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IS DEEP SOWING BENEFICIAL FOR DRY SEASON CROPPING WITHOUT IRRIGATION ON SANDY SOIL WITH SHALLOW WATER TABLE?

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SUMMARY

Deep sowing (15 cm) on sands in the dry season is a practice used in post-rice sowing of legumes without irrigation, designed to increase moisture access for germination, growth and crops yield. However, with such deep sowing there can be a penalty for emergence and growth if there is abundant water stored in the upper soil profile during the growing season. Hence, there is a need to define the soil water regimes under which deep sowing is advantageous for different legumes. To investigate the adaptation of legume crop species to deep sowing, we studied their emergence, growth and yield on three deep soils (3–16% clay) with shallow water tables during two years in northeast Thailand. At site 1 and 2, peanut, cowpea, mungbean and soybean were sown shallow (∼5 cm) or deep (∼15 cm). At site 3, only cowpea and peanut were shallow or deep sown. Shallow water tables maintained soil water content (0–15 cm) above permanent wilting point throughout the growing season. Deep sowing of all legumes delayed emergence by 3–7 days at all locations. Shoot dry weight of legumes after deep sowing was mostly similar or lower than weight after shallow sowing. Yield and harvest index of legumes did not differ meaningfully among sowing depths. Therefore, deep sowing was not beneficial for dry season cropping without irrigation when there was a shallow water table and sufficient water for crop growth throughout soil profiles in the growing season. Taken together with previous studies, we conclude that shallow rather than deep sowing of legumes was preferred when the soil water content at 0–15-cm depth remained higher than permanent wilting point throughout the growing season due to shallow water table.

INTRODUCTION

In the dry season of the semi-arid tropics, land with a standing water table is able to grow some field crops without irrigation. Such land commonly occurs in the rice-based lowlands in Thailand (Jintrawet *et al.*, 1983; Polthanee, 1991), Nigeria (Adigbo *et al.*, 2007), Bangladesh (Hassan *et al.*, 2003), India (Kar and Kumar, 2009), Indonesia and the Philippines (Rahmianna *et al.*, 2000; So and Ringrose-Voase, 2000). Success of dry season cropping depends largely on crop establishment and the subsequent availability of soil moisture (Zandstra, 1982). The amount of water potentially available to dry season crops depends on both the amount of stored soil moisture at sowing plus

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additions from rainfall or capillary water rising from a shallow water table (Kerdsuk, 1986; Logsdon *et al.*, 2009).

Previous studies on dry season cropping suggested that peanut seeds should be sown deeply (10–15 cm) in the field when the water table gradually receded downward in the soil profile and topsoil (0–15-cm depth) dried out very quickly to below permanent wilting point (PWP) late in the growing season (Chantron, 1983; Kerdsuk, 1986; Khongmorn, 1994; Polthanee, 2001). Polthanee (2001) indicated that peanut after deep seeding (15 cm) in the dry season with a shallow water table gave highest leaf area index (LAI), dry matter and seed yield because of the greater root length density in the deep soil layer. Sowing deeply may enhance establishment because of higher soil moisture content around the seed and lead to better germination and emergence of seedlings (Mahdi *et al.*, 1998; Schillinger *et al.*, 1998). Since soil moisture generally increases with depth, deeper planting may ensure an adequate plant population (Stucky, 1976). Siddique and Loss (1999) reported that sowing large seeded legumes, chickpea (*Cicer arietinum* L.) and faba bean (*Vicia faba* L.) at depth may improve crop establishment where moisture from summer and autumn rainfall is stored in the subsoil below 5 cm, by reducing damage from herbicides applied immediately before or after sowing and by improving the survival of *Rhizobium* inoculated on the seed due to more favourable soil conditions around the deeply placed seed. Increased sowing depth may enhance root penetration to greater soil depth to explore the soil moisture that remains available at depth throughout the crop cycle (Polthanee, 2001). In addition, greater sowing depth can reduce the chance of damage by birds, mice (Brown *et al.*, 2003) and white mold (Lamb and Johnson, 2004).

