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Original article

Effects of Thailand and Sri Lanka agronomic practices on mungbean (*Vigna radiata* (L.) Wilczek) production in rice-based cropping system

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ABSTRACT

The effects of agronomic practices were evaluated on mungbean production, using a randomized complete block design conducted at the Farming Research Development Center, Phaniat sub-district, Khok Sumrong district, Lop Buri province, Thailand during February to July 2015. Five agronomic practices (each with four replications) were tested—Thai farmer practice (TFP) as the control; Thailand recommendation (TR); Sri Lankan farmer practice (SLFP); Sri Lankan new recommendation (SLNR); and Thailand recommendation with paddy straw mulch (TRM)—each practice was composed of different tillage methods, seeding rates, mulching and seed inoculation (with *Rhizobium*). At the maturity stage, the lowest height (38.04 cm) was found in TFP compared to 78.8%, 56.6%, 31.5% and 20.8% height increases reported in TRM, SLNR, SLFP, and TR, respectively. Furthermore, TFP had the lowest leaves per plant at maturity (8.73), whereas the percentage of leaves per plant at maturity in TR, SLFP, SLNR and TRM was 20.9%, 27.4%, 33.1% and 60.1%, respectively, higher than in TFP. TFP produced the lowest yield (0.657 t/ha) while TRM, TR, SLFP and SLNR which produced increased yields by 109.13%, 41.4%, 46.1% and 86.8%, respectively, compared to the control. Overall, the results showed that the method of tillage, mulching and inoculum collectively determined the growth and seed yield of mungbean in a rice-mungbean cropping system.

Introduction

A cereal-legume cropping system is very often adopted because it provides cheap sources of energy and protein (International Institute of Tropical Agriculture, 2016). Mungbean (*Vigna radiata* L.) is an important legume crop in Asia and a major component in many cropping systems (Asim et al., 2006). Mungbean seeds contain 20–25% protein, 1.0–1.2% fat and are rich in vitamins, such as A, B1, B2, C and niacin and minerals, such as potassium, phosphorous and calcium (Prabhavat, 1987); thus they serve as a valuable nutrient source for human consumption.

A rice-mungbean cropping system is not a novel introduction in either Thailand or Sri Lanka and technical appropriateness is very important among other factors (socio-cultural, economic, agro ecological) influencing the sustainability of the cropping system (Willem, 2015). The current study focused on a comparative analysis of the effects of the agronomic practices of both countries (different tillage systems, different seeding rates, seed inoculation and mulching) on overall sustainability.

Among crop management practices, the seeding rate or plant population greatly affects crop growth and finally the seed yield (Riaz et al., 2004). Seeding rates recommended by the two countries (18 kg/ha and 20 kg/ha in Thailand and Sri Lanka, respectively) were used for the experiment.

The tillage process affects various physical changes in crop land. This operation loosens, granulates, crushes or compacts the soil structure, changing soil properties, such as bulk density, pore size distribution and the composition of the soil atmosphere that all affect plant growth (Opara-Nadi, 1993). Different pieces of land preparation equipment, such as a disc plow or rotavator create a different physical soil structure. For land preparation, a 3-disc plow followed by a 7-disc plow is recommended in Thailand, but usually,

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farmers use a 3-disc plow (Field and Renewable Energy Crops Research Institute, 2014). In Sri Lanka, a rotavator is recommended for initial land preparation in the rice-mungbean cropping system (Department of Agriculture, 2006). Regardless, soil types and their various reactions to tillage are of paramount importance in determining the superiority of one practice over the other (Ofori, 1993).

The efficient use of remaining soil moisture for the mungbean crop is one of the major targets of the cropping system. Mulching with paddy straw is practiced in Sri Lanka (Department of Agriculture, 2006), while in Thailand this is not practiced very often (Field and Renewable Energy Crops Research Institute, 2014). However, mulching helps to conserve soil moisture by increasing percolation and retention, reducing evaporation and reducing weeds (Chalker, 2007). Ogban et al. (2008) observed that tillage reduced the soil bulk density, but that soil infiltration increased only when tillage and mulching were combined.

Rhizobium spp. invades the root hairs of mungbean and result in the formation of nodules, where free-air nitrogen is fixed (Ahmed et al., 2006). Thailand's establishment package includes adding inoculum, since it has been argued that usually, native soil rhizobial populations are inadequate and are ineffective in biological nitrogen fixation (Ahmed et al., 2006). However, this is not included in Sri Lanka (Department of Agriculture, 2006). The current study paid attention to evaluating the effect of adding inoculum on mungbean production.

Thus, the current study emphasized investigation of the effect of agronomic practices on mungbean production in a rice-based cropping system and their appropriateness for sustainability.

Materials and methods

The field experiments were conducted over two seasons at the Farming Research Development Centre (FRDC), Phaniat, Lop Buri province in Thailand to identify the effects of Thai and Sri Lankan agronomic practices on mungbean production in a rice-based cropping system. The first experiment was carried out during February–May 2015 and the second was during May–July 2015.

Five agronomic practices were tested for crop growth and yield (Table 1). The experiment was laid out in a randomized complete block design with four replications. Each treatment plot was 20 m × 20 m and was divided into four blocks each with an area of 100 m^2.

The mungbean variety, Chai-Nat 84-1 was used with a *Rhizobium* mungbean strain for inoculation. Land preparation was done using a 4-wheeled tractor with relevant tillage tools (Table 1). A sprinkler irrigating system was installed for irrigation at crop establishment and all treatments were irrigated evenly. Paddy straw from previous rice cultivation and from a commercial supplier was used. No inorganic or organic fertilizer was used and the initial soil nutrient conditions were tested in each plot treatment using a Kasetsart University soil testing kit before establishing the experiment. Standard crop management practices, such as weeding, irrigating and plant protection measures were done as required.

The plant height, leaf number per plant and leaf appearance rate (LAR) were measured as growth data at five growth stages—early vegetative (EV), late vegetative (LV), flowering (FL), pod filling (PF) and maturity (MT)—while the number of pod-bearing plants per square meter, number of pods/plant, number of seeds per pod and 1000 seed weight were obtained as yield data using 15 randomly selected plants in each replicate. Variation in the standing count and weed infestation in a 1 m^2 area were also measured at 2 wk after sowing among the agronomic practices. No disease symptoms were observed during the growth seasons except for an aphid (*Acyrthosiphon pisum*) infestation (controlled chemically) and weed control was undertaken by hand. Meteorological data during the growth season (February–July 2015) was obtained from the FRDC. Collected data were analyzed using the SPSS statistical software (SPSS Inc.; Chicago, IL, USA) by ANOVA and means were compared using Duncan's multiple range test at the 5% probability level.

Results and discussion

Soil nutrients

The soil testing reports showed that the pH was in the range 4.0–5.6, the organic matter percentage was 1–0.6% (very low) and the average composition of sand, silt and clay was 73%, 18% and 9%, respectively, which was categorized as a “sandy loam”. Ammonium and phosphorous levels were very low, while nitrate and potassium were at medium and low levels, respectively, in all treatment plots.

Standing count

The tested agronomic practices showed different results for the standing count at 2 wk after sowing and the highest (23.15/m^2) was reported in SLNR (Table 2), which was 98.1% of the estimated count

Table 2
Standing count at 2 wk after sowing for different agronomic practices.

Practice	Number of plants/m^2
Thai farmer practice (TFP)	16.50[b†]
Thailand recommendation (TR)	16.68[b]
Sri Lanka farmer practice (SLFP)	20.50[ab]
Sri Lanka new recommendation (SLNR)	23.15[a]
Thailand recommendation with mulching (TRM)	16.93[b]
F test	*
Coefficient of variation (%)	10.60

†Means with same lowercase superscripts are not significantly different at $p < 0.05$ by Duncan's multiple range test.
‡ * = significant different at $p < 0.05$.

Table 1
Agronomic practices applied in different plots to test appropriate combinations.

Treatment[a]	Practice	Combination of agronomic practices			
		Tillage tool used	Seed rate (kg/ha)	Inoculation (200 g/3 kg of seed)	Mulching with paddy straw (2 t/ha)
TFP	Thai farmer practice	7-Disc plow	18	NA[b]	NA
TR	Thailand recommendation	3-Disc plow & 7-disc plow	18	AP[b]	NA
SLFP	Sri Lanka farmer practice	Rotovator	20	NA	AP
SLNR	Sri Lanka new recommendation	Rotovator	20	AP	AP
TRM	Thailand recommendation with mulching	3-Disc plow & 7-disc plow	18	AP	AP

[a] TFP = Thai farmer practice; TR = Thailand recommendation; SLFP = Sri Lanka farmer practice; SLNR = Sri Lanka new recommendation; TRM = Thailand recommendation with mulching.
[b] NA = not applied; AP = applied.

Table 3
Estimated seedling count of seed stock at two different seed rates used in field experiment.

If germinate all seeds in the stock[a] (80% germination)	Number of plants/m^2	
Estimated standing count	At seed rate of 18 kg/ha 21.23	At seed rate of 20 kg/ha 23.59

[a] Measured weight of 1000 seeds in seed stock is 67.8 g.

(Table 3). Furthermore, the standing counts of TFP, TR, SLFP and TRM were 77.7%, 78.6%, 86.9% and 79.7% of the estimated seedling counts, respectively.

Weed infestation

The emergence of weeds showed little difference among practices. Lower weed infestation was observed in mulched SLFP, SLNR and TRM and the weed coverage was 0–20% of the land area. Practices tested without mulch (TFP and TR) showed comparatively higher (21–40%) weed infestation (Table 4). The magnitude of yield losses in mungbean caused by weeds depends mainly on the weed species and their densities (Chattha et al., 2007). Hence, the comparatively high weed density in TFP and TR might have affected the growth and yield. In this study, mulching showed a positive effect on reducing weed emergence irrespective of the method of land preparation. Furthermore (Chalker, 2007) reported that using mulch for weed control is highly effective and it can reduce the seed germination of many weed species and it also reduces light, which stresses existing weeds.

Plant height

The results showed that the agronomic practices differed significantly regarding plant height at the different growth stages except for the vegetative stages (Table 5). There was a significant increase due to mulching within TR and TRM at the FL, PF and MT growth stages by 45.7%, 37.0% and 48.1%, respectively. The plant height difference between SLFP and SLNR at TM showed the effect of inoculum (a 19.1% increase), compared to SLFP. Since there were no significant differences among TFP and TR nor for SLNR and TRM (except for the MT stage), it was difficult to identify any direct effect of the tested tillage practices on plant height, but many studies have commented on the effect of different tillage methods on growth and yield, when the only treatment was different tillage methods (Abdipur et al., 2012; Aikins et al., 2012). However, a combined effect of tillage and mulching was highlighted. These results were comparable to Polthanee and Wannapat (2000) who reported significant differences among soybean cultivation options.

Number of leaves

The number of leaves per plant is directly related to the leaf area per plant and the final dry matter weight of shoots (Prasad et al., 1989 cited by Ranawake et al., 2011). Hence, in terms of the number of leaves, the lowest number at each growth stage was reported in TFP, showing comparatively poor growth, which resulted in lower plant height and fewer leaves which might lead to a lower seed yield, while the highest number of leaves was in TRM. Aikins et al. (2012) reported that the combination of disc plowing followed by disc harrowing, produced a higher number of leaves per plant compared to a disc plowing only treatment, while the no-tillage option produced the lowest number of leaves per plant. This is supported by the results obtained in the current study, though the tillage methods were slightly different. Furthermore, the results showed the number of leaves significantly differed between mulched and unmulched practices up to the flowering stage irrespective of the method of tillage.

Mulching produced a positive response in TRM and it increased the number of leaves by 32.5% over TR at MT. Mulching helps to conserve water, reduces moisture losses and maintains good growth as well as improving seed germination and seedling survival, enhancing root establishment and transplant survival and increasing plant performance when compared to an unmulched treatment (Chalker, 2007). A similar pattern was reported by Polthanee and Wannapat (2000).

The effect of inoculum on the number of leaves per plant was not clear between SLFP and SLNR.

Table 4
Weed infestation in different agronomic practices at 2 wk after sowing.

Practice	Rank[a]
Thai farmer practice (TFP)	2
Thailand recommendation (TR)	2
Sri Lanka farmer practice (SLFP)	1
Sri Lanka new recommendation (SLNR)	1
Thailand recommendation with mulching (TRM)	1

[a] Ranking based on percentage of weed cover in 1 m^2; 1 = (very low) = 0–20%; 2 = (low) = 21–40%; 3 = (fair) = 41–60%; 4 = (high) = 61–80%; 5 = (very high) = 81%–100%.

Leaf appearance rate

A similar trend was observed in the leaf appearance rate (LAR) resulting in the lowest value being in TFP and the highest in TRM except in the late vegetative stage. However, the tested agronomic practices showed highly significant differences ($p < 0.01$) in the mean number of leaves per plant and in the LAR in every growth stage. The higher the value of LAR, the lower the number of days taken to produce leaves. No effect of tillage was observed but mulching showed a significant difference in LAR between TR and TRM in all growth stages.

Seed yield

The ultimate objective in mungbean production is the economic yield (seed yield). Yield and yield attributes of mungbean measured in the study were the number of pods per plant, the number of seeds per pod, and the 1000 seed weight. The seed yield is governed by many genetic factors as well as environmental factors that are interdependent (Huseyin and Cengiz, 2014). There were significantly differences in some of the seed yields from the different agronomic practices (Table 6).

The grain yield per unit area is a function of the yield of individual plants and the population density. Both the yield and yield attributes are markedly influenced by the population density (Jahan and Abdul, 2004). However, the current results showed no statistical significance for the number of pod-bearing plants at the harvesting stage among practices. Furthermore, the results showed that the productive plant percentage from the initial standing count was 74.6%, 80.9%, 70.7%, 63.9% and 81.5% (calculated with data from Table 2) in TFP, TR, SLFP, SLNR and TRM, respectively. TRM produced a 58.6% increase in the number of pods per plant compared to TR,

Table 5
Growth characters of mungbean in response to five agronomic practices.

Parameter	Practice[†]	Growth stage[‡]				
		EV	LV	FL	PF	MT
Plant height (cm)	TFP	11.76	14.61	27.30[d]	36.63[d]	38.40[d]
	TR	11.93	15.35	31.46[cd]	43.48[cd]	45.94[cd]
	SLFP	10.94	14.51	37.39[bc]	47.22[bc]	50.03[c]
	SLNR	11.21	17.21	44.70[ab]	54.43[ab]	59.58[b]
	TRM	12.33	17.54	45.82[a]	59.58[a]	68.02[a]
	CV (%)	5.93 ns[‖]	10.69 ns	13.57**[‖]	13.16**	10.13**
Number of leaves/plant	TFP	2.95[b§]	4.08[c]	7.00[c]	7.87[d]	8.73[d]
	TR	3.02[b]	4.45[c]	7.20[c]	9.52[c]	10.55[c]
	SLFP	3.27[a]	4.88[b]	9.10[b]	10.47[bc]	11.12[bc]
	SLNR	3.38[a]	5.22[ab]	9.80[b]	11.02[b]	11.62[b]
	TRM	3.48[a]	5.40[a]	11.03[a]	12.95[a]	13.98[a]
	CV (%)	4.50**	5.68**	7.70**	6.46**	5.75**
Leaf appearance rate (Number of leaves/plant/day)	TFP	0.210[c]	0.100[e]	0.110[c]	0.120[d]	0.125[d]
	TR	0.215[bc]	0.118[d]	0.130[c]	0.153[c]	0.153[c]
	SLFP	0.233[ab]	0.130[c]	0.170[b]	0.173[b]	0.163[bc]
	SLNR	0.240[a]	0.173[a]	0.178[b]	0.185[b]	0.165[b]
	TRM	0.250[a]	0.155[b]	0.205[a]	0.210[a]	0.195[a]
	CV (%)	3.48**	2.62**	3.13**	4.51**	3.52**

[§]Means in the same column for each parameter with same lowercase superscript are not significantly different at $p < 0.05$ by Duncan's multiple range test.
[‖]ns = not significantly different at $p < 0.05$; ** = significantly different at $p < 0.01$.
[†]TFP = Thai farmer practice; TR = Thailand recommendation; SLFP = Sri Lanka farmer practice; SLNR = Sri Lanka new recommendation; TRM = Thailand recommendation with mulching; CV = coefficient of variation.
[‡]EV = early vegetative; LV = late vegetative; FL = flowering; PF = pod filling; and MT = maturity.

Table 6
Yield and yield components of mungbean from five agronomic practices.

Practice	Yield component				Yield	
	Number of pod-bearing plants/m^2	Number of pods/plant	Number of seeds/pod	1000 seed weight	g/3 m^2	t/ha
Thai farmer practice (TFP)	12.3	9.33[d†]	8.57	66.21	197.21	0.657[c]
Thailand recommendation (TR)	13.5	9.80[d]	8.95	70.15	278.91	0.929[b]
Sri Lanka farmer practice (SLFP)	14.5	11.14[c]	8.82	67.01	288.07	0.960[b]
Sri Lanka new recommendation (SLNR)	14.8	13.54[b]	8.51	68.48	388.11	1.227[a]
Thailand recommendation with mulching (TRM)	13.8	15.54[a]	8.83	66.86	412.05	1.374[a]
Coefficient of variation (%)	17.82 ns[‡]	6.43**[§]	3.00 ns	2.84 ns	14.3**	14.070**

[†]Means in the same column for each parameter with same lowercase superscript are not significant different at $p < 0.05$ by Duncan's multiple range test.
[‡]ns = not significant different at $p < 0.05$.
[§]** = significant different at $p < 0.01$.

perhaps because of the mulching, while comparing SLFP and SLNR, inoculation increased the number of pods per plant by 21.5%. However, the findings of (Ahmed et al., 2006) did not show any significant impact of inoculation alone on the biological yield.

The highest seed yield (1.374 t/ha) was obtained from TRM and the lowest (0.657 t/ha) was recorded from TFP. The calculated difference in the seed yield between TR and TRM of 0.445 t/ha clearly showed the effect of mulching and the yield increase was 47.9%. The yield increase of 0.267 t/ha between SLNR and SLFP reflected the lesser effect of inoculation.

Ranking according to the performance of each practice showed the collective effect of agronomic practices on field adoptability, crop growth and final seed yield (Table 7).

Comparing the yield and yield components, the ranked observations in order (from highest performance to lowest) were TRM, SLNR, SLFP, TR and TFP. Furthermore, with regard to plant growth, TRM ranked the lowest, while the highest was TFP. Higher field adoptability at the initial stage was observed in mulched practices; hence, the poorest ranking occurred in TR and TFP. However, the highest overall performance was observed in TRM and the lowest was in TFP while SLNR, SLFP and TR were ranked second, third and fourth, respectively.

Soil tillage using a 3-disc plow and a 7-disc plow in TRM favorably modified the physical properties, especially porosity. The increase in porosity immediately resulted in improved development of the root system and thus, better growth resulted in a significant increase in yield (Aikins et al., 2012). The main objective of introducing paddy straw to the cropping system is to conserve soil moisture. Thus, mulching could be expected to increase soil water by increasing percolation and retention, reducing evaporation and

Table 7
Ranking of overall performance of the tested agronomic practices.

Parameter	Ranking of performance[a]				
	TFP[b]	TR[b]	SLFP[b]	SLNR[b]	TRM[b]
Standing count	3	3	2	1	3
Weed infestation	4	4	1	1	1
Plant height	5	4	3	2	1
Number of leaves/plant	5	4	2	2	1
Leaf appearance rate	5	4	2	2	1
Pods bearing plants/m^2	5	3	1	1	3
Number of pods/plant	5	4	3	2	1
Seeds/pod	1	1	1	1	1
1000 seed weight	5	1	3	2	4
Yield	5	4	3	2	1

[a] Rankings from 1 (highest performance) to 5 (lowest performance).
[b] TFP = Thai farmer practice; TR = Thailand recommendation; SLFP = Sri Lanka farmer practice; SLNR = Sri Lanka new recommendation; TRM = Thailand recommendation with mulching.

as an additional benefit, reducing weeds might minimize the competition for plant nutrition. Furthermore, *Rhizobium* might act positively with the prevailing soil conditions; hence, TRM showed overall better growth and the highest yield, not because of one factor but from the combined effect of tillage, mulching and inoculation as an agronomic package.

Conflict of interest

The authors declare that there are no conflicts of interest.

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