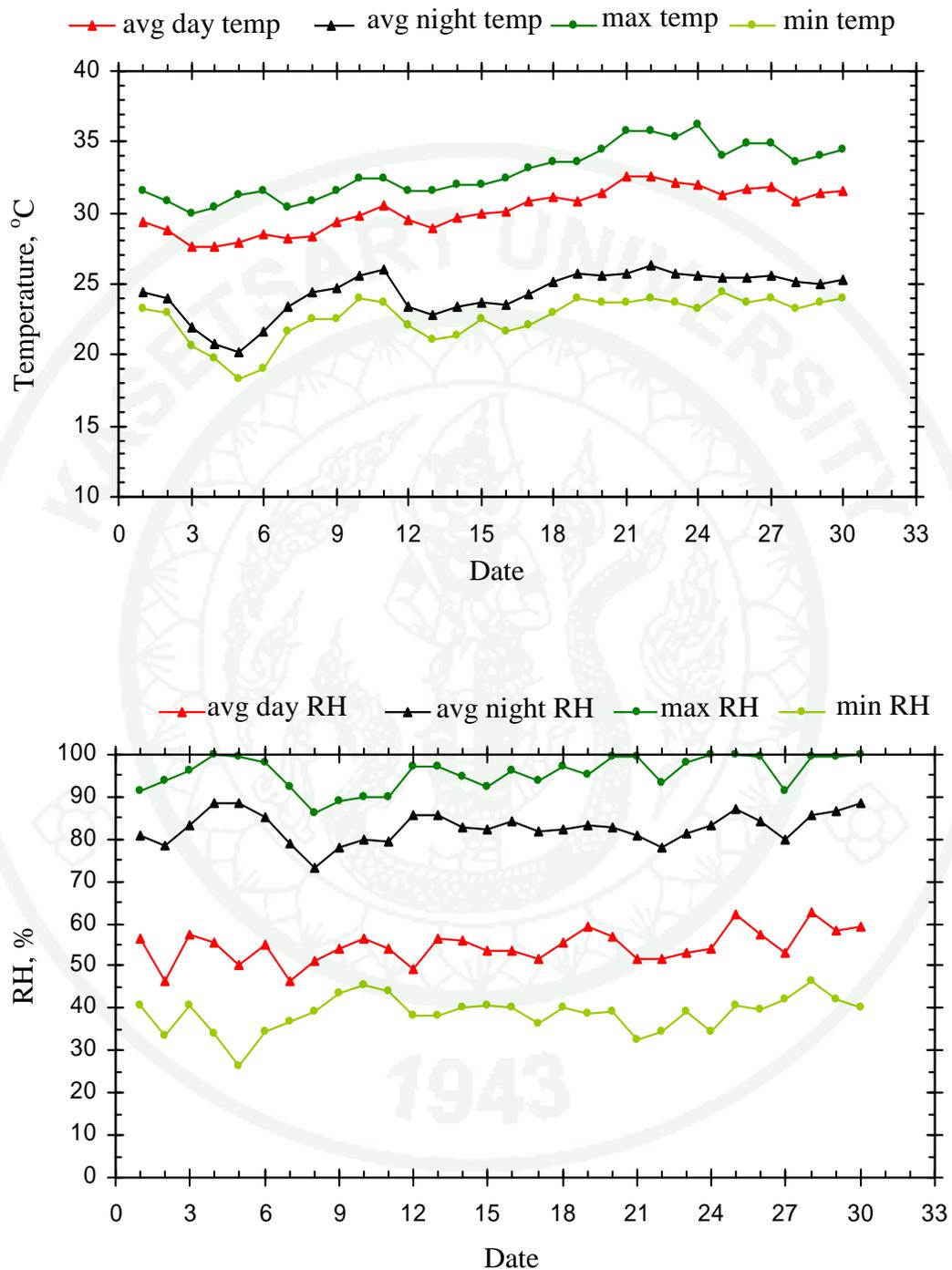
Appendix Figure 6 Temperature and percentage of Relative humidity (%RH) at

TVRDC, Kasetsart University, Kamphaeng Saen Campus,
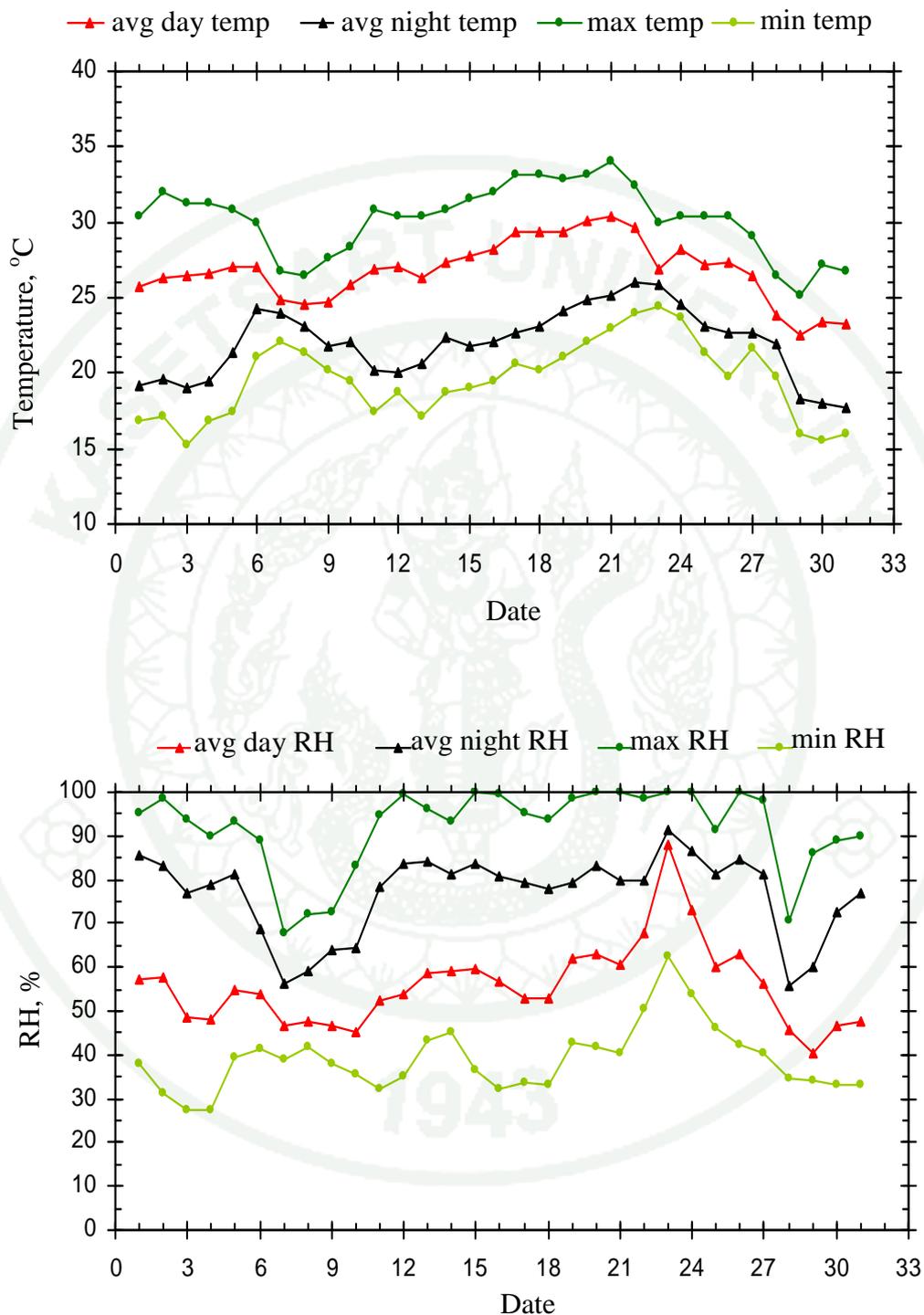
November, 2006.