Notwithstanding the above benefits of deep sowing, this is also reported in other circumstances to hamper or delay emergence of seedlings (Banks and Gilmour, 1979; Hadjichristodoulou *et al.*, 1977; Paula Júnior *et al.*, 2007; Roundy *et al.*, 1993) and to decrease subsequent growth and yields of plants (Nambiar and Srinivasa Rao, 1987; Ouled Belgacem *et al.*, 2006; Paula Júnior *et al.*, 2007; Yagmur and Kaydan, 2009). Seedling emergence was decreased with depth of sowing due to lack of aeration (Roundy *et al.*, 1993) and a thick soil layer above seedling shoots (Aikins and Afuakwa, 2008). The time of emergence of the first leaf is greater from deep sowing than from shallow sowing because the first leaf starts from a deeper point (Hadjichristodoulou *et al.*, 1977; Kudair and Adary, 1982). Shanmuganathan and Benjamin (1992) suggested that increased sowing depth delayed seedling emergence and reduced seedling relative growth rate due to low light interception by small cotyledons. In previous studies, damage of the first leaf due to opening of the coleoptile within the substrate was proposed as the main cause of decreased emergence with deep sowings of wheat (Andrews *et al.*, 1991; Whan, 1976) although no equivalent reports exist for large seeded legumes. However, deep sowing (>10 cm) was reported to reduce growth and yield of crops, such as peanut (Nambiar and Srinivasa Rao, 1987; Rao and Reddy, 1985), even though it placed the seed closer to the stored moisture in the soil profile.

When there is adequate moisture throughout the soil profile in the dry season, there may be a penalty from sowing seeds too deep. It was hypothesized that under field conditions with a shallow standing water table and enough soil moisture for crop growth in the soil profile for the entire growing season it would not be necessary to sow seeds deep. Direct experimental evidence is lacking or inconclusive for our hypothesis. To investigate the hypothesis, three field experiments were conducted on sandy soil profiles with standing water tables at varying depths. The objectives of this study were to determine effects of sowing depth on emergence, growth and yield of four legume crop species in sandy soils without irrigation in fields where there was a shallow standing water table after harvest of rice.

MATERIALS AND METHODS

Experimental design and treatments

Field experiments were undertaken at three sites in Khon Kaen province, Northeast Thailand. Sites 1 and 2 were conducted in farmers' fields at Kokeyai village (Baan Fang district; latitude 16°28′ N, longitude 102°39′ E) and Samjan village (Muong district; latitude 16°42′ N, longitude 102°48′ E) from 13 December 2007 to 27 March 2008 (dry season). Site 3 was conducted at the Fruit Crops Research Station (latitude 16°28′ N, longitude 102°48′ E) located in Khon Kaen University (KKU) from 17 December 2008 to 27 March 2009 (dry season). Average temperature in Khon Kaen province during the growing season in 2007–2008 and 2008–2009 ranged from 25 to 27 °C and 22 to 29 °C, respectively. The soil in Kokeyai is a Typic Paleustults (Satuk soil series), in Samjan it was an Arenic Haplustalf (Nam Phong soil series) and in KKU it was a Typic Kandiustult (Chum Phuang soil series). Soils were analysed for texture by the hydrometer method, and soil water holding capacity was analysed by a pressure plate (–10 and –1500 kPa); chemical properties, viz. pH by 1:2.5 H_2O, organic matter was determined by the Walkley–Black wet oxidation method, total N was determined by the micro-Kjeldahl method, extractable P by the Bray II method and exchangeable K and Ca were determined by using 1 M ammonium acetate extraction at pH 7 (Simard, 1993). Physical and chemical properties of soils in Kokeyai, Samjan and KKU are presented in Table 1. All locations were selected because the soils experience capillary water rise from a shallow water table in the dry season.

A split–split plot design was used with four legume species (peanut, cowpea, mungbean and soybean) in the main plot, two levels of sowing depth (5 and 15 cm from soil surface) as the split plot factor and sampling time as a repeated measure. Experiments were replicated four times.

In the year 2007–2008, peanut (*Arachis hypogaea* c.v. Tainan 9), cowpea (*Vigna unguiculata* c.v. KKU 264 R), mungbean (*Vigna radiata* c.v. U-thong 1) and soybean (*Glycine max* c.v. NakhonSawan 1) were grown at shallow and deep sowing depths. In the year 2008–2009, cowpea (*Vigna unguiculata* c.v. KKU 264 R) and mungbean (*Vigna radiata* c.v. U-thong 1) were grown at shallow and deep sowing depths.

Legume seeds were sown at two depths, approximately 5 cm (called shallow sowing), which was the ordinary seeding depth (Dungan and Ross, 1957; Martin and Leonard, 1965), and approximately 15 cm (referred to as deep sowing).

At each sampling date, samples were collected from plots in separate replicate blocks.

Table 1. Soil physical and chemical properties in Kokeyai and Samjan (2007–2008), and KKU (2008–2009) at 0–15, 15–30, 30–45, 45–60 and 60–100-cm depth.

	(%)					(%)			($mg\ kg^{-1}$)	
Soil depth (cm)	Sand	Silt	Clay	Texture	pH (H_2O)	Organic matter	Total N	P	K	Ca
				2007–2008 (Kokeyai)						
0–15	49	40	11	Loam	6.09	3.19	0.159	13.3	19	394
15–30	43	41	16	Loam	6.35	2.81	0.140	5.7	13	612
30–45	47	41	12	Loam	6.42	0.61	0.030	3.5	12	260
45–60	44	43	14	Loam	5.29	1.68	0.084	5.4	10	445
60–100	50	38	12	Loam	6.40	0.66	0.033	3.4	11	278
				2007–2008 (Samjan)						
0–15	75	9	16	Sandy loam	6.39	1.67	0.083	5.3	37	941
15–30	82	9	9	Loamy sand	6.59	1.01	0.050	4.5	15	470
30–45	82	10	7	Loamy sand	6.56	0.63	0.031	3.2	12	277
45–60	82	12	6	Loamy sand	6.50	0.28	0.014	2.5	9	298
60–100	83	10	7	Loamy sand	6.38	0.66	0.033	4.9	11	251
				2008–2009 (KKU)						
0–15	76	21	3	Loamy sand	5.32	1.49	0.074	26.0	47	261
15–30	75	22	3	Loamy sand	5.33	1.12	0.056	11.6	26	193
30–45	76	20	4	Loamy sand	5.33	0.66	0.033	6.2	21	132
45–60	78	17	5	Loamy sand	5.13	0.50	0.024	6.0	17	132
60–100	74	19	7	Sandy loam	5.22	0.46	0.023	4.7	10	106

Crop management

After rice was harvested from each field in 2007–2008, rice straw was removed and soil was ploughed and harrowed thrice to loosen the topsoil to 15-cm depth. The soil was allowed to dry for two to three days after each round of plowing and harrowing. Before final plowing and harrowing, soil was fertilized with 15–15–15 compound fertilizer ($N:P_2O_5:K_2O$) at 156 kg ha^{-1} by broadcasting and limed at 625 kg ha^{-1} to raise pH to nearly 7. In 2008–2009, after weeding, soil was prepared in a similar manner as done in the previous year. Sub-plot dimensions in Kokeyai, Samjan and KKU were 2.5 × 11, 5 × 8, and 7 × 7 m, respectively.

For shallow sowing, seeds were placed in furrows made by a Planet Jr. (approximately 5 cm from soil surface). For deep sowing, seed sowing was accomplished using a plow drawn by two-wheel tractor to make furrows of approximately 10 to 15-cm depth. The seeds were then dropped in the furrows and covered with the soil when the adjacent furrow was prepared. Peanut seeds were soaked in water for 24 h before planting but seeds of other legume species were soaked for only 4 h and treated with Captan at 5 g kg^{-1} seed to protect seedlings from crown rot. Only soybean seeds were inoculated with 1 mL of dense *Rhizobium japonicum* before planting; other legumes nodulate effectively without inoculation in these soils (Hinson and Hartwig, 1982; Khongmorn, 1994). In 2007–2008, seeds were sown with two seeds per hill at 0.5-m row-to-row spacing and 0.10-m plant-to-plant spacing. In 2008–2009, seeds were sown with two seeds per hill in the plant spacing of 0.35 × 0.10 m, and seedlings were thinned to one plant per hill at two weeks after seeding. There was no weeding or fertilizer application after planting. Pests and diseases were controlled by weekly applications of carbosulfan (20% w/v, water soluble concentrate) at the rate of 2.5 L ha^{-1}, methomyl (40% soluble powder) at the rate of 1.0 kg ha^{-1} and carboxin (75% wettable powder) at the rate of 1.68 kg ha^{-1}. The experiment was kept under rainfed conditions, so there was no irrigation in the field.

Soil moisture and water table

Soil moisture was recorded throughout the growing season using the gravimetric method for the depths of 0–15, 15–30, 30–45, 45–60 and 60–100 cm. Soil samples were collected one core per plot. Water table level was observed by the rise of water in perforated polyvinyl chloride (PVC) tubes, installed at 20-, 40- and 100-cm soil depth. Four PVC tubes were installed to measure average water table levels at all locations. Each tube was located near the corner of each experimental field. Water table depth was measured from the soil surface in the PVC tube throughout the experiment by using a calibrated wooden stick.

Seed yield and harvest index (HI)

After physiological maturity, seed yields were determined from 50 hills randomly chosen in each plot. Pods were shelled out and cleaned after air-drying. Mature, intact and healthy seeds were then weighed for yield calculation. Harvest index was calculated as the ratio of total seed yield to total biomass, including good seed weight at final harvest.

Emergence and shoot dry weight

Seedling emergence in each plot was counted from five groups of 20 hills. Plant samples for shoot growth analyses were collected from 16 hills per plot randomly selected at 3, 6 and 9 weeks after sowing (WAS) in 2007–2008 and 3, 6, 9 and 11 WAS in 2008–2009. Plants in each plot were sampled for shoot growth analysis by separating the plant into stem, leaf and pod (when present), and dried at 80 °C for 48 h. Crop growth rate (CGR) was computed as described by Hunt (1978) in g m^{-2} day^{-1}:

$$\mathrm{CGR} = \mathrm{W}_2 - \mathrm{W}_1/\mathrm{t}_2 - \mathrm{t}_1,$$

where W_1 and W_2 are the total dry weights harvested at time t_1 and t_2, respectively.

Data analysis

Data were analysed for emergence percentage, total shoot dry weight, seed yield and harvest index. A split plot design was applied using STATISTIX-8, except where there were multiple harvests or sampling times when a repeated measures design was applied.

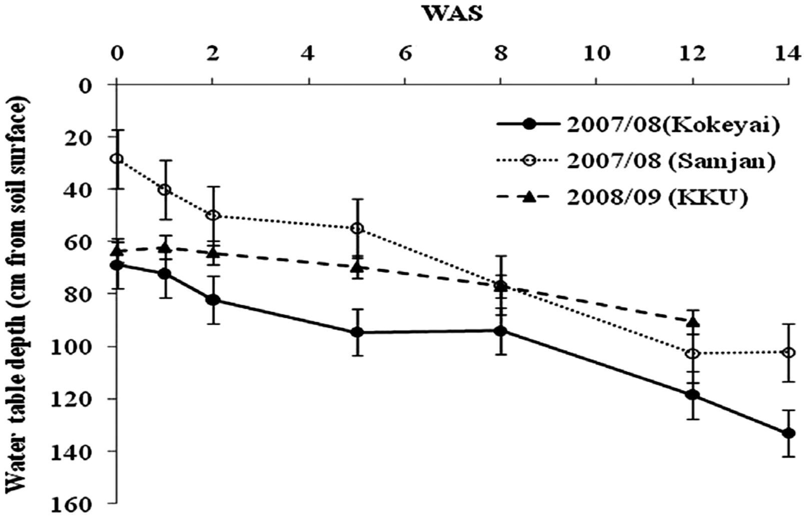

Figure 1. Water table depth after sowing (weeks after sowing, WAS) in Kokeyai and Samjan (2007–2008), and Khon Kaen University (KKU) (2008–2009) during the growing season. Vertical bars represent standard error.

RESULTS

Rainfall and water table depth

In 2007–2008, legumes received rainfall in Kokeyai twice at 7 (8.5 mm) and 13 (24.3 mm) WAS, and Samjan received rainfall at 6 (4.8 mm), 7 (2.7 mm) and 13 (7.8 mm) WAS. In 2008–2009, legumes received rainfall in KKU at 1 (0.5 mm) and 10 (6.2 mm) WAS. Total rainfall at all locations in both years was minimal. Therefore, growth of crops relied largely on capillary water rising from the shallow water table apart from residual soil moisture in the soil profile at sowing.

In 2007–2008, measured water table depths ranged from 69 to 133 cm below the soil surface in Kokeyai and 28 to 102 cm below the soil surface in Samjan. In 2008–2009, water table depth ranged from 62 to 90 cm below the soil surface in KKU. The water table depth declined below 100 cm at 9 WAS in Kokeyai and 12 WAS in Samjan, while at KKU it never declined below 100 cm (Figure 1).

Soil water content

Soil water in the topsoil (0–15 cm from soil surface) of all locations decreased to near PWP at harvest. However, soil water levels increased with depth. Soil water contents in the subsoil (>15 cm from soil surface) remained in the available ranges throughout the growing season (Figure 2). Thus, legumes at all locations seemed to have enough water during the growing season and did not experience water deficit. The depth of sowing did not affect soil moisture content (Figure 2).

Emergence percentage

Deep sowing delayed emergence by approximately 3–7 days for all legumes at all locations. Cowpea and mungbean had higher emergence percentage than peanut and

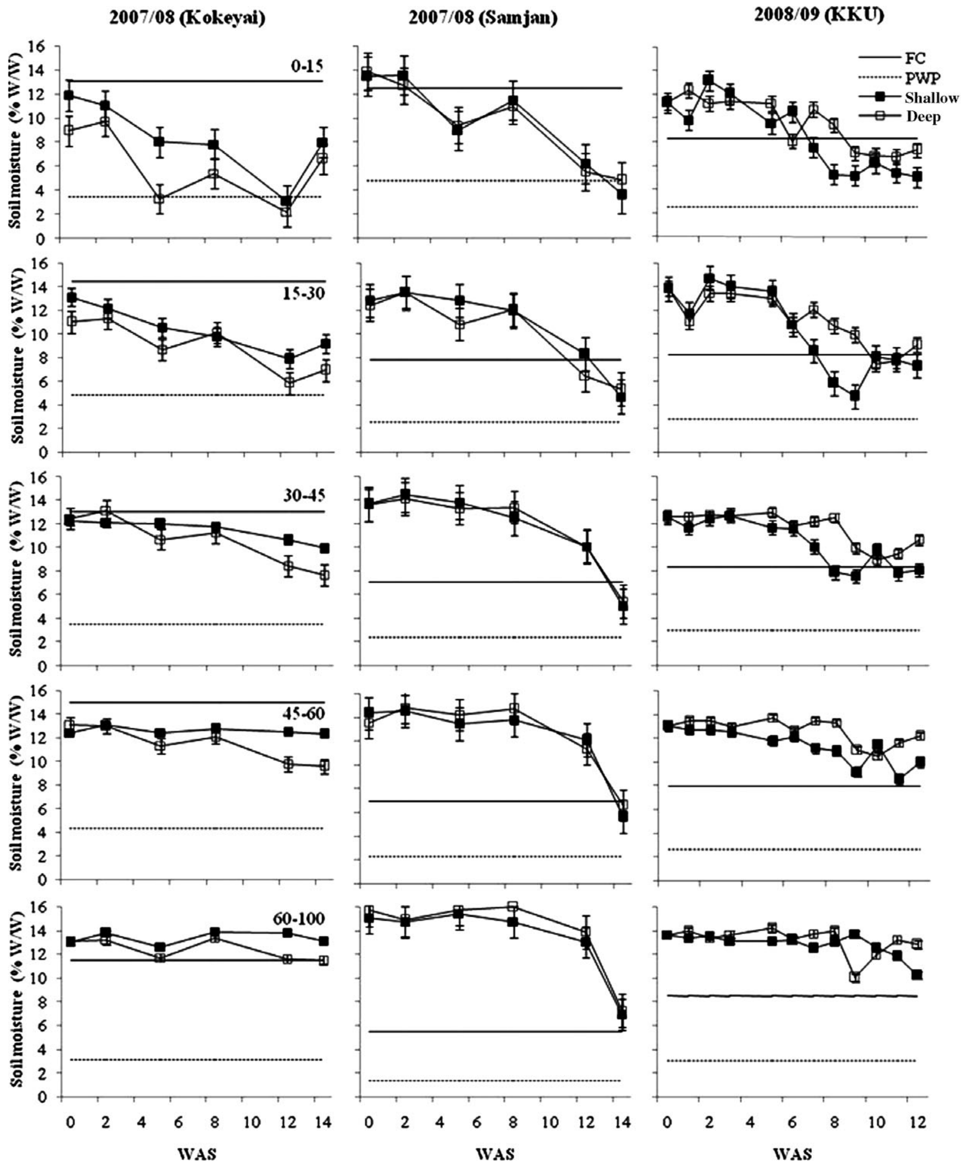

Figure 2. Soil water content of shallow- and deep-sown plots (weeks after sowing, WAS) at 0–15, 15–30, 30–45, 45–60 and 60–100 cm in Kokeyai and Samjan (2007–2008), and Khon Kaen University (KKU) (2008–2009) during the growing season. Horizontal lines represent water contents at field capacity (FC) and permanent wilting point (PWP). Vertical bars represent standard error.

mungbean in Kokeyai and Samjan (Table 2). Emergence percentage of legumes after shallow sowing was higher than after deep sowing at all locations by approximately 14–83% (Table 2). There was no interaction between legume species and sowing depth for emergence at Kokeyai and Samjan. In KKU, deep-sown mungbean had the lowest emergence percentage at 9, 14 and 21 days after sowing (Table 2).

Table 2. Emergence percentage (%) of legumes after shallow and deep sowing in Kokeyai and Samjan (2007–2008), and KKU (2008–2009).

	Emergence percentage (%)											
	Kokeyai				Samjan				KKU			
	Days after sowing (DAS)											
Treatment	6	9	14	21	6	9	14	21	6	9	14	21
Legume (L)												
Cowpea	28.2	75.6	79.9	83.4	24.8	56.9	71.1	75.9	49.9	89.2	93.8	94.2
Mungbean	31.5	63.6	68.6	73.0	33.1	60.8	71.5	75.5	50.5	79.5	86.9	87.2
Peanut	13.8	43.9	69.6	72.9	3.0	33.0	59.9	66.1				
Soybean	25.5	39.1	48.2	51.1	13.8	34.1	44.5	51.8				
LSD	15.7	15.5	17.6	17.5	14.8	10.3	13.9	16.4	3.0	9.0	7.5	7.0
F-test	ns	***	*	*	**	***	**	*	NS	*	NS	NS
Depth (D)												
Shallow	49.5	58.9	66.4	68.3	25.9	61.4	70.6	73.2	91.8	95.1	96.5	96.6
Deep	0.0	52.2	66.8	71.9	11.4	31.0	52.9	61.4	8.6	73.6	84.1	84.9
LSD	16.4	15.8	14.6	14.2	8.9	10.6	11.0	11.0	3.6	5.8	4.3	4.6
F-test	***	NS	NS	NS	**	***	**	*	***	***	***	***
L × D												
Cowpea × Shallow	56.5	67.2	70.2	72.0	36.0	68.0	72.5	74.2	89.8	94.0	95.8	96.0
Cowpea × Deep	0.0	84.0	89.5	94.8	13.5	45.8	69.8	77.5	10.0	84.5	91.8	92.5
Mungbean × Shallow	63.0	68.0	72.0	73.2	42.0	76.2	78.5	81.2	93.8	96.2	97.2	97.2
Mungbean × Deep	0.0	59.2	65.2	72.8	24.2	45.2	64.5	69.8	7.2	62.8	76.5	77.2
Peanut × Shallow	27.5	46.0	60.0	62.2	5.5	55.2	79.2	82.0				
Peanut × Deep	0.0	41.8	79.2	83.5	0.5	10.8	40.5	50.2				
Soybean × Shallow	51.0	54.5	63.2	65.8	20.0	46.0	52.2	55.2				
Soybean × Deep	0.0	23.8	33.2	36.5	7.5	22.2	36.8	48.2				
LSD	32.8	31.7	29.2	28.4	17.8	21.1	22.0	22.0	5.1	8.2	6.1	6.6
F-test	ns	ns	ns	ns	ns	ns	ns	ns	ns	**	**	**

LSD: Least significant difference at the 0.05 probability level.
NS: Non-significant.
Significant at the *0.05, **0.01 and ***0.001 probability levels.

Total shoot dry weight

In 2007–2008, shoot dry weights of legumes after shallow and deep sowing were not significantly different at 3, 6 and 9 WAS for all legumes at both locations. Except at 9 WAS, deep sowing of soybean raised shoot dry weight in Kokeyai, but deep sowing of cowpea depressed shoot dry weight in Samjan. (Table 3 and Figure 3)

In 2008–2009, shoot dry weights after shallow sowing were higher than after deep sowing in cowpea and mungbean at every sampling date (Table 3 and Figure 3).

Seed yield and harvest index

Legumes after shallow and deep sowing had similar seed yield in both years and at all locations except cowpea in KKU, where shallow sowing raised seed yields (Table 3 and Figure 4). Harvest indices of legumes after shallow and deep sowing were not significantly different at every location except cowpea at KKU and mungbean at

Table 3. Shoot dry weight, seed yield and harvest index (HI) of cowpea, mungbean, peanut and soybean after shallow and deep sowing depth in Kokeyai, Samjan and KKU.

Location	Treatment	Shoot dry weight (kg ha^{-1})				Yield (kg ha^{-1})	HI
Kokeyai	Legume (L)	3 WAS	6 WAS	9 WAS			
	Cowpea	274	926	3074		360	0.069
	Mungbean	110	703	2388		952	0.364
	Peanut	329	1136	3660		809	0.226
	Soybean	191	899	1874		798	0.365
	LSD	50***	185**	709**		281**	0.068***
	Depth (D)						
	Shallow	225	909	2700		737	0.263
	Deep	227	923	2798		723	0.250
	LSD	39^{ns}	190^{ns}	598^{ns}		292^{ns}	0.053^{ns}
	L × D						
	LSD	78^{ns}	381^{ns}	1195^{ns}		584^{ns}	0.106^{ns}
Samjan	Legume (L)	3 WAS	6 WAS	9 WAS			
	Cowpea	176	653	1990		426	0.184
	Mungbean	68	523	2981		992	0.360
	Peanut	198	646	2446		451	0.148
	Soybean	120	481	1616		444	0.263
	LSD	29***	93**	544**		176***	0.058***
	Depth (D)						
	Shallow	140	589	2591		599	0.237
	Deep	142	562	1926		557	0.240
	LSD	16^{ns}	130^{ns}	659*		186^{ns}	0.032^{ns}
	L × D						
	LSD	31^{ns}	260^{ns}	1317^{ns}		371^{ns}	0.064^{ns}
KKU	Legume (L)	3 WAS	6 WAS	9 WAS	11 WAS		
	Cowpea	203	1052	2822	3229	720	0.226
	Mungbean	44	433	2021	2447	619	0.370
	LSD	23***	166**	561*	1354^{ns}	319^{ns}	0.129*
	Depth (D)						
	Shallow	163	914	3111	3405	910	0.361
	Deep	84	571	1733	2271	430	0.234
	LSD	20***	123***	415***	788*	219**	0.104*
	L × D						
	LSD	28***	174*	587^{ns}	1115^{ns}	310*	0.148^{ns}

WAS: Weeks after sowing.
LSD: Least significant difference at the 0.05 probability level.
NS: Non-significant.
Significant at the *0.05, **0.01 and ***0.001 probability levels.

Samjan, where shallow-sown legumes had higher *harvest index* than deep-sown legumes (Table 3 and Figure 4).

DISCUSSION

Emergence percentage

Deep sowing delayed emergence rate of all legumes at all locations by 3–7 days. Such delays in emergence could make seedlings more susceptible to emergence constraints such as soil crusting, waterlogging due to unseasonal late rain, diseases, insect damage

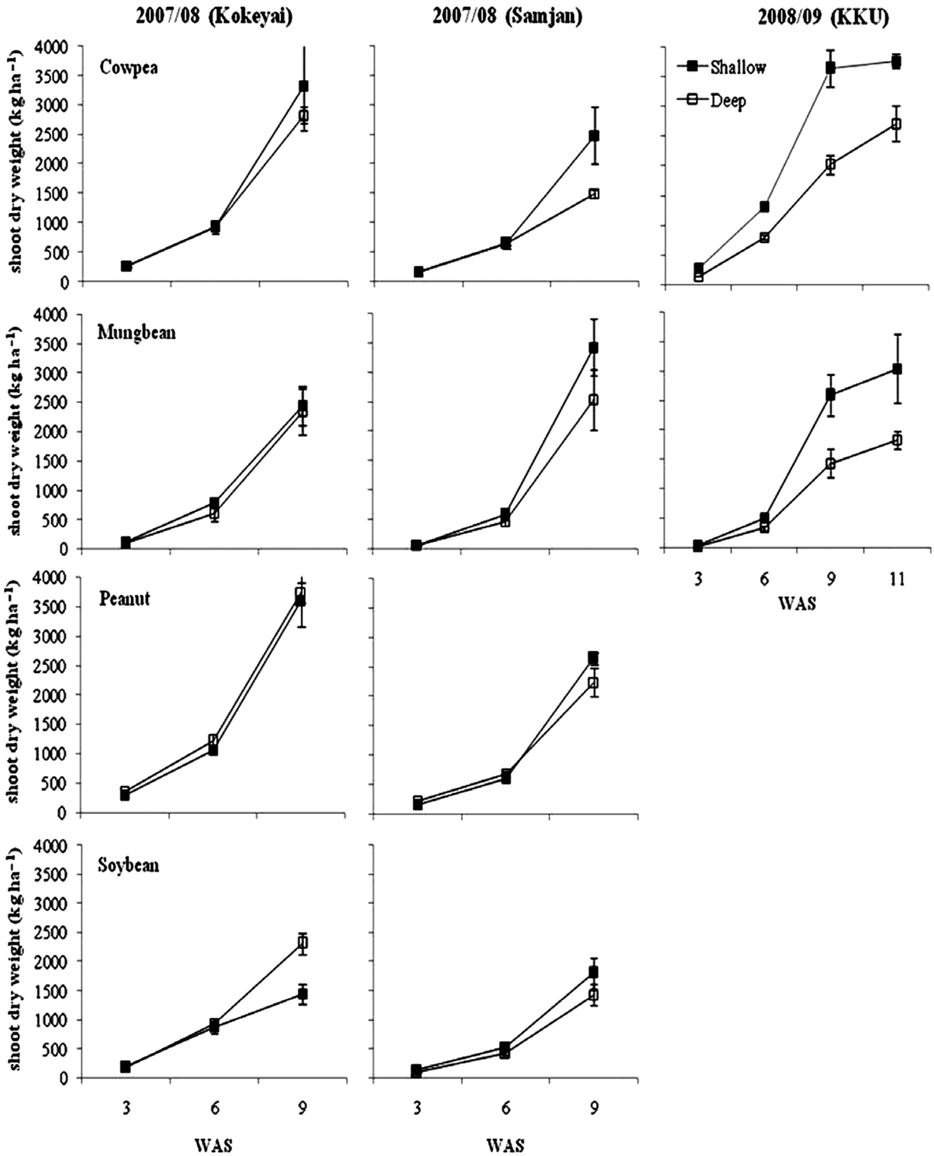

Figure 3. Total shoot dry weight (kg ha^{-1}) of legumes after shallow and deep sowing in Kokeyai and Samjan (year 2007–2008), and KKU (year 2008–2009) at 3, 6 and 9 weeks after sowing (WAS). Values are means of four replicates. Vertical bars represent standard error. Statistical tests for the data are shown in Table 2.

and weed competition (Banks and Gilmour, 1979). Moreover, plant emergence was more variable with deep sowing. Variation in plant age by up to a week could cause inconsistent maturity leading to harvesting difficulties and quality variation (Banks and Gilmour, 1979).

Notwithstanding the delay in emergence, final emergence counts of deep-sown legumes were similar to or lower than shallow-sown legumes except increase with

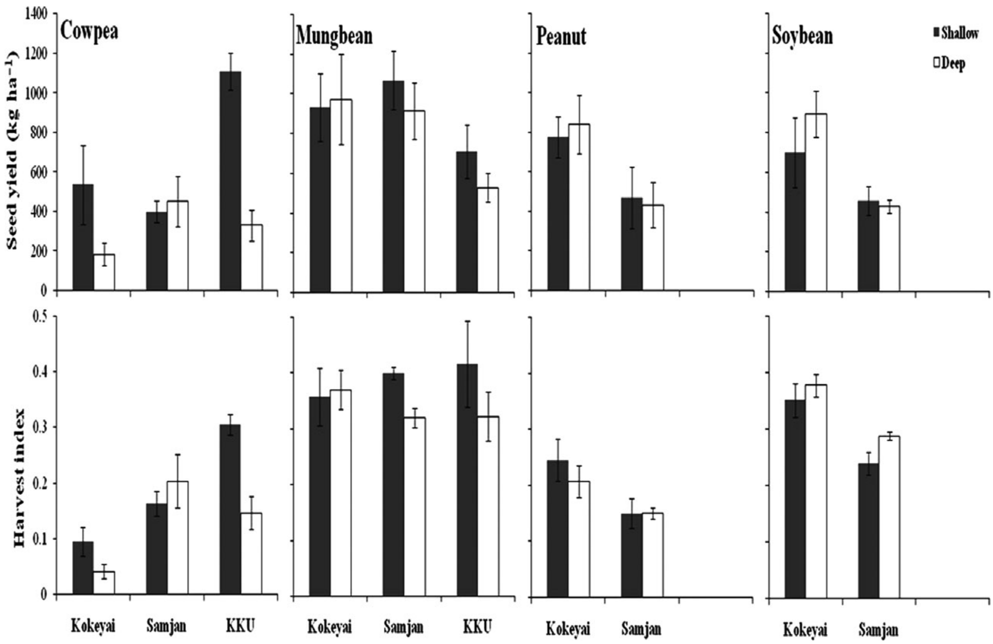

Figure 4. Seed yield (kg ha^{-1}) and harvest index (HI) of legumes after shallow and deep sowing in Kokeyai and Samjan (year 2007–2008), and KKU (year 2008–2009). Values are means of four replicates. Vertical bars represent standard error. