PHYSIOLOGICAL RESPONSES OF COTTON (*Gossypium hirsutum* L.) TO THE INTERCROPPING WITH MUNGBEAN (*Vigna radiat*a L.)

INTRODUCTION

Cotton (*Gossypium* spp.) is one of the world's major fiber crops. It is an important source of the fiber, oil, seed meal and about 90 % of the commercial cotton is obtained from *Gossypium hirsutum*-upland cotton (Bajaj, 1998). It was grown in close to 70 countries in the world and average world cotton yield was about 580 kg per hectare (ICAC, 2005). The most important cotton production country is China (23 % of the world fiber production), followed by the United States of America (17 %), India (15 %), and Pakistan (8 %) (ICAC, 2005). Cotton is also one of the economic important crops in Thailand and Myanmar Cotton production of Myanmar is highest among the South East Asia countries, and then followed by Thailand (Thirasack, 2002).

Cotton is grown in Myanmar for fiber and used mainly in the local textile mills and for export of surplus (MCSE, 2005). In Thailand, because of high cotton production cost for local farmers, there was a sharp decrease of cotton production and it had accelerated an attempt of collaborations between researchers and extension staffs to find suitable systems of production for cotton farmers (Sayampol and Changsalak, 1997). To meet the demand of textile industry, most of the cotton deficit has been made annually through imports in Thailand. Reducing the cost of cotton production has become even more important and intercropping of cotton is one of the ways for reducing cotton production costs.

Intercropping has been important in the US and other countries and continues to be an important practice in developing nations (Sullivan, 2003). Lemaire (1995) also stated that with the increasing problem of protecting the environment in very intensive cropping systems, intercropping is often presented as a solution for sustainable agriculture. By growing mungbean between cotton rows, farmers can get additional income and it can assist the high production cost of cotton growing. Farmers have generally regarded intercropping as a technique that reduces risks in crop production; if one member of intercrop fails, the other survives and compensates in yield to some extent, allowing the farmer an acceptable harvest.

In Myanmar, local farmers intercrop upland cotton (*Gossypium hirsutum* L.) with mungbean, cowpea, sesame, peanut and they intercrop short staple cotton (*Gossypium arboreum*) with pigeon pea because these crops have similar crop duration and growing time. With this technology, farmers can produce cotton and protein rich legumes at the same time in the same field. While cotton is an important industrial raw material crop, Mungbean (*Vigna radiata* L.), also known as green gram, is a marketable and foreign exchange earning crop in Myanmar and Thailand.

Mungbean, an important short-duration pulse is grown mainly for its edible seeds which are high in protein, easily digested and prepared in numerous forms for consumption. Because of its ready market, nitrogen fixation, early maturity and ability to fit well into crop rotation program, mungbean is an important tropical crop for local farmers. Thailand exports about 40% of its total production and dominates the world mungbean trade (Wen, 1996). Intercropping of cotton with Mungbean is a common practice in tropical regions. Systematic intercropping patterns are necessary to get higher productivity of unit land area.

Several different intercropped patterns between cotton and mungbean can be observed in local farmers and the three main patterns were examined in this study. The changes of canopy photosynthesis affected by different light environment in intercropping systems were investigated in this study. The yield and yield components of cotton and mungbean together with the productivity of cotton and mungbean intercropping systems from over all yields of the two crops were examined. The specific objectives of this study were to study the physiological responses of intercropped cotton in terms of light interception efficiencies, canopy photosynthesis and to examine the yield and yield component changes of cotton and mungbean in intercropping systems. The overall objective was to examine the productivity of cotton and mungbean intercropping systems. The insect diversity of cotton and mungbean intercropping was also examined in this study which intended to propose this information for integrated pest management, IPM strategies.

LITERATURE REVIEW

1. Cotton and mungbean intercropping systems

Intercropping is presently a major method of crop production in tropical Africa, subtropical Asia, and Central and South America (Allen and Obura, 1983). The goal of intercropping is to produce a greater yield on a given piece of land, by making use of space that would otherwise be wasted with a single crop. In cotton, its seedlings are slow growing and large interrow space can be utilized by intercrops for 2 to 2.5 months after sowing (Musande *et al.*, 1981). Gomez (1983) also stated that fast-growing legumes like mungbean are ideal crops to grow as intercrop.

The intercropping can be done as the replacement of reducing the main crop row width and also can be additive planting between the normal existing plant rows. If the cropping pattern is compatible and suitable in sharing the resources, the cotton production may be the same as in monocrop because cotton plant population is not reduced. Mungbean can give the harvestable yield in short duration before cotton harvesting. Kantor (1999) also stated that to take advantage of the differences in demands for nutrients, water, and sunlight among the individual crops; intercrops can be planted with crops having different maturity dates.

Cotton and mungbean intercropping practices in tropical countries were reported in the previous studies. In Thailand, one row of Sri Sumrong 60 and 3 rows of peanut, with spacing of 1.5 m between rows gave the maximum incomes (Sayampol and Changsalak, 1997). Intercropping of early maturing crops such as glutinous corn and mungbean are suitable for the system in which rice is planted as subsequent crop and it was found in central Thailand (Pookpakdi, 1980). Cotton cultivation is also mostly practices as mixed cultivation in Lao (Thirasak, 1994) and in Cambodia, intercropping of cotton is done with corn (Huor, 1994).

Mungbean can be grown as a monocrop or a mixed crop. Mungbean enriches soil fertility by biological nitrogen fixation, checks soil erosion as a cover crop and sometimes, it can be used as a green manure and fodder crop. In Myanmar, cotton plus mungbean gave the highest values of Land equivalent ratio among the other intercrops-LER (1.57) in pre monsoon and (1.42) in post monsoon seasons (Naing, 2002). In Vietnam, cotton-mungbean intercropping has also been recommended to farmers to gain more profit (Hy, 1994). In Philippines, when mungbean are used as an intercrop as in corn, corn yield was greater than monocropping and the abundance of weeds decreased (Litsinger and Moody, 1989).

Moreover, Khan and Khaliq (2003) reported that cotton-legume intercropping systems increased organic matter content over cotton monocropping. The legume crops (mungbean) can fix nitrogen from the air through a symbiotic relationship with Rhizobium bacteria. There are many advantages of cotton mungbean intercropping for local farmers to be sustainable agriculture systems by reducing the risks of negative environmental impact due to chemical applications and by providing cotton and protein rich legumes at the same period in the same field. Sustainable agricultural development is seen as the solution for future food security and environmental conservation (Wongsiri, 1999).

2. Competition of intercrop species

When species are planted together there is competition for growth resources. Competition between the intercrop species means the process in which two individual plants or two populations of plants interact that at least one exerts a negative effect on the other (Vandermeer, 1989). The degree or the level of competition will differ among the different patterns depending on the row pattern, row ratio and crops management of intercropped species. Gomez (1983) stated that intercropped species have competition not only for light and CO_2 in the air but also for water and nutrients in the soil. Complementary effect is the opposite of the competition effect.

Cotton is very responsive to environmental changes and management (Oosterhuis *et al*., 1998) and the competition effects of different intercropping treatments may differ depending on different mungbean populations between the cotton rows. To get the profitable crop production, sowing dates, planting density, planting configuration (spacing and orientation of plant rows) of the intercrop species have to be carefully considered to reduce the competition between the intercrop species. Successful intercropping involves considering of the spatial arrangement, density, maturity dates, and plant architecture of these crops. Plant architecture is a commonly considered as one of the strategies in intercropping to allow one member of the intercrops to capture light that would not otherwise be available to the others.

Light is one of the most competitive effects in intercropping and the light environment is different from monocropping. The changes of light environment in intercropping systems can affect the photosynthesis. Smith and Cothren (1999) also stated that light intensity directly affects the rate of photosynthesis and then it could affect the crop yield. There is fundamental relationship between yield and photosynthesis and plant physiologists need to look at these intercropping systems to determine the most efficient patterns for maximizing the utilization of resources. Keswani and Ndunguru (1980) stated that in intercropping studies, most of the published research material has focused attention on yield and yield components of the associated crops however there was little published information on physiological factors.

3. Insects diversity of intercropping

Integrated pest management (IPM) is an ecological approach to insect management in which all available traits (cultural, biological, chemical, host plant resistance, etc) are evaluated and consolidated into a unified program to manage insect population, including both pest and beneficial insect, so that economic damage is avoided and environmental problems are minimized (Smith and Cothren, 1999). Cotton is a pest attractive crop because of its new shoots and reproductive organs are growing successively throughout the growing season. Cotton is the largest user of insecticides, accounting for 32% of the total quantity of insecticides (Acquaah, 2005). The costs of pesticides for pest management together with ecological damages (resistance of insects to insecticides) are the major problems in cotton production. The resistance cultivar to pest infestation and suitable cultural practices are necessary for cotton producers. Integrated Pest Management (IPM) concept is very useful to get this goal of reducing environmental problem.

Intercropping is one of IPM strategies in cotton production. Litsinger and Moody (1981) reported the advantages of intercropping on the pest infestation and reported the pest infestation was reduced in mixed cropping and the beneficial insects were more abundant in the intercropping. Therefore intercropping can be useful in cotton pest management program. Identification of pests and beneficial insects is of prime importance before any pest control operation.

MATERIALS AND METHODS

1. Field plantation

Cotton and mungbean intercropping experiment was conducted at the National Corn and Sorghum Research Center, Suwan farm, Nakhon Ratchasima Thailand in the dry season of 2006. The cultivars Sri Sumrong 60 for cotton and Kamphengsen 1 for mungbean were used in this study. The spacing of cotton was 125 cm x 50 cm and the spacing of the mungbean was 50 cm x 50 cm. The different intercropping systems were one mungbean row between one cotton row (T3), two mungbean rows between one cotton row (T4) and three mungbean rows intercropped between two cotton rows alternating with no mungbean row (T5) (Figure 1). The cotton monocropping (T1) and mungbean monocropping (T2) were sown as control.

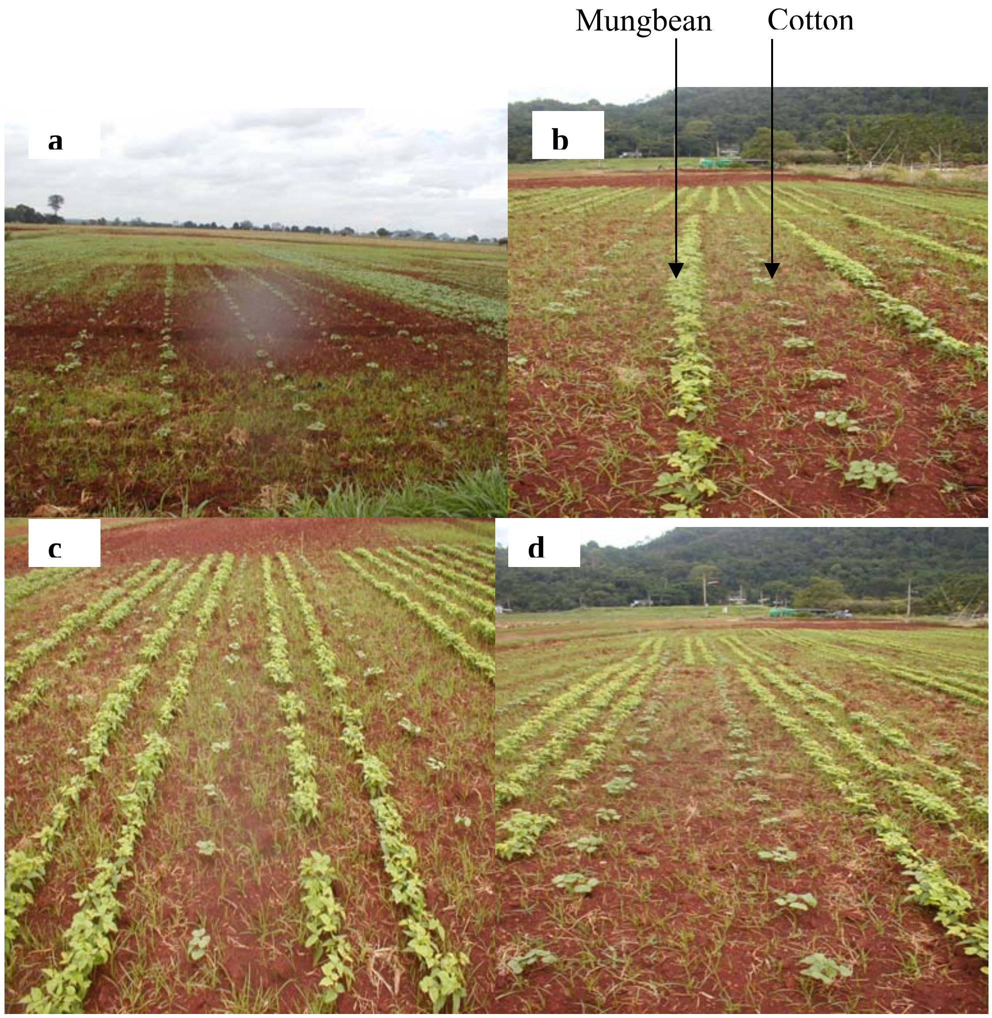


Figure 1 Cotton monocropping and intercropping treatments;

(a). Cotton monocropping (Treatment 1)

(b). One mungbean row between one cotton row (Treatment 3)

(c). Two mungbean rows between one cotton row (Treatment 4)

(d). Three mungbean rows intercropped between two cotton rows alternating with no mungbean row (Treatment 5).

The experiment was laid out as Randomized Complete Block Design with three replications. Four cotton rows of 10 m long were planted in each treatment and replication and mungbean was intercropped between the cotton rows. The experimental area was 25 m x 40 m with subplot of 37.5 m^2 each. Cotton and mungbean were planted on the same day. Five to six cotton and mungbean seeds were sown per hill and thinning was done at 14 days after planting (DAP) for mungbean and 21 DAP for cotton, leaving 2 plants per hill.

The field was irrigated by sprinkler weekly and all cultural practices (fertilization, hand weeding and insecticide application) were performed similarly in each treatment. Insecticide spraying was started at 40 DAP. Before mungbean harvesting, two times of spraying and for overall crop season six times of spraying was performed in every 2 weeks as a calendar spray. The plants were well germinated and plant canopies started closures at 50 DAP in the intercropping practices. Light interception and canopy photosynthesis studies were conducted during this time. Mungbean was harvested at 80 DAP and seed cotton was harvested twice at 130 DAP and 145 DAP. Both mungbean and seed-cotton was harvested by hand picking. Crop monitoring technique of plant mapping was used for detail study of yield distribution of cotton plants. After harvesting, the plant dry matters were also recorded with the average moisture content of 35%.

2. Light interception efficiencies of cotton and mungbean intercropping systems

The canopy geometry of the cotton and mungbean was measured by a 3D electromagnetic digitizer (Fastrak Polhemus, USA). Digitizing device consists of a system electronic unit, one (extendable to four) receiver(s), a single transmitter, and power supply. Directional light interception of each intercrop species for all treatments was computed using graphics software VegeSTAR version 3.1.1 (Adam *et al*., 2005) with plant digitize data. Light interception efficiency (LIE) is the ratio of projected sunlit leaf area to total leaf area (Planchais and Sinoquet, 1998) and it was calculated from VegeSTAR output file of cotton and mungbean digitizing data in each treatment.

Two cotton plants from the adjacent cotton rows and mungbean plants between the two cotton rows which shared the light with cotton were digitized for each treatment. Two cotton plants together with six mungbean plants in T3, twelve mungbean plants in T4 and 18 mungbean plants in T5 between the two cotton rows were digitized. The population of mungbean digitized plants was different among the treatments according to the row ratio of treatments.

3. Canopy photosynthesis of cotton and mungbean intercropping systems

Net canopy photosynthesis rate were estimated from net CO_2 exchange rate. After digitizing the plants, canopy photosynthesis was measured for cotton and mungbean. BINOS CO_2 analyzer (Rosemount 100 4P, USA) was used with an ‘open’ photosynthesis system to measure the CO_2 concentration. The air stream which known CO_2 concentration was constantly passed through the chambers and the CO_2 assimilation was calculated by the differential of CO_2 in the chamber (sample) and CO_2 entering the chamber (reference) and the air flow rate. Equation of P_n calculation;

Delta CO_2 (μmol mol^{-1}) = CO_2 in the chamber (sample) – CO_2 entering the chamber (reference)

P_n (μmol s^{-1}) = Delta CO_2 (μmol mol^{-1}) x Air flow rate (mol s^{-1})

The photosynthetic photon flux (PPF) was also measured by using LI-189 light quantum sensor (Li-Cor Inc., USA). In addition, the temperature and relative humidity inside the chambers were also recorded by Vaisala humidity and temperature sensor (50Y-Vaisala Inc., USA). During experimentation, all analyzers and sensors were calibrated before starting the measurement. Measured plants were enclosed in a transparent chamber (Figure 2) made of polyethylene plastic film and air was flowing to the chambers through 4 inches pvc pipe by the air blower with flow rate of approximately about 300 centimeters per second (about 1.20 mole of air /s) which the wind speed was measured by flow meter 8455-03 Air Velocity Transducer (TSI Inc., USA). The system had been described previously by Kasemsap *et al*, (1997).

At the beginning of gas exchange measurements, we set up the photosynthesis system and made sure the connections were correct. At dawn before there was appreciable sunlight, measurement was started and it lasted the whole day till there was no light in the evening time. All recorded data were connected to an Omega data logger (Omega engineering Inc., USA) and then sent to the computer in every ten seconds interval. In every one hour, the measurement data were saved in computer and it was later opened in excel file for photosynthesis calculation.

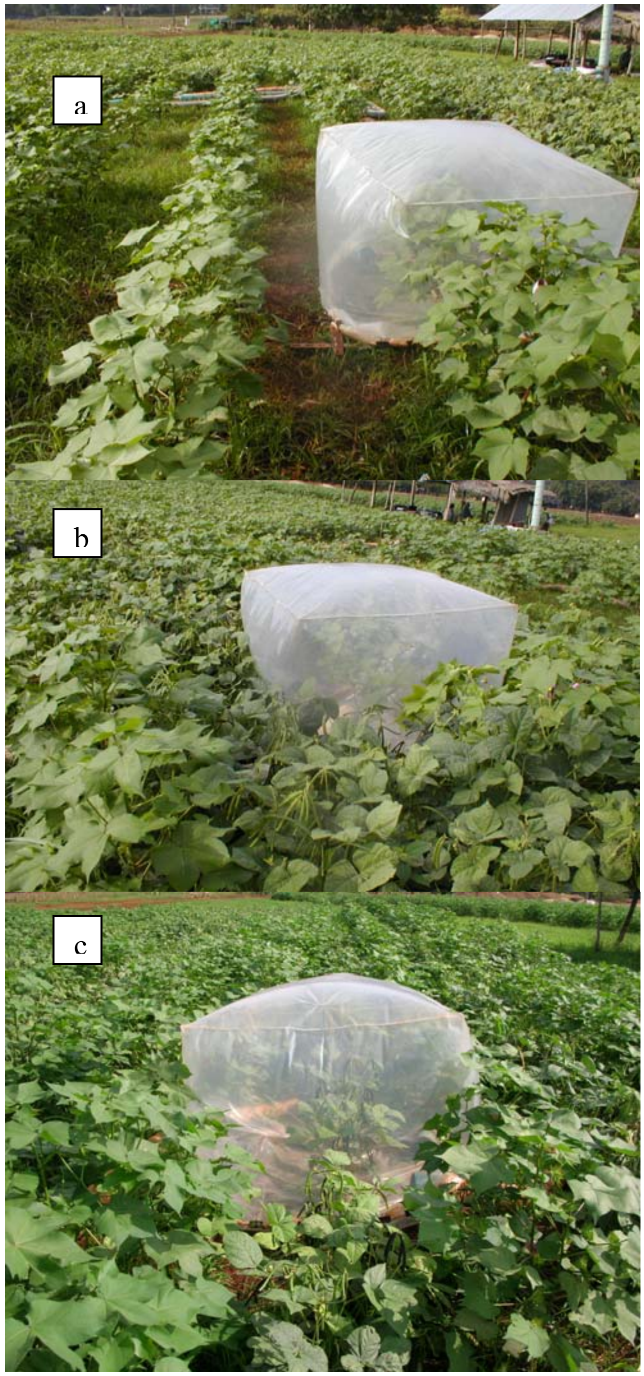


Figure 2 Field records of canopy photosynthesis (P_n) measurement;

(a). P_n measurement for monocrop cotton (Treatment 1)
(b). P_n measurement for intercrop cotton (Treatment 4)
(c). P_n measurement for intercrop mungbean (Treatment 3).

3.1 Net photosynthesis calculation

All expressions in this study are expressed in ground area basis calculation. After getting the measurement data, it had to be changed to the correct unit for P_n calculation. The unit of the flow rates has to be changed to mole of air per second and the differential CO_2 was µmol per mol (air). Therefore, P_n was expressed in µmol s^{-1}. P_n of the measured plants were then divided by the ground area of the plants occupied by the plant canopy and the unit of P_n was µmol $m^{-2}s^{-1}$.

3.2 Light response curves

Light response curve is a graphical presentation of the dependence of P_n on PPF. Light response curve also allows comparison of the rate of CO_2 uptakes among treatments. Net photosynthesis data were fitted with non-rectangular hyperbola model to estimate P_{max}, light compensation point and light saturation point for cotton and mungbean in every treatment.

Non-rectangular hyperbola model (Johnson *et al*., 1989)

$$P_n = 1/2\theta\ [\alpha I + P_{max} - \sqrt{(\alpha I + P_{max})^2 - 4\alpha I \theta P_{max}}\ ] - Rd$$

P_n = net photosynthesis (µmol CO_2 m^{-2} s^{-1})

I = Light density, photosynthesis active radiation (PAR) (µmol m^{-2} s^{-1})

P_{max} = maximum photosynthesis (µmol CO_2 m^{-2} s^{-1})

α = Slope at low light density

θ = Parameter controlling the curvature of light response curve ($0 \leq \theta \leq 1$, unitless)

Rd = dark respiration (µmol CO_2 m^{-2} s^{-1})

4. Insect diversity in cotton and mungbean intercropping systems

Two pitfall traps with the diameter of 3 inches were placed at 6 m apart from each other under the cotton plant canopies in the central two rows of each plot and left overnight in the field before collection (Figure 3). All insects caught were preserved for identification purposes. Insect identification was done at Department of Entomology, Kasetsart University. The traps used here were simply consisted of detergent water in a plastic cup and sunk in the ground with their rims at the soil surface. It was done for all plots including monocropping treatments for every week after 30 DAP until mungbean harvesting time.

The number of pests and beneficial insects were recorded separately and the insect diversity was calculated using the Shannon-Wiener diversity index. Shannon-Wiener diversity index is a term in biology/ecology. It measures the rarity and commonness of insect family in a community.

Formula, Shannon-Wiener Diversity Index;

$$H = - \sum p_i \ln (p_i) .$$

Here p_i is the proportion of each insect family to the total number of insect.

Figure 3 Pitfall trap for ground insect under cotton plant canopy.

5. Yield and yield components of cotton

Cotton yield is a combination of two major components: boll number and boll weight. Cotton plants initiate more fruiting buds than are matured and fruit retention % of the cotton plant is the major determinant for getting higher seed cotton yield. To determine the fruiting patterns in term of fruiting sites (P positions) of harvestable bolls in each treatment, cotton plant mapping was used in this study. Plant mapping can demonstrate the responses of cotton plants in detail to different environment of intercropping systems (Crozat and Kasemsap, 1997).

Plant mapping consisted of plant height, number of nodes on main stem and positions of fruiting organs (squares, flowers, green bolls and open bolls) was conducted weekly on thirty cotton plants which had been randomly selected from each treatment starting from 30 DAP until harvesting. For counting the main stem nodes, the cotyledon node was considered as zero nodes, and then the subsequent nodes of the main stem were counted toward the terminal of the plant. The number of bolls and yields of each fruiting sites were recorded separately. In this study P1 refers to the first potential boll from first nodes of all sympodia branches (fruiting branches); P2 refers to the second potential boll from the second nodes of all the fruiting branches and so on (Figure 4). Cotton height to node ratio (HNR) is the measurement of the level of vegetative growth or vigor of a crop and in this study HNR was also calculated from dividing the cotton plant height by the number of nodes.

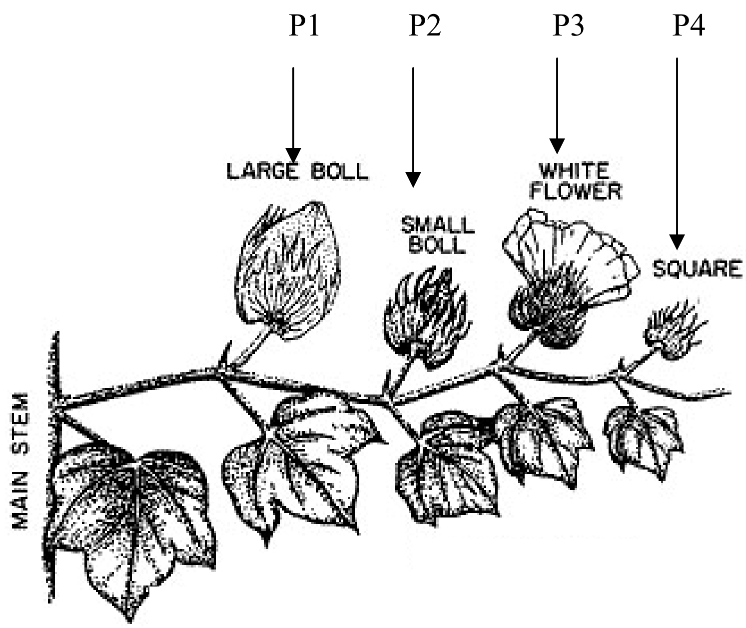


Figure 4 Cotton fruiting positions on fruiting branch (sympodia branch) (David, 2005).

The numbers of bolls and seed cotton yield from monopodia branches (vegetative branches) were also recorded to calculate the representative yield per plant. To get the yield distribution pattern in each treatment, percentage of yield from each fruiting sites was calculated to the proportion of total yield per plant. The numbers of aborted sites from the first and second fruiting positions were also recorded from all fruiting branches. The fruit retention percentage of the cotton plant in each treatment was also calculated base on P1 and P2 fruiting sites and calculation of fruit retention in this study was the same method as that described by Smith and Cothren, 1999 and Jeffrey, 2001. Duncan Multiple Range Test (DMRT) was performed for the mean comparisons among the treatments.

6. Yield and yield components of mungbean

Mungbean plant height and number of nodes at harvesting time were recorded from thirty randomly selected plants from each treatment. Average mungbean yield per plant and its yield components (pods per plant, seeds per pod and seed index) were studied. The harvested mungbean yields per area together with seed cotton yield per area from each subplot were determined to compare the productivity of the intercropping systems. Mean comparisons between the treatments were performed using Duncan's Multiple Range Test (DMRT).

7. Overall productivity of cotton and mungbean

The productivity of intercropping patterns can be evaluated in terms of Land equivalent ratio (LER) value (IRRI, 1975). LER is the sum of the fractions of the yields of the intercrops relative to their sole crop yields. This information tells us the area needed under sole cropping to give an equal amount of yield to the intercropping at the same management level.

Harvested yield of cotton and mungbean from each subplot are used to determine LER. Mean LER value was calculated from the yield of the three replications. The LER values were calculated using the following formula:

LER $= \sum_{i=1}^{n} \left[Y_i^I / Y_i^M \right]$, where: Y_i^I is the yield of crops i in intercropping, Y_i^M is the yield of crops i in sole cropping.

In our study, yield of cotton and yield of mungbean in intercropping were calculated with the yield of those crops in monocropping.

RESULTS

1. Light interception efficiencies of cotton and mungbean intercropping systems

LIE quantifies the effects of different intercropping patterns on light interception. Intercropped cotton and mungbean had less LIE than monocropping throughout the day because of sharing light for the two crops (Figure 5 and 6). Cotton plants in T4 and T5 had less LIE than those of T3 showing highly competition for light between the intercrop species because of higher mungbean plant population between the cotton rows. For mungbean, LIE in all intercropping treatments had less LIE than those of monocropping. Figure 5 and 6 demonstrated the light interception efficiencies (LIE) of cotton and mungbean for the whole day. Intercropping systems gave less LIE for both cotton and mungbean.

LIE of cotton monocropping gave the highest LIE value throughout the day and LIE value was in the range of 0.3 to 0 .6 in morning and evening time and it reached maximum value of about 0.6 at the noon time. However, in the intercropping treatments, the LIE values were less than monocropping and among the intercropping treatment LIE value of T3 had greater value than T4 and T5. The maximum value of LIE at noon time is about 0.3 for T3 and 0.2 for T4 and T5. Similar to these results, LIE values for mungbean plants also had greater value which the range from 0.3 to 0.5 in mungbean monocropping and LIE values of the mungbean in all intercropping treatments had less value which the range from 0.1 to 0.2 which less than those of monocropping.

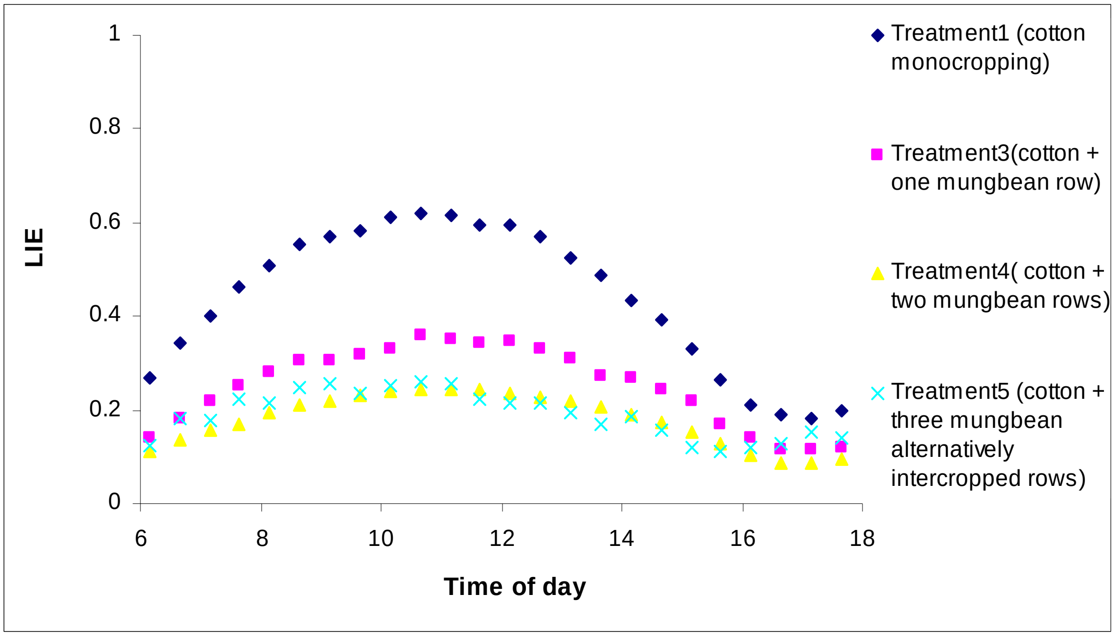


Figure 5 Light interception efficiencies of cotton.

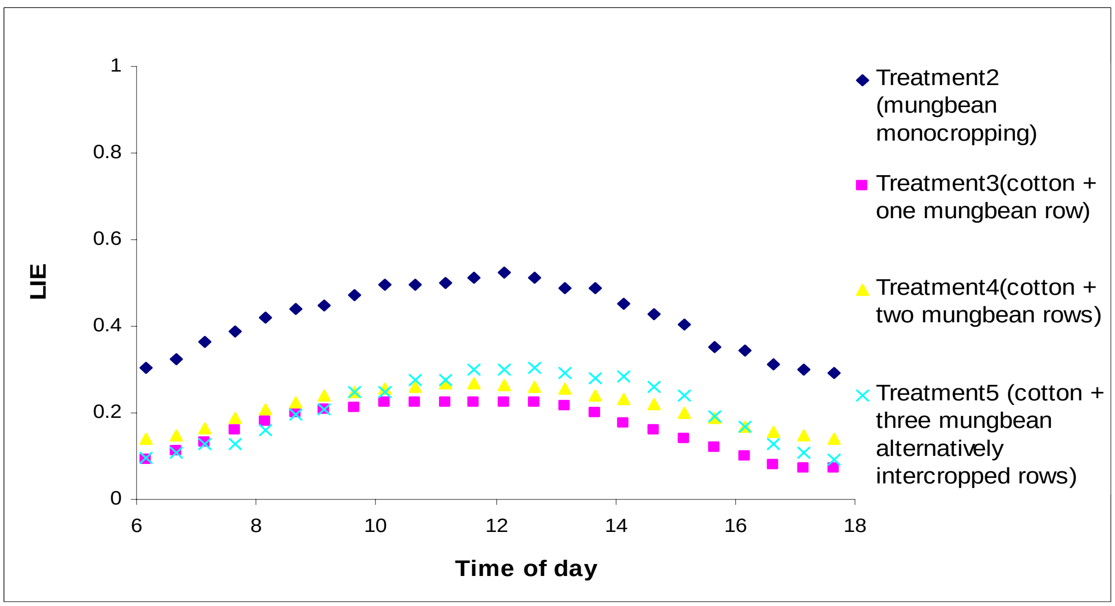


Figure 6 Light interception efficiencies of mungbean.

2. Canopy photosynthesis of cotton and mungbean intercropping systems

The effects of mungbean intercrops to the cotton photosynthetic light use efficiency were clearly identified in this study. Light use efficiency is the slope of the light response curve (Gardner *et al*., 1985). In this study, cotton monocropping gave the higher efficiency than intercropping treatments (Table 1).

Canopy photosynthesis was curvilinear function of PPF for both cotton and mungbean. The light responses curves of the cotton and mungbean in all treatments fitted with non-rectangular hyperbola model are shown in Figure 7 and 8. Starting from the complete darkness, net CO_2 exchange rate was negative due to respiration and then net CO_2 exchange rate gradually increased with increasing light, until compensation point (the light level at the CO_2 exchange rate or CER=0) was reached. There was steadily increase in CER for each unit increase in light level until the light saturation level was reached.

Table 1 and Table 2 are the estimated P_{max}, light saturation, light compensation and initial slope of light response curves for cotton and mungbean by non-rectangular hyperbola model. P_{max} of cotton and mungbean were higher in monocropping than that of intercropping treatments. Light saturation was attained in lower light level in intercropping treatments. Even though there was not competition in T1 and T2, the light saturation is not reached full sunlight which is about 2000 μmol m^{-2} s^{-1}. Similar to this information, Gardner *et al*. (1985) reported that most C3 species reach light saturation before full sunlight and C4 species are able to increase photosynthesis for the light levels equal to full sunlight.

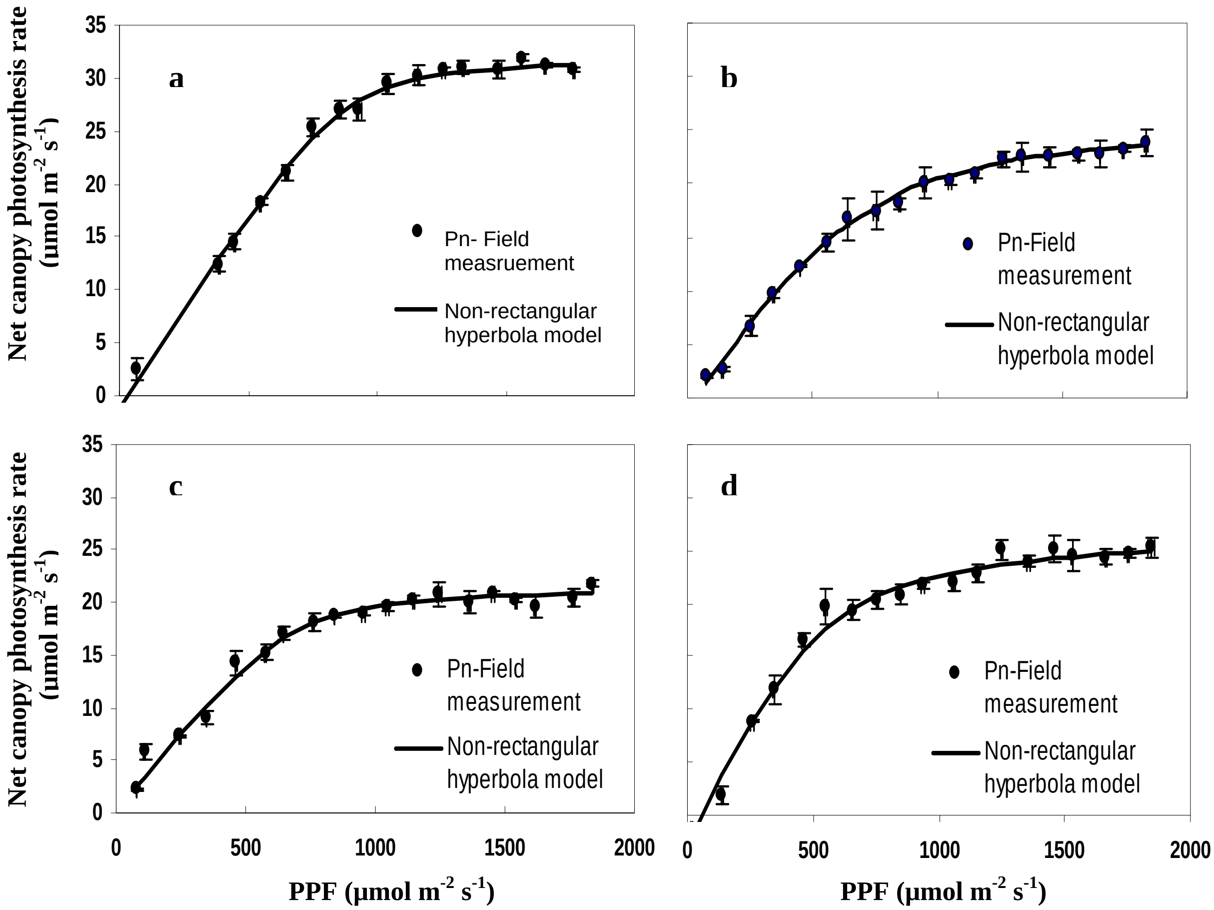
The average P_n rates of cotton and mungbean plant over one hour period throughout the measured time of the whole day for all treatments are shown in Figure 9. The P_n values of cotton and mungbean in monocropping had higher rate than intercropped cotton and mungbean. The two crops shared the space, resources in intercropping systems and the reduction of cotton P_n in intercropping was due to mungbean intercrops. If we consider the total P_n (intercropped cotton and mungbean) per area, it had approximately the same value of P_n as those of monocrop cotton for a unit area (Figure 9). The photosynthesis rates of the cotton and mungbean plant canopies were increased in the morning and reached the peak at noon, then gradually decreased in the afternoon. P_n of each cotton and mungbean were reduced in all intercropping treatments. The photosynthesis photon flux density of the photosynthesis measurement day is shown in figure 10.

Table 1 Estimated P_{max}, light saturation points, light compensation points and initial slope for cotton light response curve by non-rectangular hyperbola model.

Treatments	Light saturation (μmol $m^{-2}s^{-1}$)	Light compensation (μmol $m^{-2}s^{-1}$)	P_{max} (μmol $m^{-2}s^{-1}$)	Initial Slope (α)
Treatment1(Cotton monocropping)	1045	30	33.28	.037
Treatment 3 (Cotton + 1 mungbean row)	959	14	25.40	.031
Treatment 4 (Cotton + 2 mungbean rows)	751	25	21.51	.030
Treatment 5 (Cotton + 3 alternative mungbean rows)	942	26	29.87	.035

Table 2 Estimated P_{max}, light saturation points, light compensation points and initial slope for mungbean light response curve by non-rectangular hyperbola model.

Treatments	Light saturation (μmol $m^{-2}s^{-1}$)	Light compensation (μmol $m^{-2}s^{-1}$)	P_{max} (μmol m^{-2} s^{-1})	Initial Slope (α)
Treatment 2 (mungbean monocropping)	996	20	11.65	.009
Treatment 3 (Cotton + 1 mungbean row)	938	15	8.56	.008
Treatment 4 (Cotton + 2 mungbean rows)	884	16	7.50	.006
Treatment 5 (Cotton + 3 alternative mungbean rows)	887	18	7.78	.007



Figures 7 Net canopy photosynthesis rate of cotton, estimated by CO_2 exchange rate as a function of photosynthetically active photon flux (µmol m^{-2} s^{-1})

(The lines are fitted to the data by using non-rectangular hyperbola model).

(a). Treatment 1-Cotton monocropping ,

(b). Treatment 3-Cotton with one mungbean row,

(c). Treatment 4-Cotton with two mungbean rows and

(d). Treatment 5-Cotton with alternatively intercropped three mungbean rows.

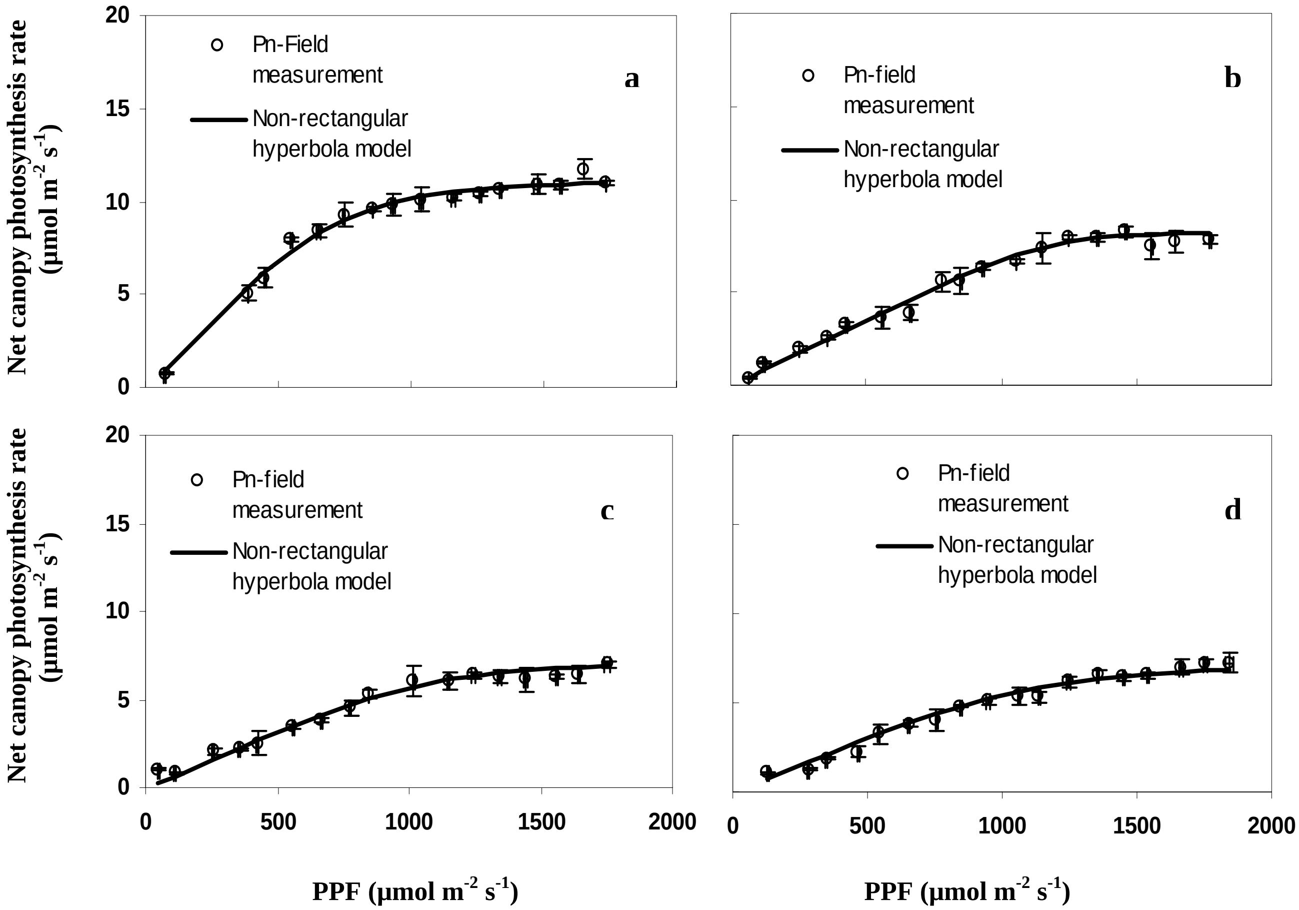


Figure 8 Net canopy photosynthesis rate of mungbean, estimated by CO_2 exchange rate as a function of photosynthetically active photon flux (µmol m^{-2} s^{-1})

(The lines are fitted to the data by using non-rectangular hyperbola model).

(a). Treatment 2-mungbean monocropping

(b). Treatment 3-one mungbean row intercropping

(c). Treatment 4- two mungbean rows intercropping

(d). Treatment 5- three mungbean rows alternatively intercropped.

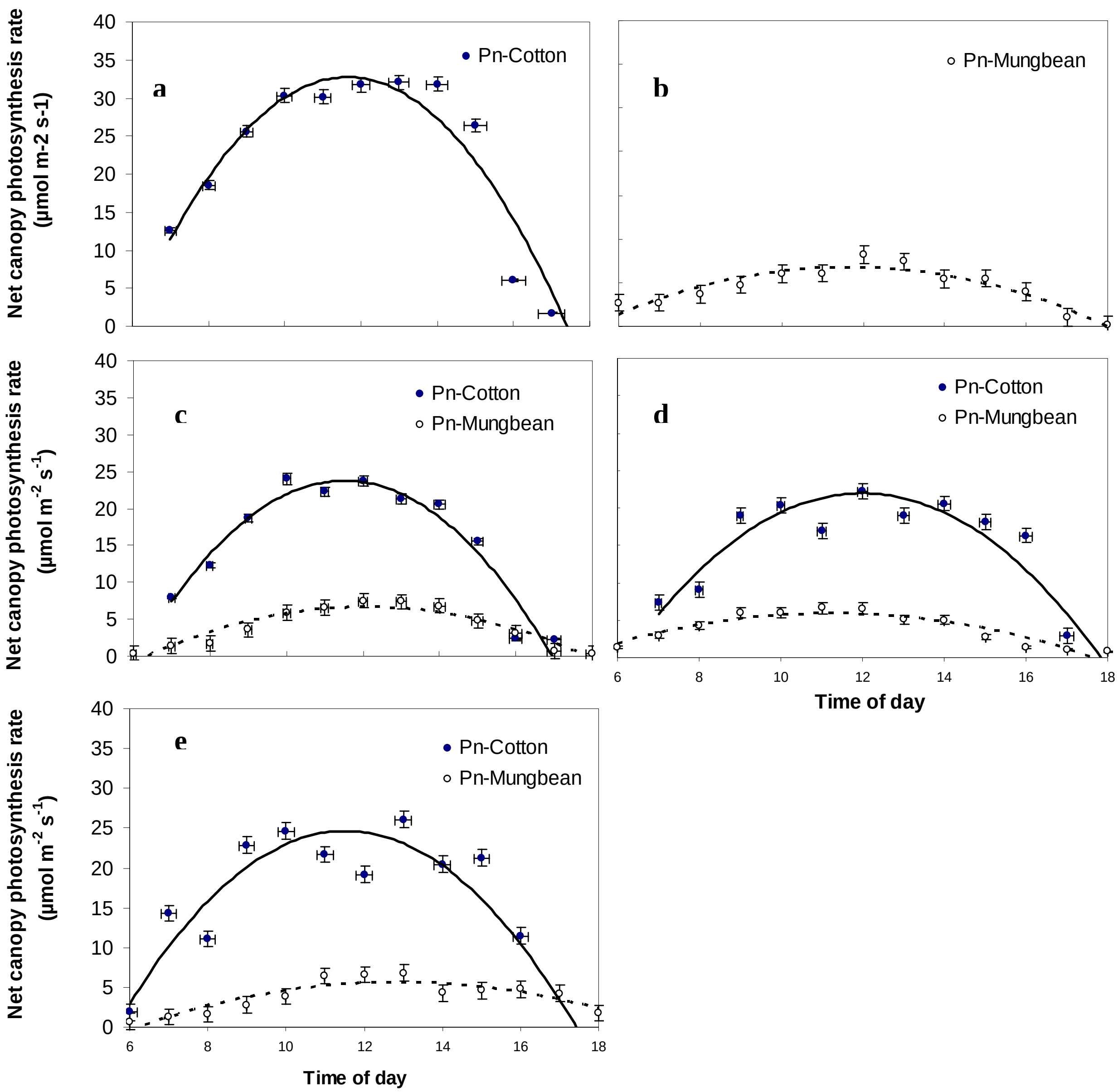


Figure 9 Average canopy photosynthesis of cotton and mungbean for every one hour for the whole day (6 AM to 6 PM) in every treatment;

(a). Treatment 1-Cotton monocropping,

(b). Treatment 2-Mungbean monocropping

(c). Treatment 3-Cotton with one mungbean row

(d). Treatment 4-Cotton with two mungbean rows and

(e).Treatment 5 -Cotton with alternatively intercropped three mungbean rows.

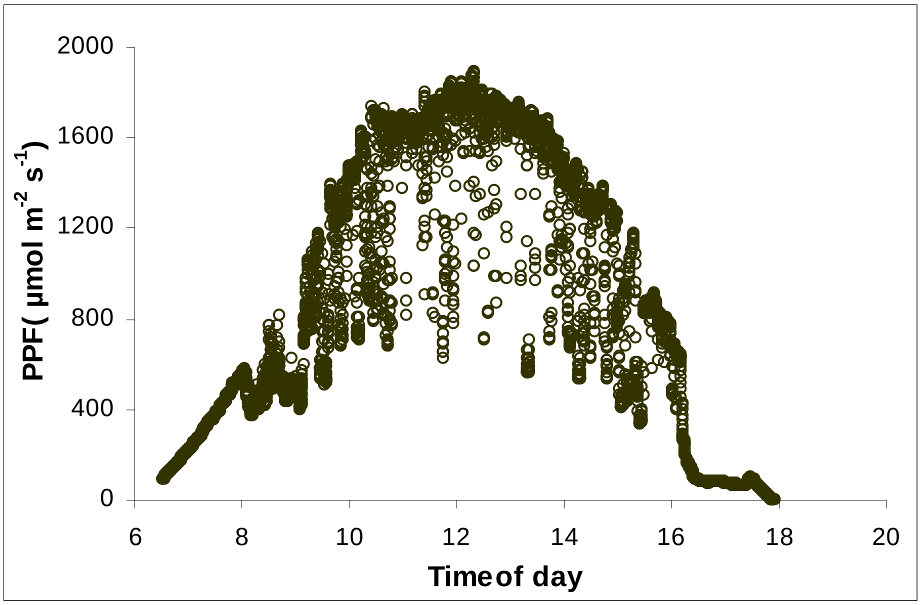


Figure 10 Photosynthetic photon flux of research field on P_n measurement day.

3. Ground Insect diversity index of cotton and mungbean intercropping systems

Insect diversity index of cotton and mungbean intercropping systems and the number of beneficial insects were recorded in this study. Figure 11 demonstrated the ground insect diversity of field records from 30 DAP to 70 DAP. The insect diversity of the intercropping treatments tends to be greater than monocropping system. Insect diversity was related to plant diversity. The more plant species in intercropping resulted in the greater insect diversity. Insecticide spraying of the experimental field was started at 40 DAP. Insect diversity was greatest at 37 DAP and it decreased approximately 30% following the first insecticide spray on 40 DAP. Therefore insect diversity dropped on the recording date of 44 DAP. T4 and T5 which had higher plant population showed the higher insect diversity index.

Several beneficial arthropods such as Coccinellidae, Carabidae and Spider were found abundantly in cotton and mungbean intercropping systems. The recorded average numbers of recorded beneficial arthropods throughout the study period were greater in intercropping treatments than those in monocropping (Figure 12).

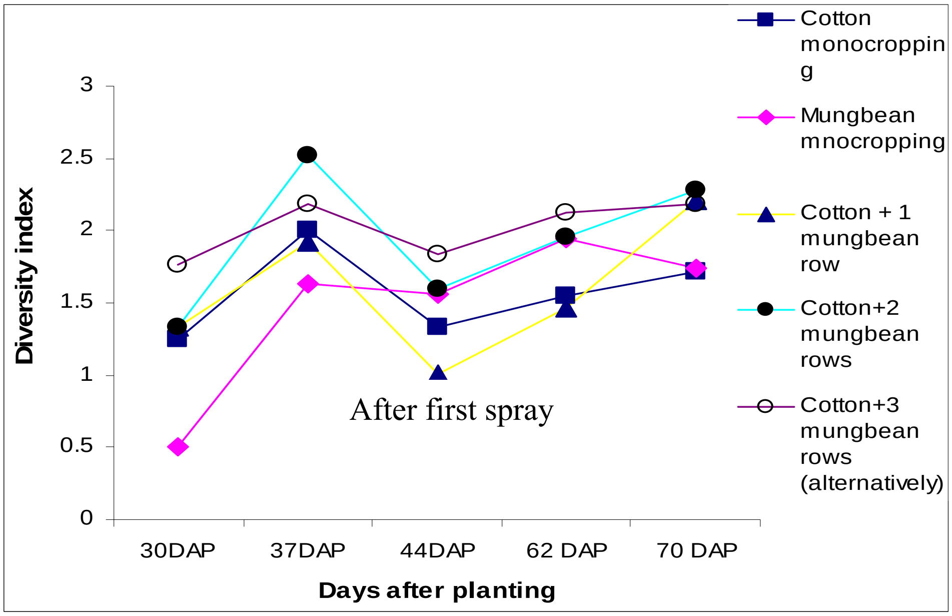


Figure 11 Insect diversity of the cotton and mungbean intercropping system.

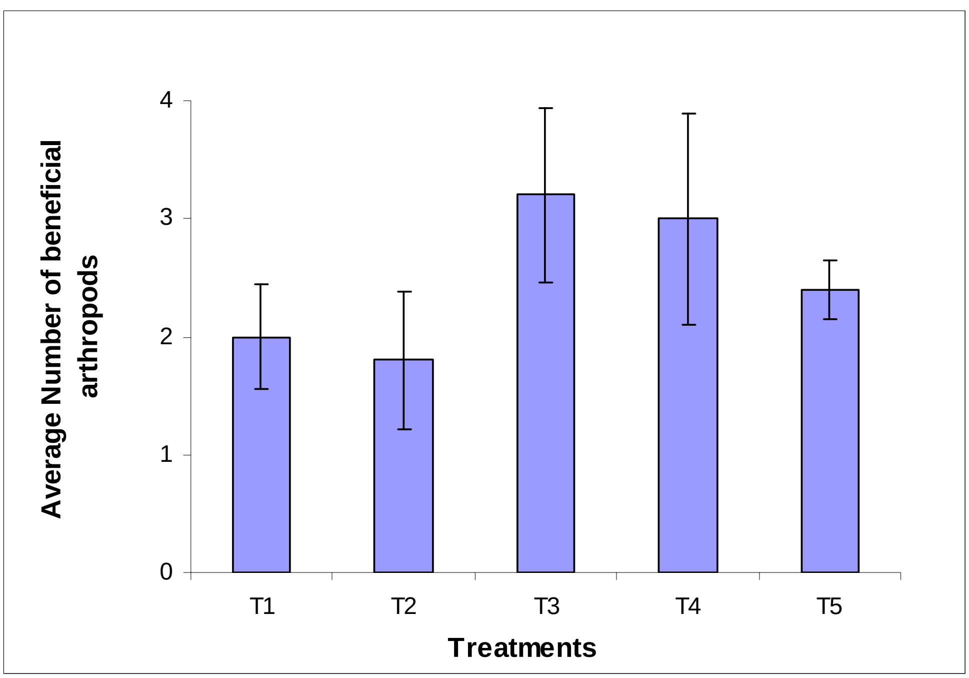


Figure 12 Average numbers of beneficial arthropods in cotton and mungbean intercropping system.

4. Yield and yield components of cotton

The growth pattern of cotton plants in all treatments were not difference in this study. The first fruiting branch usually occurs at node 5 to 6. In all treatments, the number of nodes reached about 24 to 25 and cotton plant height reached about 1 m high in all treatments and so HNR between the treatments are also not significantly difference (Table 3). In this study, Sri Sumrong 60 cotton cultivar produced about 16 fruiting branches with one or two vegetative branches in all treatments of monocropping and intercropping. Vegetative branches (VB) also gave the harvestable cotton bolls in all treatments contributing some to cotton yield but yield of vegetative branches were not difference among the treatments.

The seed cotton yields per plant from monocropping were statistically greater than those from intercropping treatments and T3 gave the greater yield among the intercropping treatments (Table 4) ($P<0.05$). Boll weight (g/boll) was not statistically different among monocropping and intercropping treatments where as the number of harvestable bolls of T1 was significantly higher than T3 which was greater than T4 and T5. Many potential reproductive sites were aborted in a square and young boll stages in T4 and T5. Variation of seed cotton yield was concerned to the fruit retention percentages of P1 and P2 which are 28.13 %, 25.57 %, 20.30 % and 22.08 % for T1, T3, T4 and T5 respectively (Table 4). Yield distribution pattern was similar in all treatments which the P1 positions possess high yielding contribution in all treatments (Table 5). Yield of P1 and P2 in T1 and T3 were significantly greater than T4 and T5 while other P positions did not contribute to yield difference ($P<0.05$) (Figure 13).

Table 3 Mean comparisons of cotton plant height, numbers of node, HNR and plant dry matter at harvesting.

Treatments	Plant height (cm)	Numbers of nodes	HNR (cm/node)	Dry matter (g)
Cotton monocropping (T1)	109.3	25.3	4.33	263.7
Cotton + 1 mungbean row (T3)	111.2	25.0	4.45	258.8
Cotton + 2 mungbean rows (T4)	105.7	24.7	4.28	273.7
Cotton + 3 alternative mungbean rows (T5)	104.0	25.0	4.16	272.5
F test	NS	NS	NS	NS
C.V. (%)	9.8	7.3	8.6	16.0

NS represent means in the same column are not significantly different.

Table 4 Mean comparisons of seed cotton yield and yield components.

Treatments	Boll weight (g/boll)	Numbers of bolls	Yield per plant (g)	Fruit retention (%)
Cotton monocropping (T1)	4.1	15 a	71a	28.13
Cotton + 1 mungbean row (T3)	4.2	13 ab	58b	25.57
Cotton + 2 mungbean rows (T4)	3.9	10 c	40c	20.30
Cotton + 3 alternative mungbean rows (T5)	4.0	11 c	39c	20.30
F test	NS	*	*	
C.V. (%)	10.4	14.0	8.9	

* Significant at 0.05 probability level. Means followed by the same letters in the same column are not significantly different by DMRT at P<0.05.

Table 5 Differences in percent contribution to total yield by fruiting positions of the cotton plant in monocropping and intercropping (% Total Yield).

	Fruiting Positions				
Treatments	P1	P2	P3	P4	VB
Cotton monocropping (T1)	58.6	19.7	8.9	3.3	9.5
Cotton + 1 mungbean row (T3)	59.7	22.8	8.0	4.8	4.7
Cotton + 2 mungbean rows (T4)	51.7	17.3	14.5	6.2	10.3
Cotton + 3 alternative mungbean rows (T5)	55.7	25.2	9.4	4.7	5.0

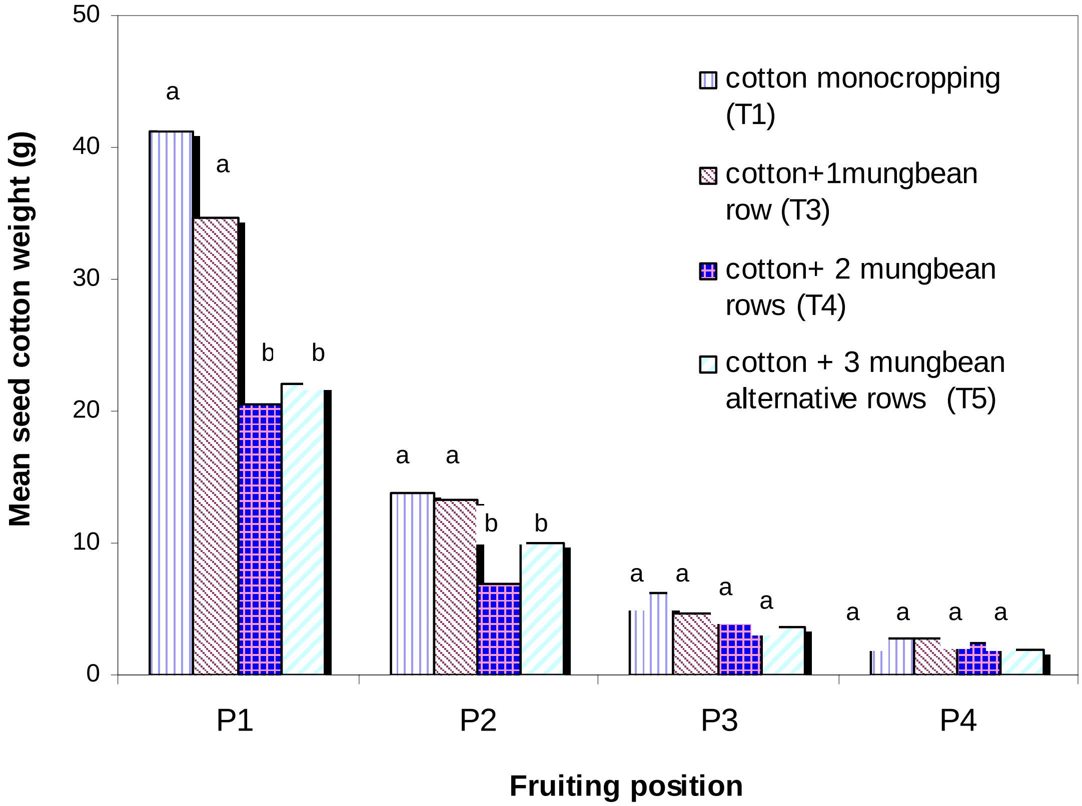


Figure 13 Comparisons of yield production by fruiting sites between cotton monocropping and intercropping treatments.

5. Yield and yield components of mungbean

The number of nodes and the plant height at harvesting tended to be higher in mungbean monocropping but there were not statistically different between the treatments ($P<0.05$) (Figure 14 and 15). Moreover, number of pods per plant, number of seeds per pod, 1000 seed weight (seed index) were not significantly different between monocropping and intercropping ($P<0.05$) (Table 6). Yield per area of monocropping treatment was significantly greater than intercropping treatments. Yield in the mungbean intercropping depended on mungbean population of each treatment. With similar yield components, yield of treatment 2 was much greater than treatment 3 and yield of treatment 4 and 5 were greater than treatment 3 mainly because of greater planting population.

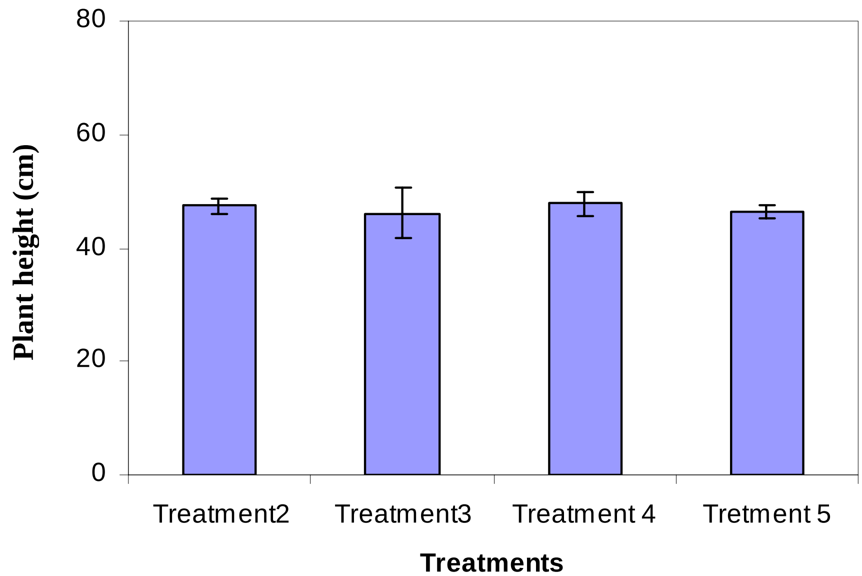


Figure 14 Plant height of mungbean at harvesting.

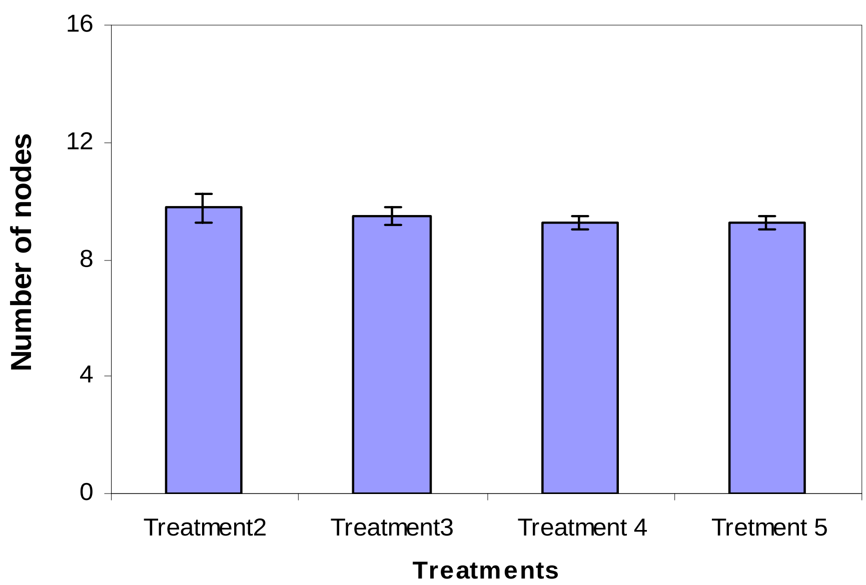


Figure 15 Number of nodes of mungbean at harvesting.

Table 6 Mean comparisons of yield and yield components of mungbean.

Intercrop patterns	Number of pods per plant	Number of seeds per pod	1000 Seed weight (g)	Yield per area (g m^{-2})
Mungbean monocropping (T2)	32	9	67	105 a
Cotton + 1 mungbean row (T3)	31	9	65	39 c
Cotton + 2 mungbean rows (T4)	25	8	65	67 b
Cotton + 3 mungbean rows (T5)	23	8	63	74 b
F test	NS	NS	NS	*
C.V %	17.22	8.11	3.07	16.43

* Significant at 0.05 probability level. Means followed by the same letters in the same column are not significantly different by DMRT at $P<0.05$.

6. Overall productivity of cotton and mungbean

Mungbean intercropping reduced the yield of cotton but the overall production of cotton and mungbean was the superior cropping patterns with high production efficiencies. In our study the LER of 1.18, 1.24 and 1.29 were observed for T3 (cotton with one mungbean row), T4 (cotton with two mungbean rows) and T5 (cotton with three mungbean rows) respectively. All three intercropping patterns gave higher productivity than monocropping where LER values were greater than 1 and Pattern 3 gave the highest LER value. Greater mungbean population provided greater competition to cotton plants especially in T4 and T5 where seed cotton yield was significantly reduced in these treatments. However, these intercrop patterns gave the higher mungbean harvestable yield due to changes of the crop mixture ratio.

Table 7 Yield of cotton and mungbean from intercropping treatments and land equivalent rato (LER) values (Yield per area of each subplot of 37.5 m^2).

Cropping patterns	Cotton yield (g/area)	Mungbean yield (g/area)	Total yield(g/area)	LER
Cotton Monocropping	3631	0	3631	
Mungbean monocropping	0	3967	3967	
Cotton + 1 mungbean row	2920	1471	4391	1.18
Cotton + 2 mungbean rows	2166	2539	4705	1.24
Cotton + 3 alternative mungbean rows	2097	2791	4888	1.29

DISCUSSION

Intercropping system reduced the light interception efficiencies of each crop. And the Pn was also reduced in intercropping treatments and this investigation showed the effects of light competition of the intercrops mungbean on canopy photosynthesis of cotton. T1 which cotton had no competition from mungbean and P_n were increased sharply with light increasing showing the higher light use efficiency. T4 and T5 which had higher mungbean populations between the cotton rows had less photosynthesis in this experiment due to the competition of mungbean. T3 had the higher P_{max} in intercropping treatments.

Heitholt (1994) studied the correlation between the lint yield and PPF and he reported that the careful control of plant density was required to achieve the maximum yield. In this study P_n was clearly influenced by LIE and the correlation between P_n and LIE was further investigated for cotton and mungbean. Figure 16 and 17 demonstrated the correlation of the LIE and P_n of all cotton and mungbean. LIE explained 63% to 92% of variation in canopy photosynthesis of both cotton and mungbean in all treatments with one exception of cotton in treatments 5 where LIE explained just 32% of variations. Regression equations from this information could be useful to construct the mathematical model to estimate P_n and combine yield of cotton and mungbean for next studies.

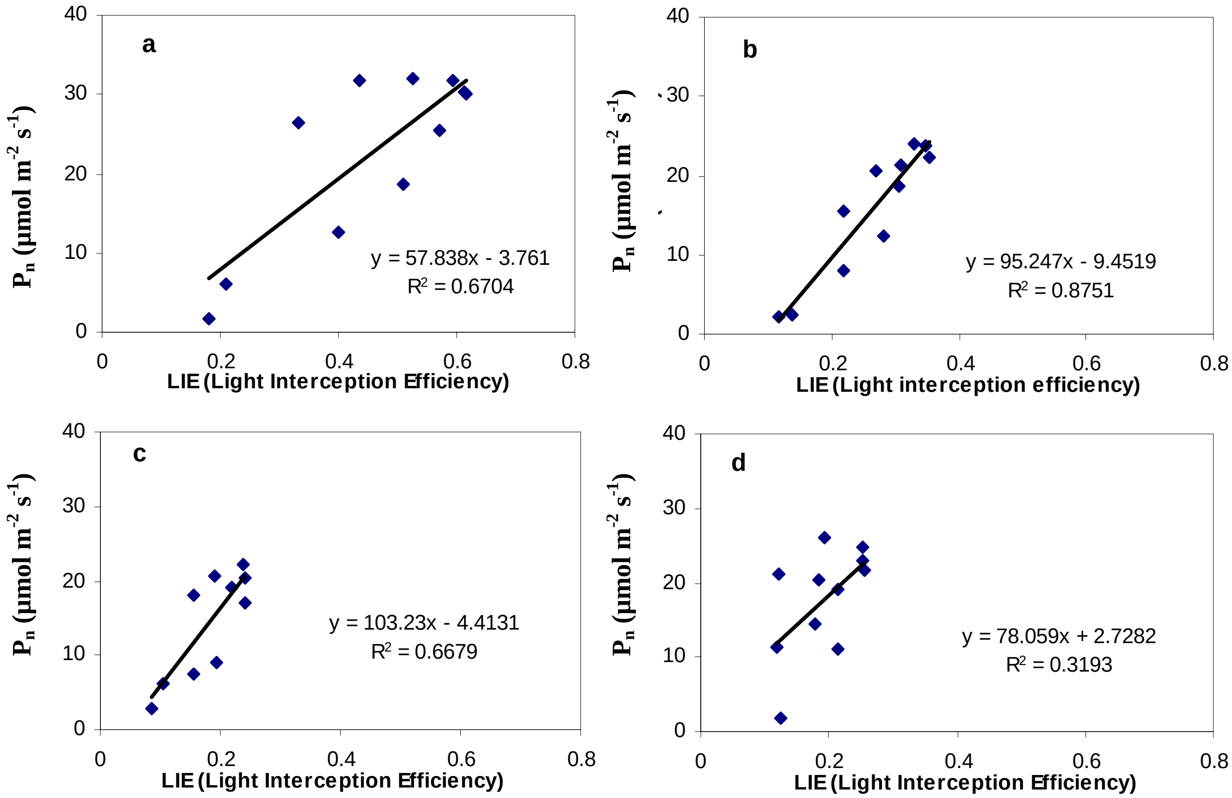


Figure 16 Correlation between the canopy photosynthesis and light interception efficiency of cotton;

(Average P_n rate for every one hour corresponded to LIE in the same period)

(a). Treatment1- Cotton monocropping

(b). Treatment 3- Coton with one mungbean row

(c). Treatment 4- Cotton with two mungbean rows

(d). Treatment 5- Cotton with three mungbean rows alternatively intercropped.

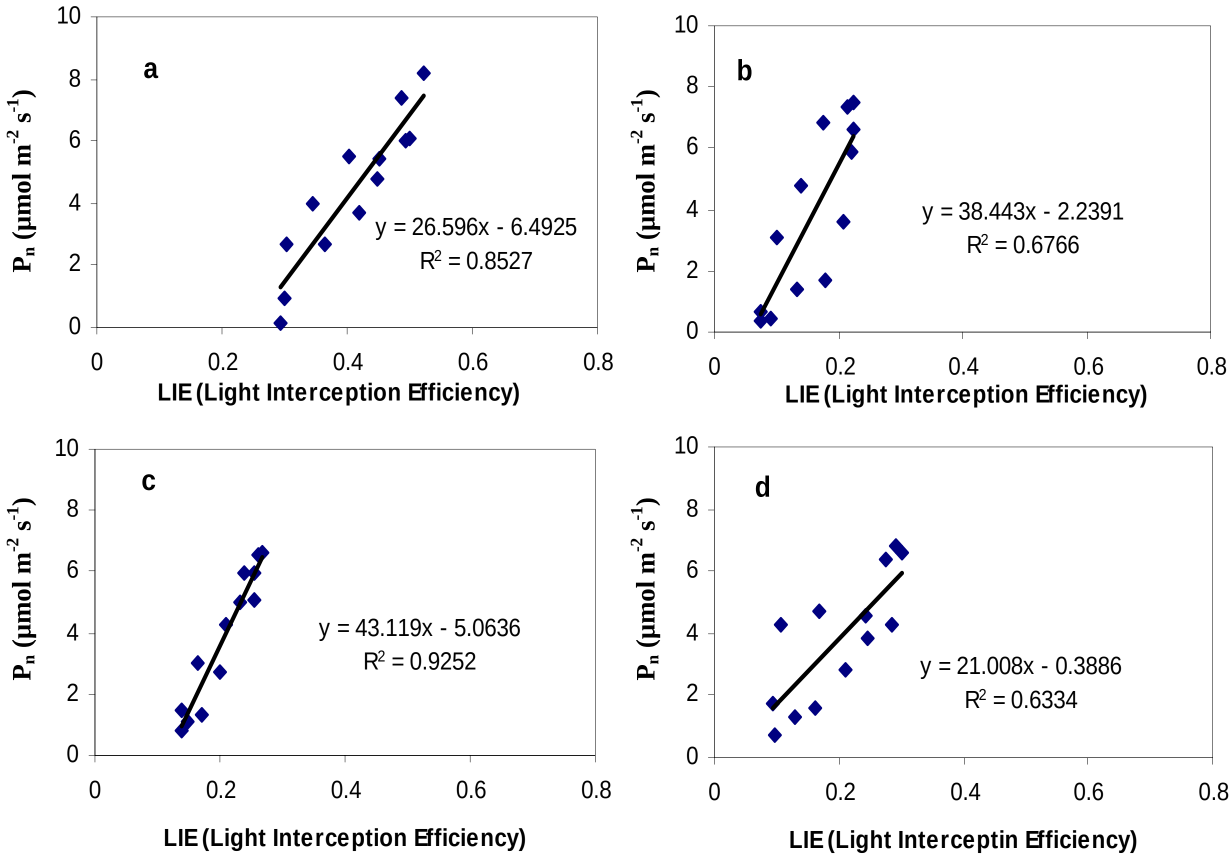


Figure 17 Correlation between the canopy photosynthesis and light interception efficiency of mungbean;

(Average P_n rate for every one hour corresponded to LIE in the same period)

(a). Treatment2 -Mungbean monocropping

(b). Treatment 3 -One mungbean row intercropping

(c). Treatment 4 - Two mungbean rows intercropping

(d). Treatment 5 - Three mungbean rows alternatively intercropped.

Insect diversity was higher in cotton and mungbean intercropping treatments because of more plant population per area. All intercropping treatments have the higher number of beneficial insects. It confirmed the previous information that cotton and mungbean intercropping has higher population of natural enemies (Hy, 1994). It is an important to take considerations of cotton and mungbean intercropping systems with IPM concepts to reduce the insecticide spraying and to help the environment. Mungbean intercropping with cotton could be one of IPM trends to minimize the pesticide usage with biological control by adjusting insect ecology as the beneficial insects would be more abundant in intercropping systems.

Further studies are necessary which emphasis on the concept of beneficial insect, insecticide treatment and intercropping systems. Extra cautions should be take care to decide the insecticide spraying in intercropping systems because beneficial insects are higher in intercropping treatments. The insecticides spraying decision in the intercropping should be done after scouting to reduce the insecticide usage with greater consideration of biological control.

In this study, yield of cotton and mungbean were directly related to photosynthesis (Figure 18) and such an attempt had been made with varying success to correlate photosynthesis and yield in a range of species (e.g. Shimshi and Ephrat, 1975 for wheat and Peet *et al*., 1977 for peas). And our study confirmed the previous studies that that the higher cotton yields were closely associated with photosynthesis rate (Cornish *et al*., 1991 and Philip *et al*., 2000).

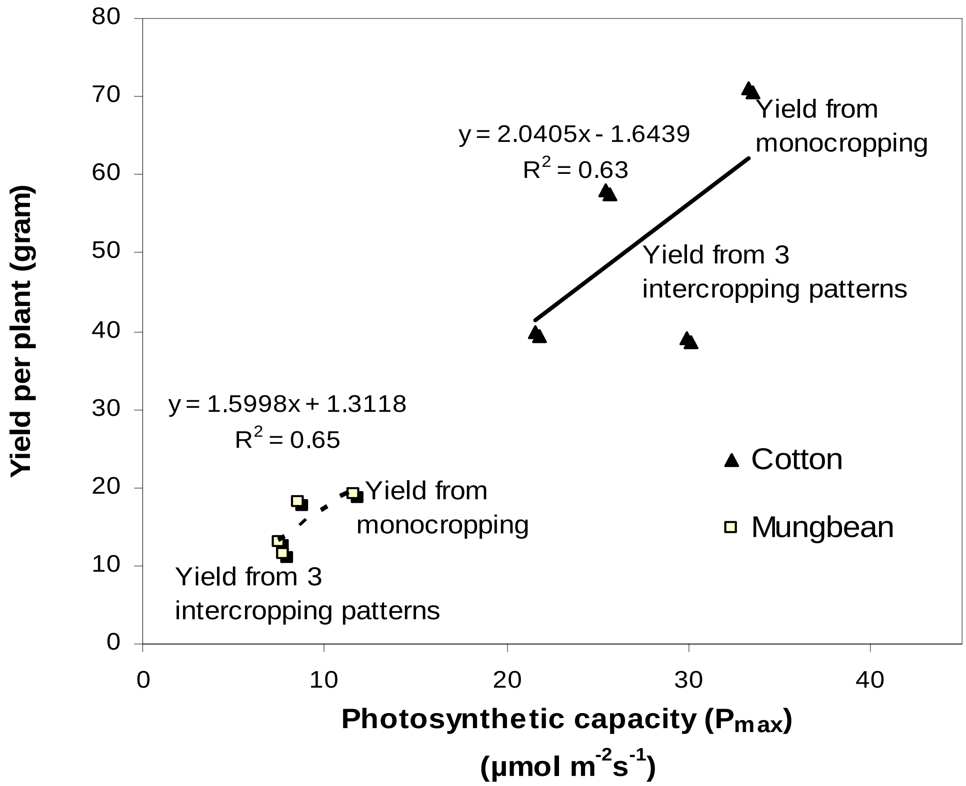


Figure 18 Correlation between yield and photosynthesis of cotton and mungbean.

Seed cotton yield reduction in intercropping treatments was affected by reduction of photosynthesis. Many potential cotton bolls were aborted in squares and young boll stage in intercropping treatments and seed cotton yield was significantly reduced in these treatments. Photosynthesis produces carbohydrate for cotton fruit production (Crozat and Kasemsap, 1998) and Smith and Cothren (1999) also stated that any condition that results in a decrease of available photosynthetic supply will increase square and boll shedding. Yield reduction of intercropped cotton was probably due to less carbohydrate supply from Pn reductions in these intercropping treatments in this study.

The yields from P1 were at higher proportion in all treatments in this study and this information confirms the previous study by Crozat *et al*. (1997) that fruits located on P1 sites survived more than others for cotton cultivar Sri Sumrong 60. Fruit retention of P1 positions was important for getting higher seed cotton yield and therefore careful management to get high fruit retention percentage is essential for getting high yield in intercrop cotton. Planting configuration (spacing and orientation of plant rows) of intercrop species needs careful consideration to prevent the yield losses in intercropping systems.

Though mungbean intercropping reduced the yield of cotton, the over all yield of the two crops gave higher productivity in this study. A significant feature of intercropping was a higher productivity in a given land compared to monocropping in this study. All the intercropping systems had high production efficiencies than monocropping base on LER analyses and T5 gave the highest LER value among the intercropping treatments.

CONCLUSION

The effect of light competition between intercropped cotton and mungbean was investigated in this study. P_n of intercropped cotton was reduced because of less light interception efficiencies in intercropping systems. The results showed that achieving greater P_n was necessary to get greater seed cotton yield. T3 which has only one mungbean row gave the higher seed cotton yield in cotton mungbean intercropping systems. This result showed the seed cotton yield was related to the higher photosynthesis rate which was influenced by light intercepting efficiencies.

Seed cotton yield was mainly from P1 and P2 positions and the fruit retentions of this two fruiting sites are important determination for getting high yield. Cotton yield reduction of intercropping treatments T4 and T5 was caused by severe young bolls and squares abscissions and it was probably due to the less photosynthesis with reduction of carbohydrate supply. Land equivalent ratio values of cotton and mungbean intercropping treatments indicated cotton and mungbean intercropping systems had up to 30% advantages over the monocropping system. Among the intercropping patterns, the pattern 3 (T5) which had 3 mungbean rows alternatively intercropped between the cotton rows had highest LER value.

Though mungbean intercropping reduced the seed cotton yield, the overall yield from the two crops gave the greater overall beneficial cropping patterns. It is possible that the farmers can get the additional income from intercropping cotton with mungbean. Since cotton intercropping with mungbean had the higher number of beneficial insects and therefore mungbean intercropping with cotton could be one of IPM trends to minimize the pesticide usage with biological control by adjusting insect ecology. Cotton production cost can be reduced by mungbean intercropping due to the decrease in insecticide spraying.

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APPENDIX

Estimation of cotton leaf area by using Tree Analyzer and its accuracy from direct method (Li-COR 3100 area meter)

LAI estimation by using direct and indirect method

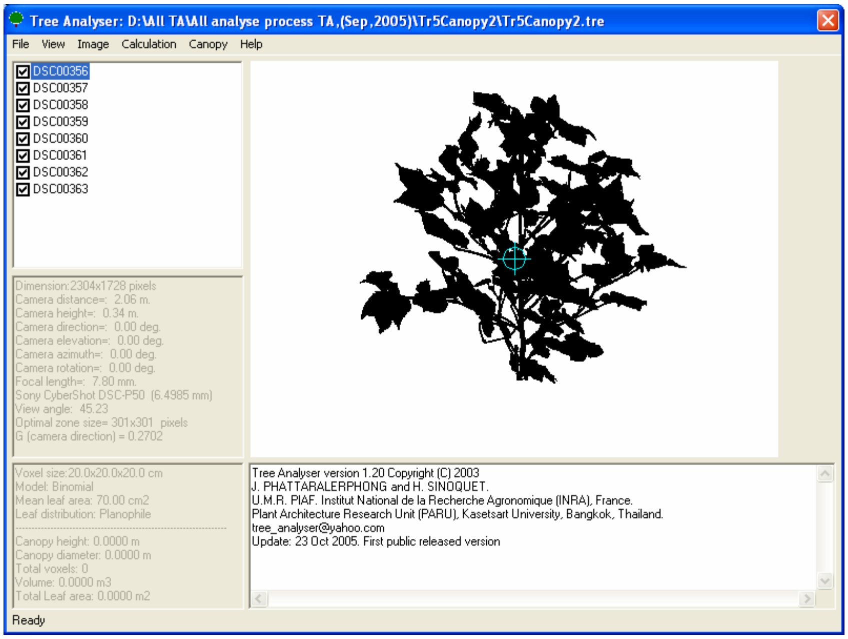
Leaf area index (LAI) of cotton i.e. the unit area of leaves per unit area of soil surfaces, is an important canopy descriptor for plant growth in terms of many physiological aspects. The leaf area of the crops can be measured either directly or indirectly. Direct LAI determinations are time consuming, labor intensive and involving removal of all leaflets. The possible method to obtain LAI value at a high sampling rate or for a larger spatial scale is by analyze the gap fraction, using hemispherical photography or other indirect techniques (Riano *et al*, 2004). LAI 2000 plant canopy analyzer is one of the indirect methods and the applicability of this method for estimating the LAI of several crops was studied by Malone *et al* (2002), Johnson and Pierce (2004). LAI 2000 is designed to be used in diffuse light conditions with either no cloud or complete cloud cover and Coops *et al*. (2004) stated that the threshold used to estimate the sky or non-sky mask was varied according to the sky conditions and was derived subjectively by an operator, there by introducing possible bias. There are certain advantages and disadvantages associated with each method and in this study, Tree Analyzer (TA) which is the new digital photograph method for studying canopy structure parameters was evaluated for cotton leaf area estimation.

Tree Analyzer

Digital image analysis has been used in a variety of novel methods for applied agricultural research (Matthew *et al*., 2000). The software named “Tree Analyzer” for estimating leaf area of the plant by using digital photographs has been developed and it is also an indirect method which base on the inversion of gap fraction (Phattaralerphong *et al*., 2006). Tree Analyzer can be run on Microsoft Windows 98, 2000 or XP (http://www.clermont.inra.fr/piaf/eng/download/download.php). TA had been already proved successful for the estimation of leaf areas of mango, olive, peach, walnut and rubber trees by comparing the leaf area computed from the photos with that of 3 D digitized plants (Phattaralerphong *et al*., 2006). TA was evaluated for cotton plant in this study.

The objectives intended to examine the applicability of this new method for the cotton plant. Twenty four cotton plants from each treatment and replication of cotton intercropping research were tested at two plant ages; 60 Days after planting (DAP) and 90 DAP. The objective of using cotton plants from different patterns were to determine the applicability of TA for cotton plant with different plant size and it was done in two plant ages to identify the effects of the branch area including the cotton bolls and flowers especially at the reproductive growth stage of 90 DAP to the leaf area estimation in cotton plant.

Leaf area meter (Li-COR 3100) was used to compare the results from Tree Analyzer (TA). Tree Analyzer provides not only leaf area, but also canopy structure parameters such as mean leaf area density, plant height, canopy diameters and canopy volume. Moreover it also gives the vertical profile of leaf area which is the amount of leaf area distribution along the each plant height level for each layer. All these canopy structure information are useful for canopy architecture studies. Both leaf area and canopy parameters are important indicators to predict light interception, photosynthesis and biomass accumulation in order to access the cotton yield.



Appendix Figure 1 Software interface of Tree Analyzer.

Taking photographs of cotton plants for TA

The first step was to take the pictures of the plant in the field by using digital camera and Sony digital camera (DSC-P 50) was used in this study. Each photograph had to be documented with camera parameters which are camera angles (elevation and azimuth), camera horizontal distance from the plant, camera height above the plant base, camera focal length and the type of the camera. These parameters are necessary to import in the calculation step. Eight photographs from different view angle of the plant are needed according to the information of the previous study that the mean value from eight photos gives the less error (Phattaralerphong *et al*., 2006).

To get the eight directions view photos, the cotton plant was pulled out and put in artificial stand equipment (plant holder) to hold the cotton plant. This stand was made from iron and it can be turned to give different direction view of the plant to the camera. Base of the stand has the degree numbers to show the plant directions. Taking photographs for TA was done in the morning time to prevent the cotton leaves from wilting. North position of the plant was marked in the field and put at 0 position and assuming that 0 for N, 45 for NW, 90 for W, 135 for S W, 180 for S, 225 for SE, 270 for E, 315 for NE. The camera height and distance were set up from the convenient view to the cotton plant (Appendix Figure 2). Except using the stand for holding the cotton plant in this experiment, all the camera set up were similar to the previous paper (Phattaralerphong *et al*., 2006).

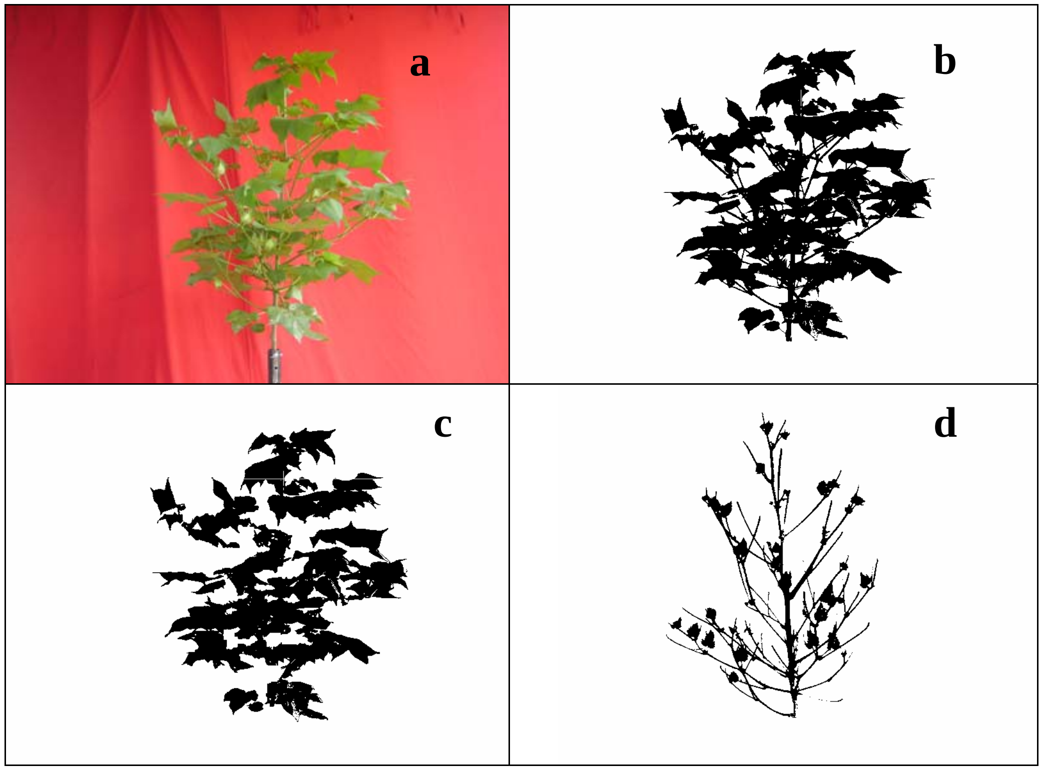
Appendix Figure 2 Taking photographs in Tree Analyzer.

Tree Analyzer's instruction for the camera is to be turned anti-clock wise movement for the isolated trees. In this case as the camera was set up in the fix place, and therefore the cotton plant in the stand was turned to the clockwise direction. The red cloth was used as a background to separate the plant parts easily in the image analyzing processes. Taking photographs had to be done in a short time to avoid the wilting of the cotton leaves. After taking the photos, all cotton leaves were cut for each 20 cm plant height and placed in the plastic bags and kept refrigerated in the laboratory. Within the next day, leaf area was determined by using Li-COR 3100 leaf area meter (Li-Cor Inc., USA) (Appendix Figure 3) at Kamphengsaen campus, Kasetsart University.

Appendix Figure 3 Leaf area measurements by direct method (Li-COR 3100).

Image processing

After getting the photos, the image processing was done in order to separate only the plant parts from the red background. The color parts of the picture (Appendix Figure 4a) were then changed to black and white pictures (Appendix Figure 4b, c, d). The image must have only two colors (black and white) in the format of bitmap file. The first analysis used black and white image after deleting only the red background from the plant parts (Appendix Figure 4b) for area estimation. The second analysis was specifically for cotton leaves by deleting all non-leaf materials (Appendix Figure 4c). The third analysis was for non-leaf areas of the cotton plants including stem, branch, boll and flowers (Appendix Figure 4d). This non-leaf area was then subtracted from the plant area to estimate the leaf area.



Appendix Figure 4 Image processing to black and white bitmap file,
4a; Actual Photograph, 4b; Plant area estimation,
4c; Leaf area estimation and 4d; Non-leaf area estimation.

Adding image with setting parameters

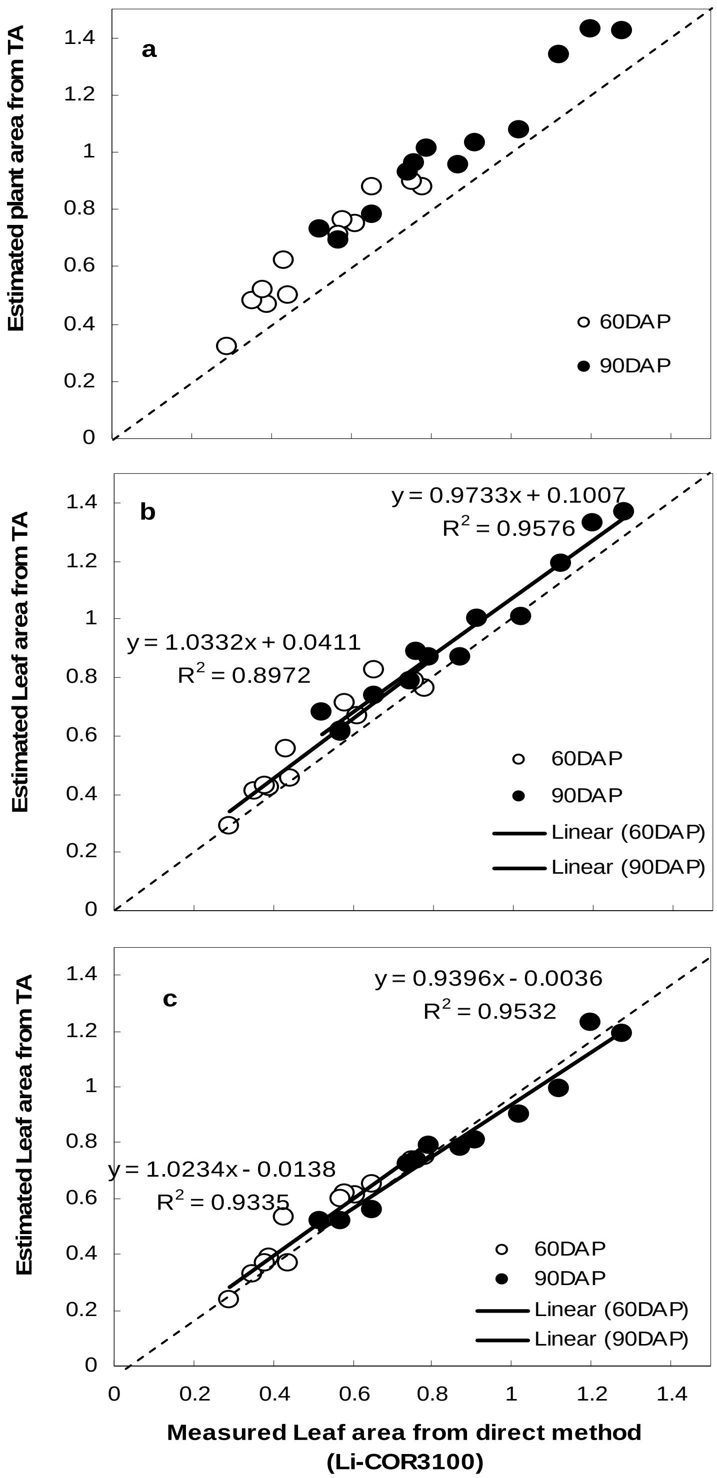
Eight bitmap type images with camera parameters were put to the TA project for calculation by the Software. In this study, mean leaf sizes of 70 cm^2 for 60 DAP and 80 cm^2 for 90 DAP was used. The mean leaf inclination was estimated from digitized image of cotton plant which was done in the morning time because the TA photograph of cotton plant was also done in the morning. Therefore, the leaf inclination value from the result of the digitizing could be used in TA and it should not have effects by the cotton leaf inclination changes during the day time. Leaf area estimation by TA was done in two ways which are by using the mean leaf inclination values getting from digitizing data and by choosing planofile leaf inclination type in the calculation of software interface because foliage inclination of Sri Sumrong 60 variety was mostly planofile (i.e., with leaf inclinations between 0 and 30) (Thanisawanyangkura *et al*, 1997).

The models of Beer's law or Positive binomial law can be chosen to relate the gap fraction in Tree Analyzer. Positive binomial law was used in this study because beers law is for the leaves which are finitely small and randomly dispersed in the canopy.

Results from TA

The results from TA and from the leaf area meter method at 60 DAP and 90 DAP are compared. TA gave some overestimated values than leaf area meter method in the first analysis (Appendix Figure 5a). But after deleting the non-leaf materials from the image in the second analysis, these over estimation values are significantly reduced. The high positive correlation (r^2 = .90 for 60 DAP and r^2 = .96 for 90 DAP) were observed between the two methods (Appendix Figure 5b).

The non-leaf area was subtracted from the cotton plant area to estimate the cotton leaves areas. The value from this method gave high positive correlation with values from direct method (r^2 = .93 for 60 DAP and r^2 = .95 for 90 DAP) (Appendix Figure 5c). The non-leaf areas accounted for approximately 17% to 27% of plant areas (Appendix Table 1). Cotton leaf areas calculated from the two types of leaf inclination (from mean leaf inclination of digitized data and planofile distribution) were similar (Appendix Figure 6). In addition, TA gave the leaf area distribution pattern of cotton plant (the vertical profile of the leaf areas) which was similar to direct method (Appendix Figure 7).



(a). Cotton plant area from first analysis after deleting only the red background,

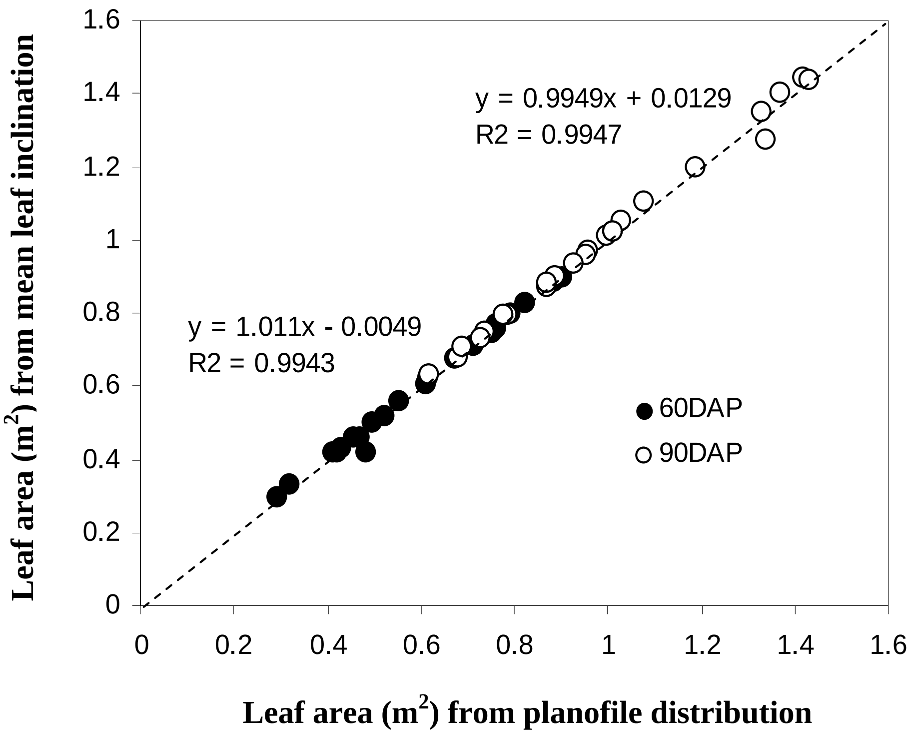
(b). Cotton leaf area from second analysis after deleting all non-leaves material,

(c). Cotton leaf area by subtracting the non-leaf areas from the plant area.

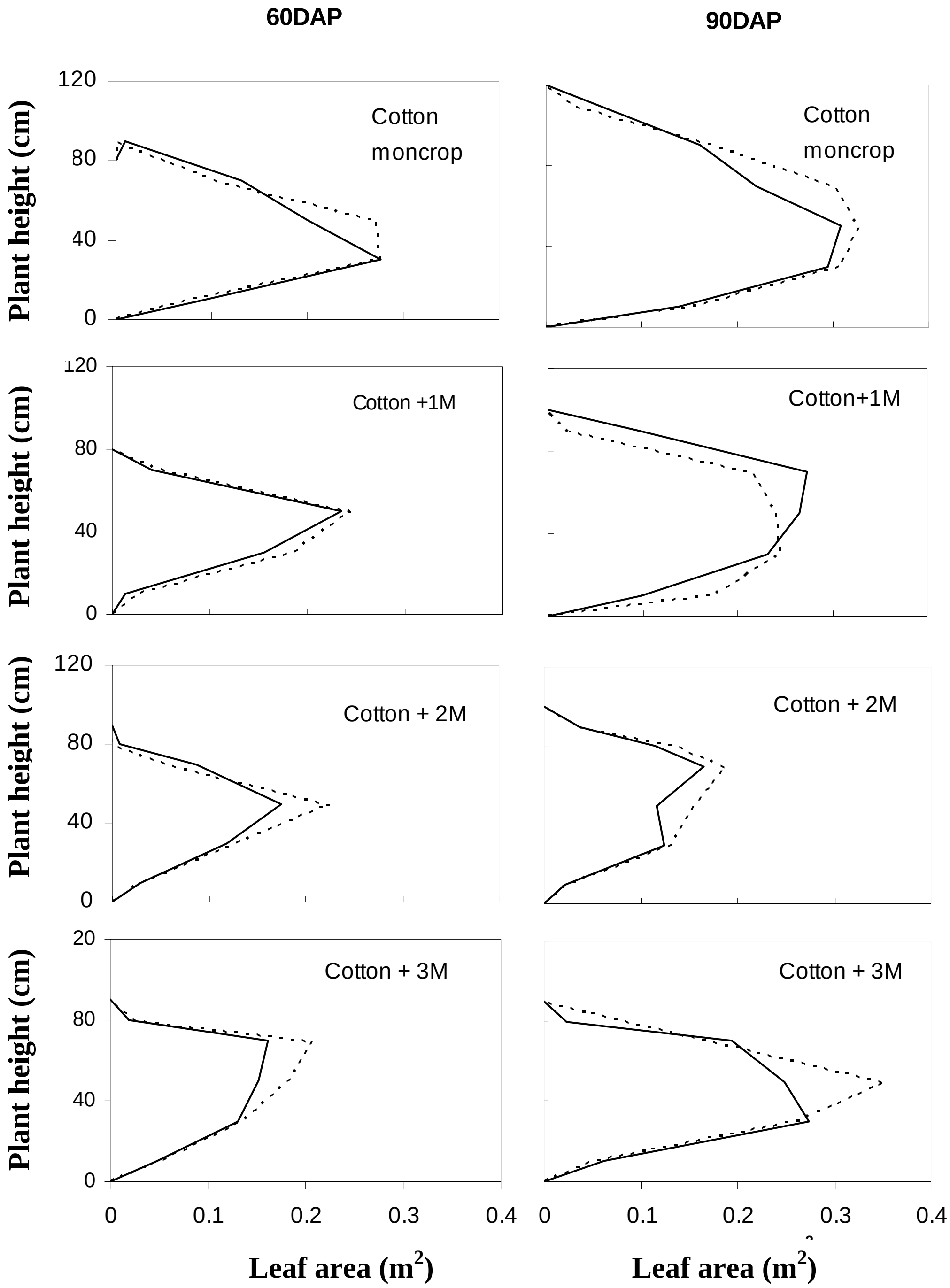
Appendix Figure 5 The comparison between the estimated leaf areas between Direct method and Tree Analyzer method in three analyses.

Appendix Table 1. Non-leaf area contribution to the leaf area of cotton plants in each plant age.

Plant age	Cotton from different patterns	Plant area (m^2)	Non-leaf area (m^2)	Contribution of non-leaf area (%)
60 DAP	Cotton monocrop	0.84	0.14	17
	Cotton + 1M	0.57	0.12	21
	Cotton + 2M	0.52	0.11	21
	Cotton + 3M	0.67	0.15	22
90 DAP	Cotton monocrop	1.40	0.26	19
	Cotton + 1M	1.02	0.21	21
	Cotton + 2M	0.73	0.20	27
	Cotton + 3M	0.99	0.20	20



Appendix Figure 6 Leaf areas estimated from planofile leaf inclination correlated well to values estimated using mean leaf inclination of digitized data.



Appendix Figure 7 Vertical profile of leaf area in 20-cm layers for cotton plant from each treatment; Comparison between the photographic method (dotted line) and the direct method (solid line)

Evaluation of TA for cotton

From cotton plant image Tree Analyzer estimated the cotton plant area and one may use the term plant area index instead of leaf area index. This plant area index overestimates LAI because of stem, flowers and bolls besides the leaf material exit in the image. For leaf area index, therefore all the non-leaf materials have to be deleted from the image. Otherwise, estimation of non-leaf area and subtracting it from the plant area will provide the leaf area estimation. For practical usage, the leaf area estimation done by deleting the non-leaf materials in image processing step will be more convenient for the users. If the background separation could be done by using some special software, it will be much more convenient. One can use planofile type leaf inclination as mean leaf inclination value. This will be useful and convenient way for the users if digitizing tools are unavailable.

If the researchers need to monitor LAI along the growing season, Tree Analyzer can be used for isolated plants. For the experiments with potted plants, TA allows the measurement of the same plants several times during the growing period. But in the case of this cotton field condition, the cotton plants are grown within the rows in the field and it is not convenient to take the photographs from different directions in the field, and so the plant had to be pulled out and put in the artificial stand.

This new digital photograph method is useful for many purposes as it can apply to study not only the leaves area but also canopy structures by using only the digital photographs. Normally measurements of the complete parameter set for canopy architecture studies need the graphical model with digitizing the plant in the field which is labor intensive. In TA, within 2 to 3 minutes run time, the output data of the images were resulted and therefore for field application, Tree Analyzer will be fast, inexpensive and simply method for plant architecture studies.

CONCLUSION

High correlation between the photograph method and direct measurement by leaf area meter method was observed. Planofile distribution type of leaf inclination gave the same results for cotton plant as the mean leaf inclination of digitized data. Cotton plants with different leaf area from monocropping and different intercropped patterns were tested and TA could be applied for cotton in all different plant size studied. The results of this study indicated that Tree Analyzer photograph method could be applied for cotton leaf area estimation.

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CURRICULUM VITAE

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From 1997 to 1998, she had been attended of post graduate studies in Israel Arava International Center for one year agricultural training course. After completing this studying, Mrs. Phyoe continued her full responsibility under MCSE; especially to upgrade the farmer's rural life by providing the agricultural extensions works. By the collaborations between Thai government and Myanmar government in 2004, she got the scholarship for her master degree to study in Kasetsart University which is Thailand's university of agriculture.

During studying in Kasetsart University, she gave a seminar on 26th August 2005 on the subject of "Traditional Myanmar Culture" and she was also completed in a training workshop of Product Development from Peanut from 6 to 17 March, 2006. She did publication paper concerning her Thesis works to distribute the information and knowledge for cotton growing farmers. She successfully completed her master degree in the first semester of 2006.

Mrs. Phyoe was married in 1999 and her husband is Major Zaw Min Oo (North – West Command) and they have one son named Mg Nobel Oo.

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