Appendix Figure 7 Temperature and percentage of Relative humidity (%RH) at
TVRDC, Kasetsart University, Kamphaeng Saen Campus,
December, 2006.
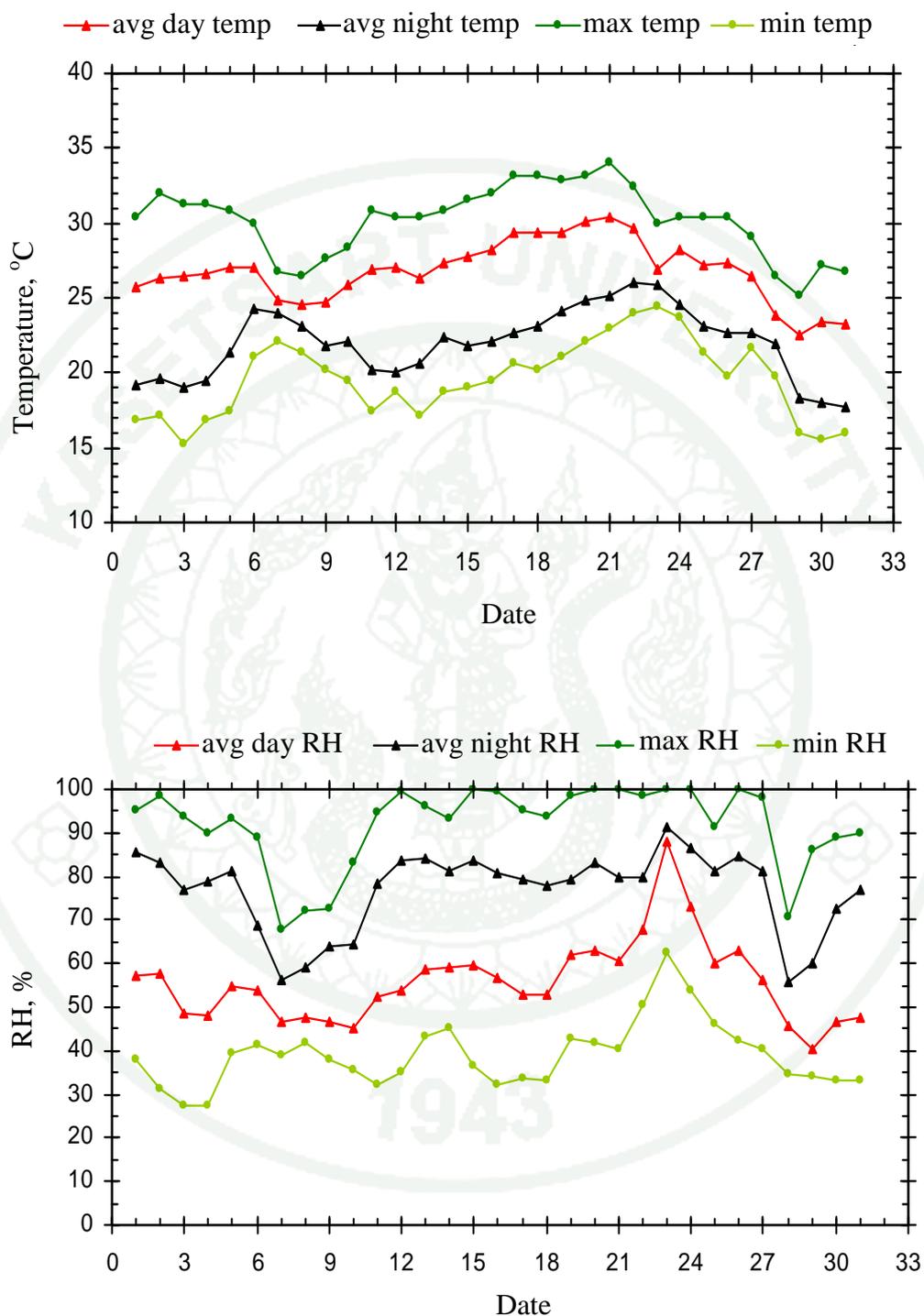
Appendix Figure 8 Temperature and percentage of Relative humidity (%RH) at
TVRDC, Kasetsart University, Kamphaeng Saen Campus,
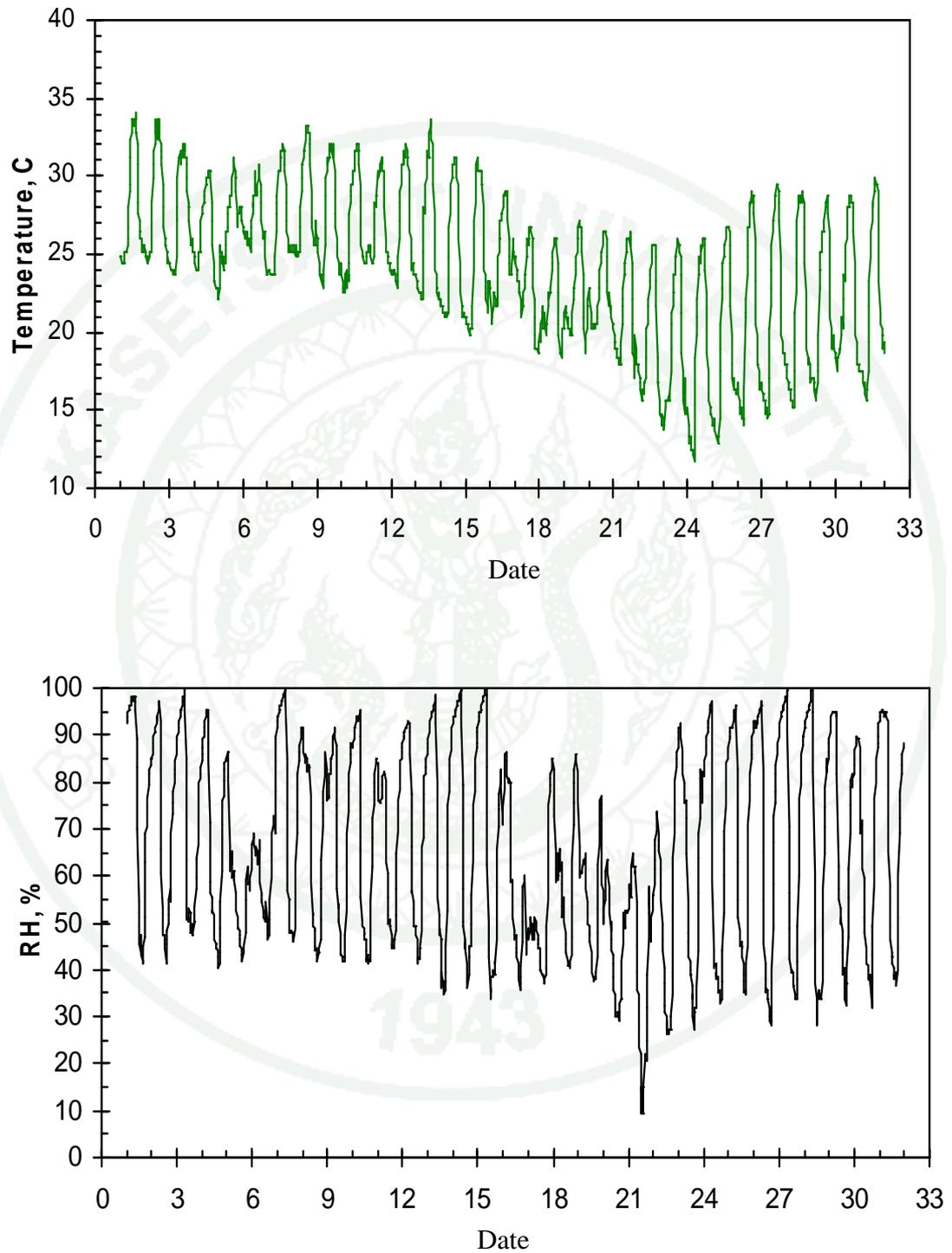January, 2007.
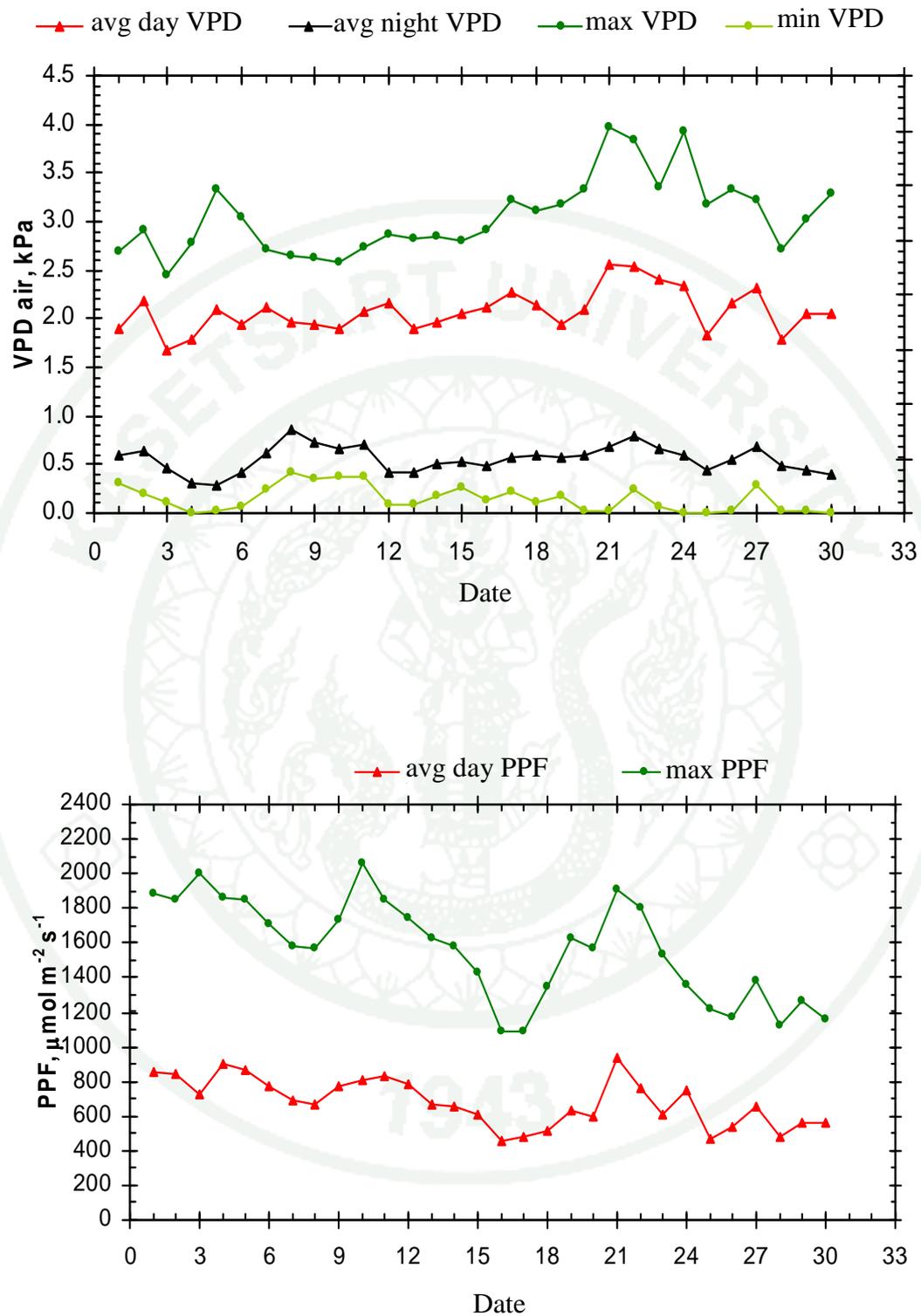
Appendix Figure 9 Vapour pressure deficit of air (VPD) and photosynthetic photon
flux (PPF) at TVRDC, Kasetsart University, Kamphaeng Saen
Campus, November, 2006.
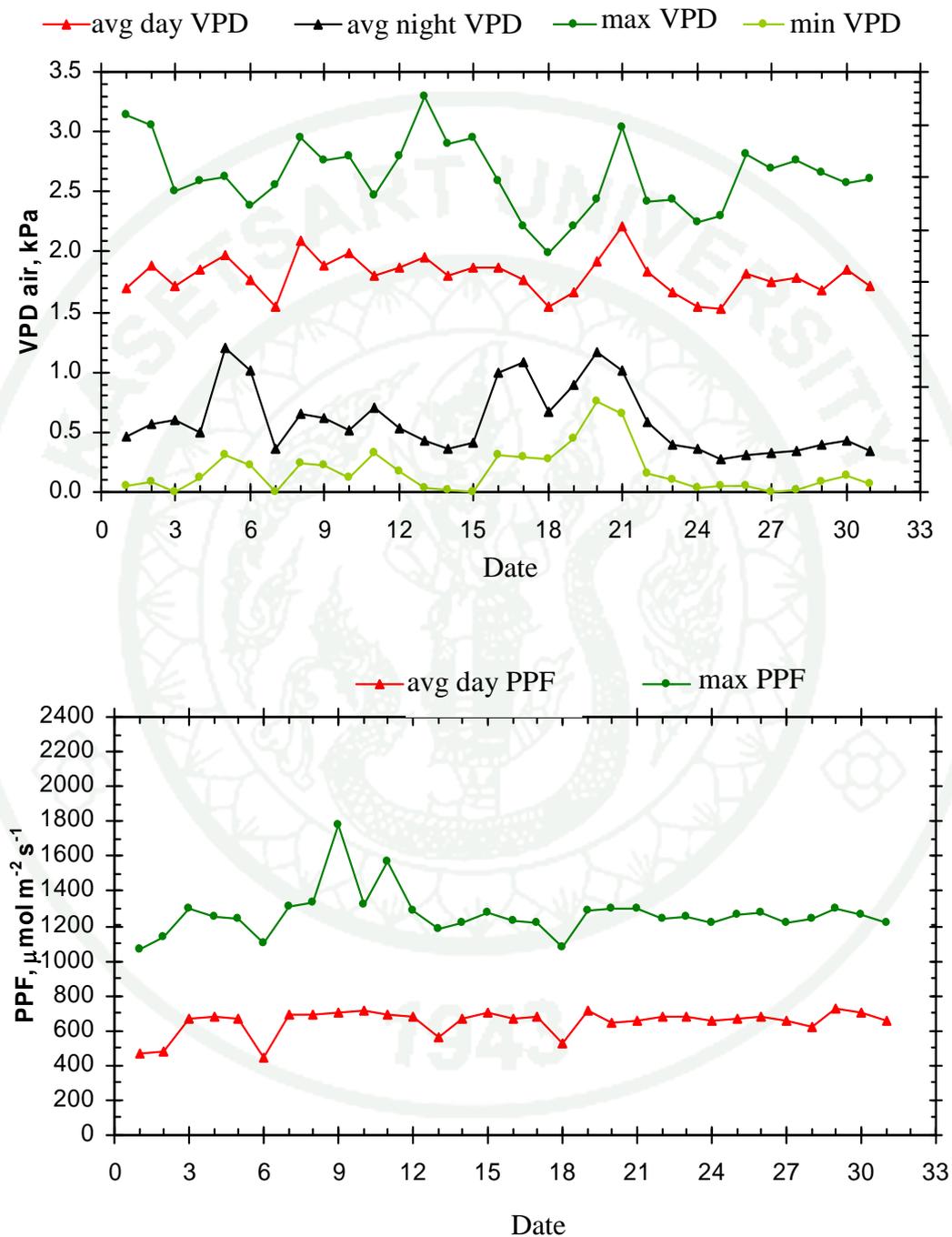
Appendix Figure 10 Vapour pressure deficit of air (VPD) and photosynthetic
photon flux (PPF) at TVRDC, Kasetsart University,
Kamphaeng Saen Campus, December, 2006.
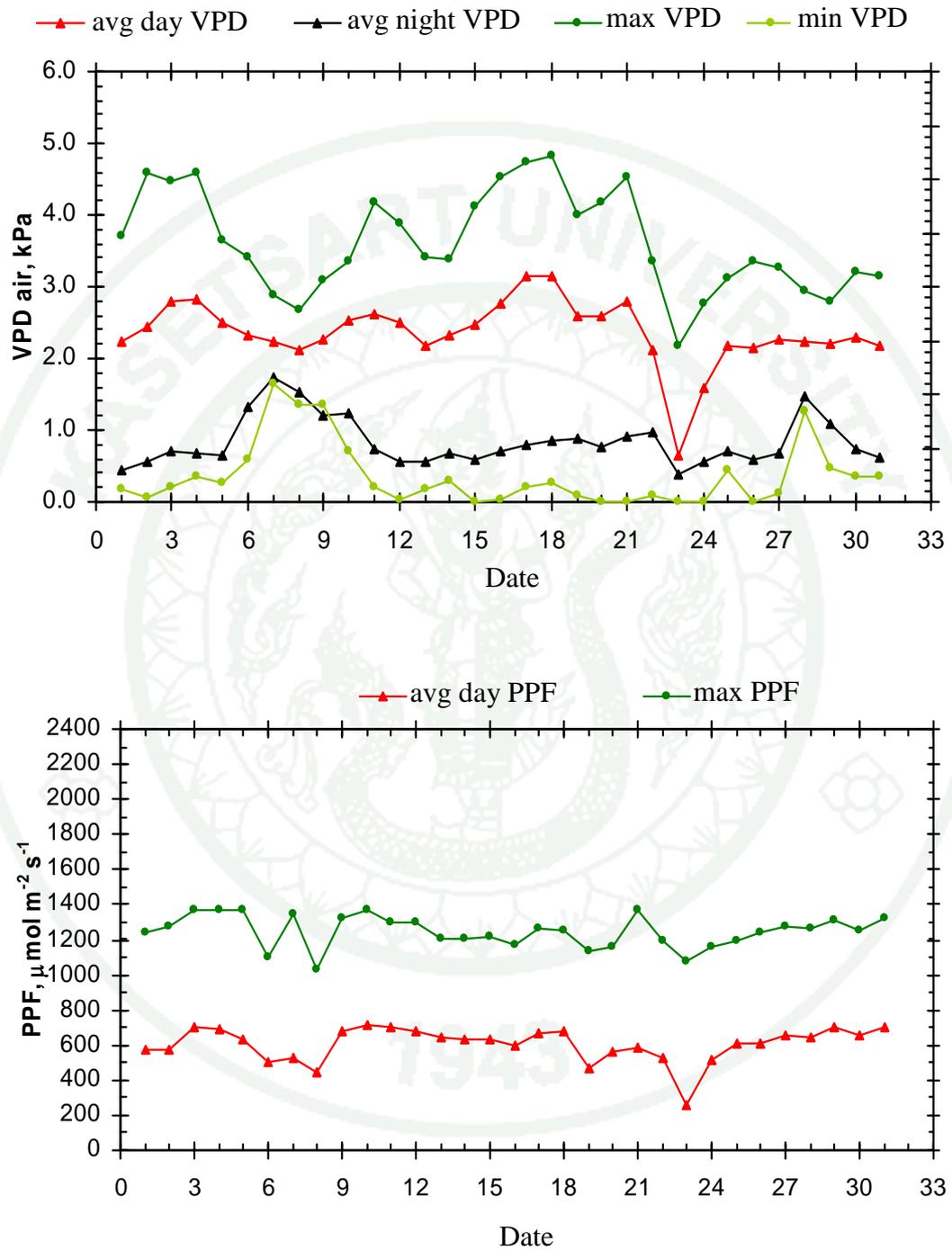
Appendix Figure 11 Vapour pressure deficit of air (VPD) and photosynthetic
photon flux (PPF) at TVRDC, Kasetsart University,
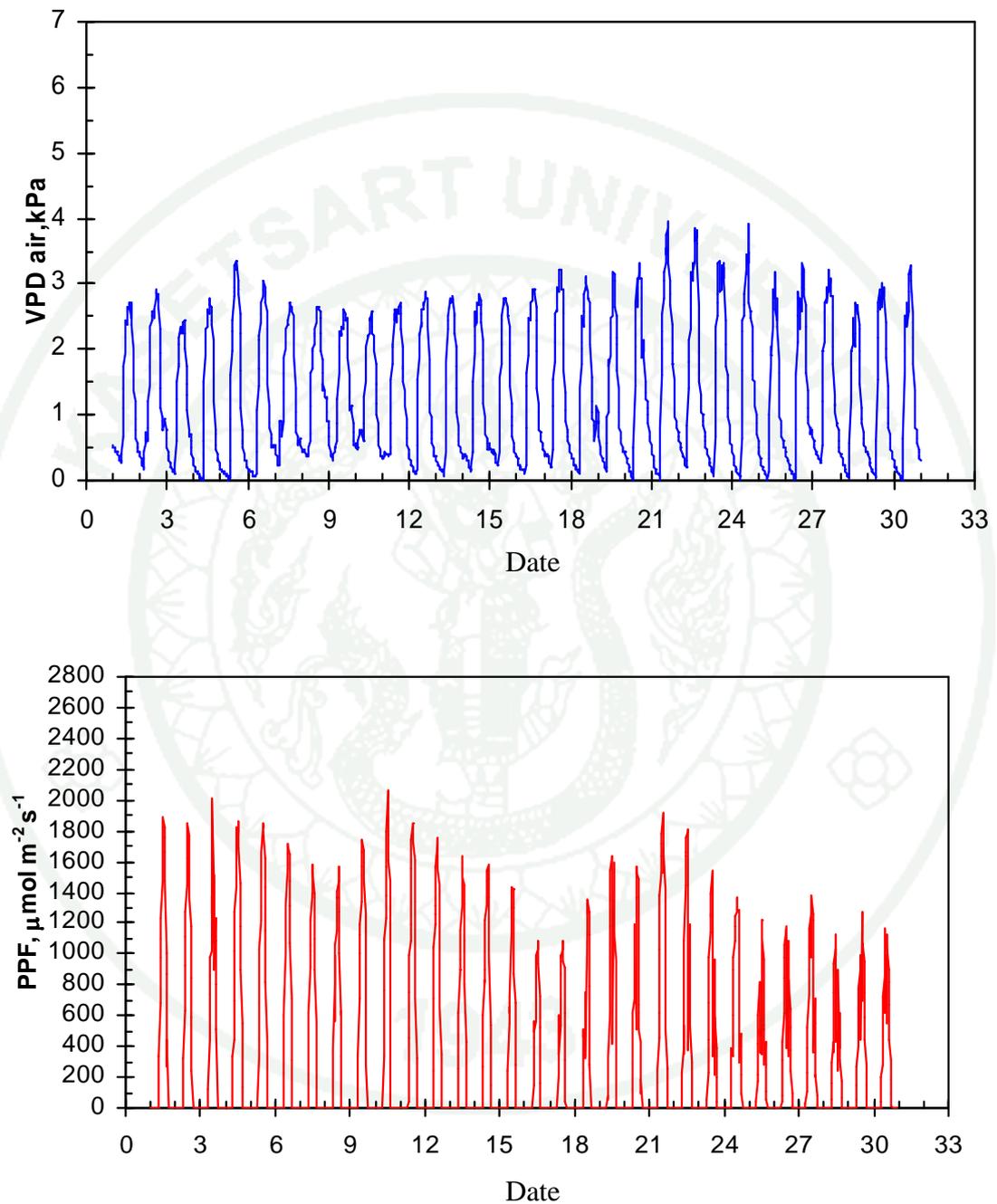Kamphaeng Saen Campus, January, 2007.
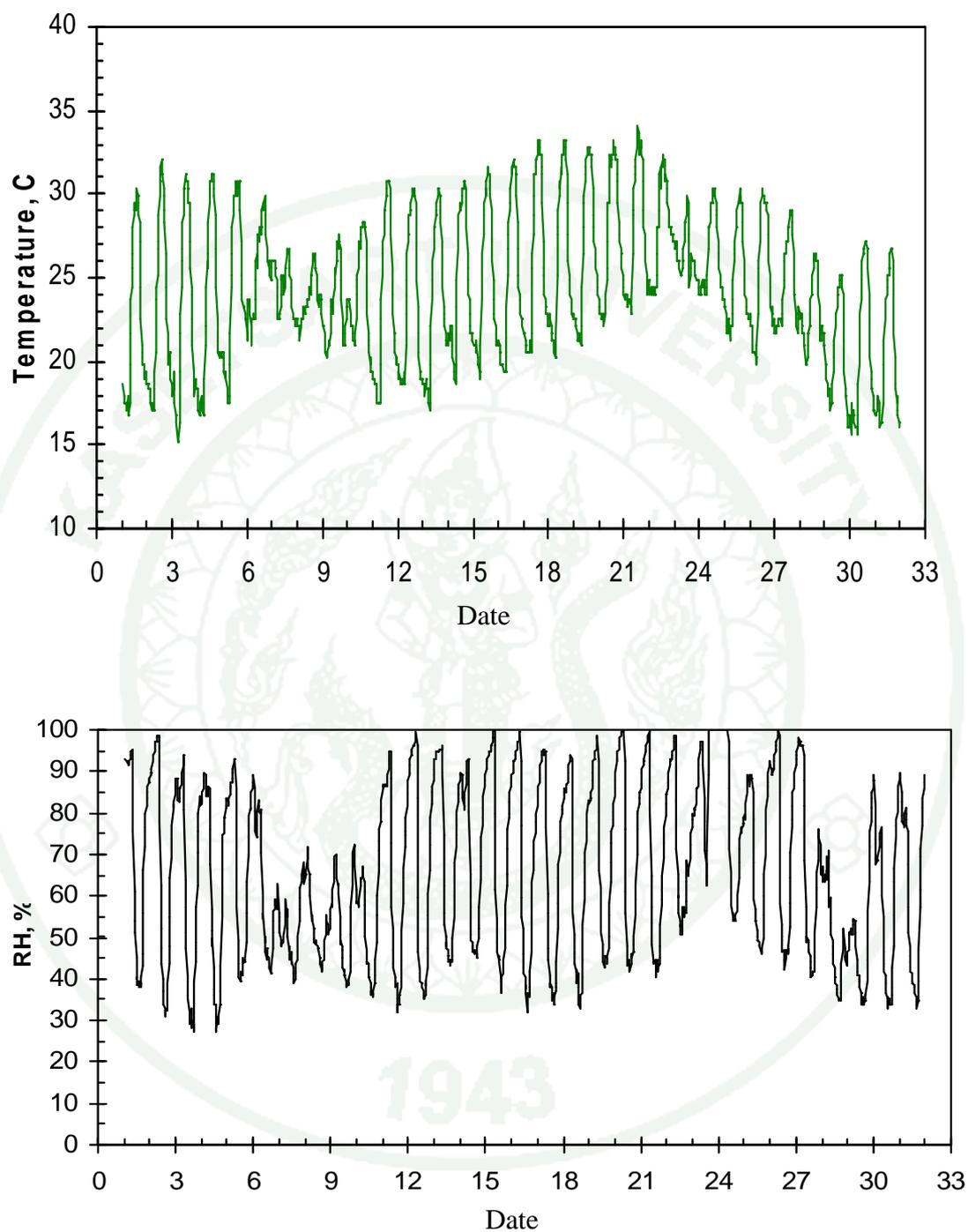
Appendix Figure 12 Temperature and percentage of Relative humidity (%RH)
recorded daily every 30 minute per day at TVRDC, Kasetsart
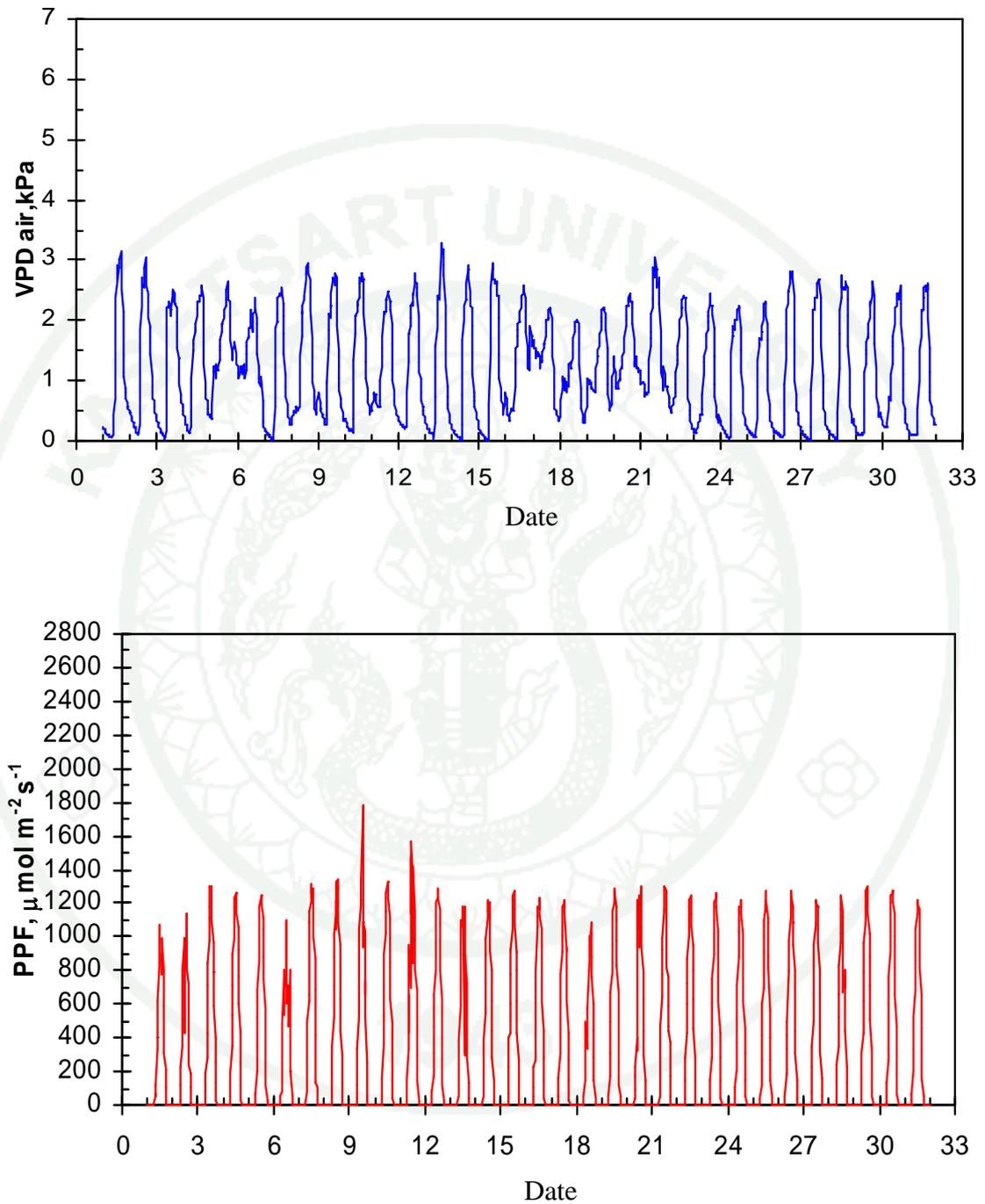University, Kamphaeng Saen Campus, November, 2006.
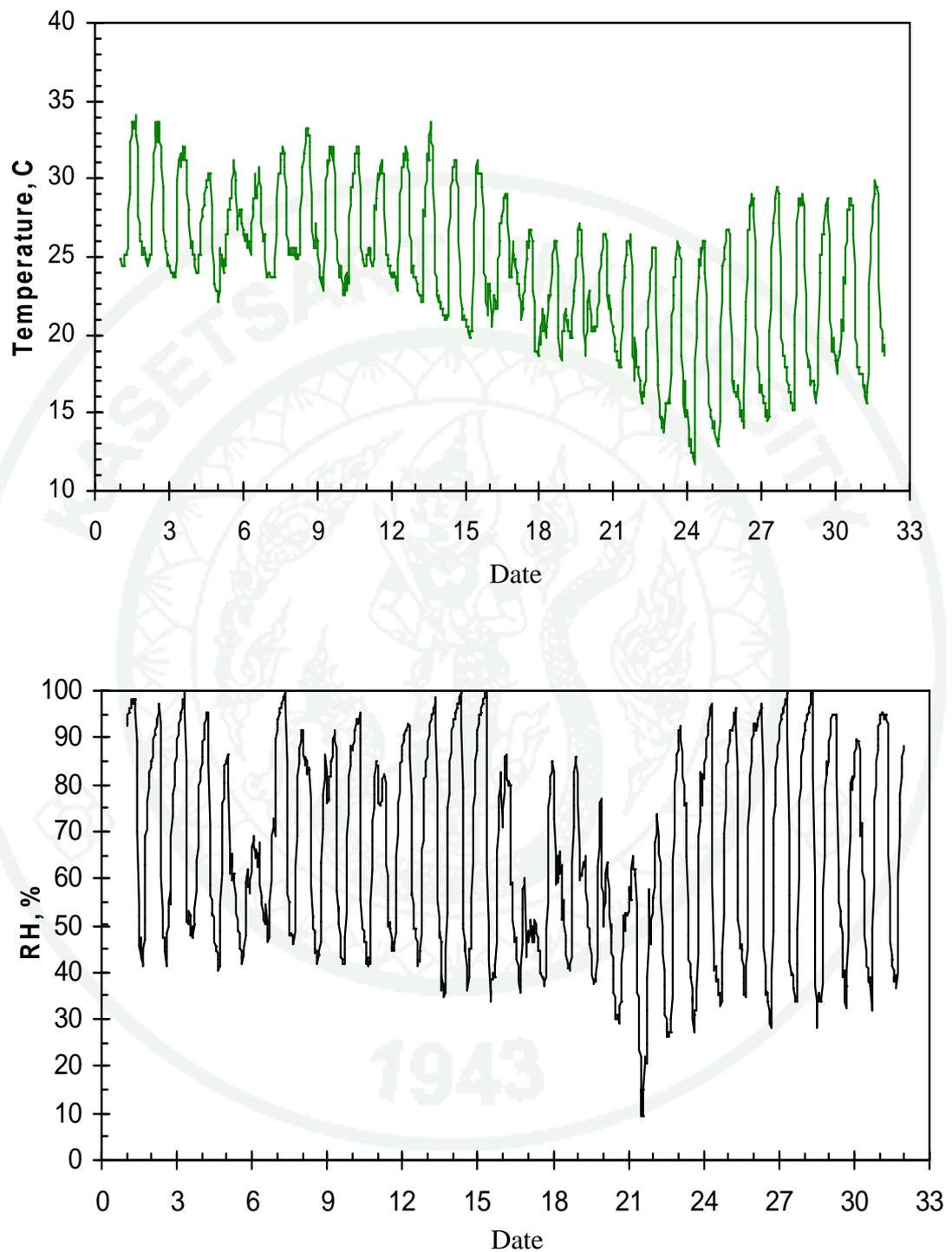
Appendix Figure 13 Temperature and percentage of Relative humidity (%RH)
recorded daily every 30 minute per day at TVRDC, Kasetsart
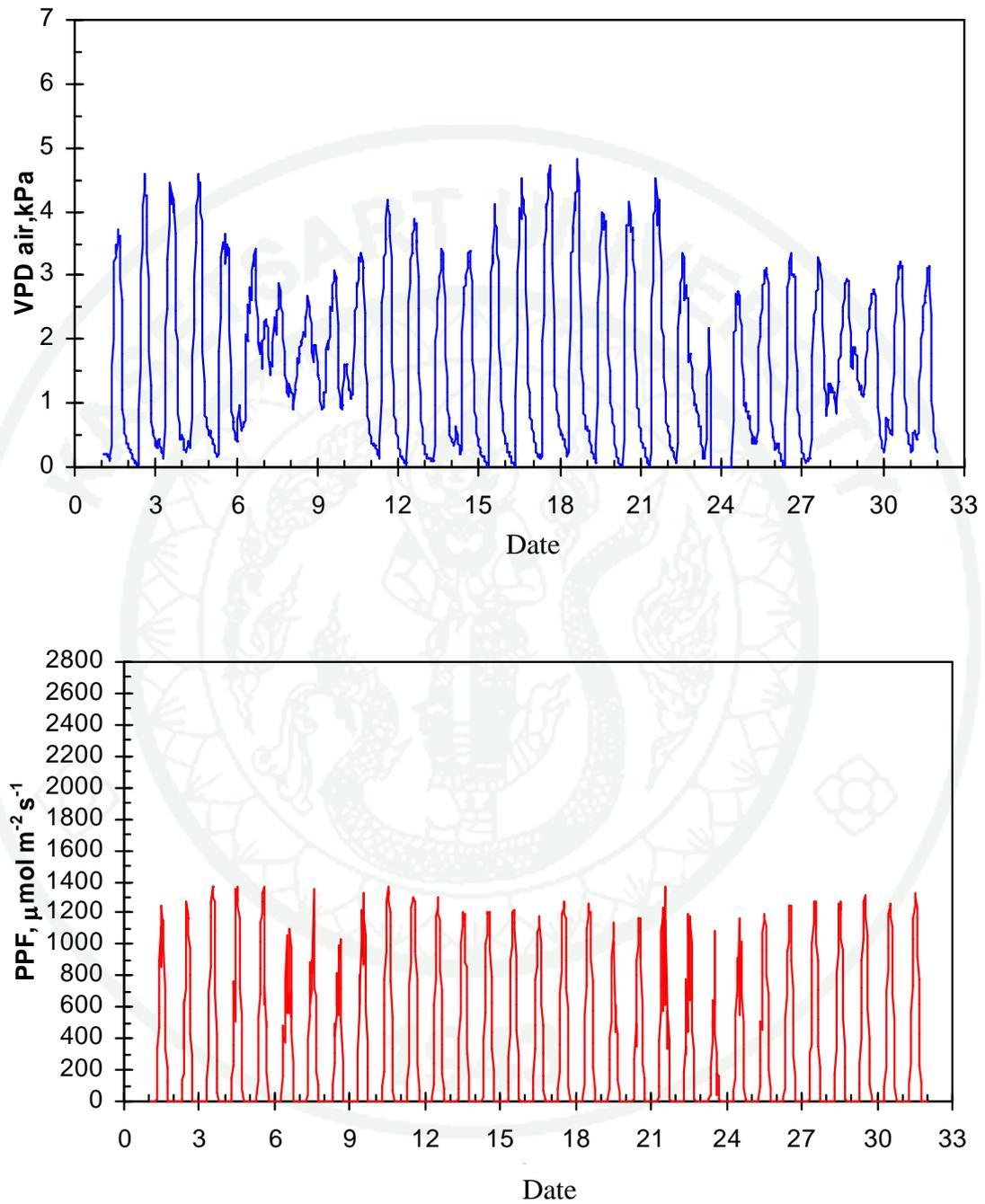University, Kamphaeng Saen Campus, December, 2006.

Appendix Figure 14 Temperature and percentage of Relative humidity (%RH)
recorded daily every 30 minute per day at TVRDC, Kasetsart
University, Kamphaeng Saen Campus, January, 2007.

Appendix Figure 15 Vapour pressure deficit of air (VPD) and photosynthetic
photon flux (PPF) recorded daily every 30 minute per day at
TVRDC, Kasetsart University, Kamphaeng Saen Campus,
November, 2006.

Appendix Figure 16 Vapour pressure deficit of air (VPD) and photosynthetic photon
flux (PPF) recorded daily every 30 minute per day at TVRDC,
Kasetsart University, Kamphaeng Saen Campus, December,
2006.

Appendix Figure 17 Vapour pressure deficit of air (VPD) and photosynthetic photon flux (PPF) recorded daily every 30 minute per day at TVRDC, Kasetsart University, Kamphaeng Saen Campus, January, 2007.

CURRICULUM VITAE

NAME   Sukumaporn Sriphadet

BIRTH DATE   November 11, 1976

BIRTH PLACE   Chumphon

EDUCATION

YEAR	INSTITUTE	DEGREE/DIPLOMA
1997	Kasetsart University	B.S. (Agriculture)
2002	Kasetsart University	M.S. (Agriculture)

POSITION/TITLE   -

WORK PLACE   -

SCHOLARSHIP   The Thailand Research Fund and Kasetsart University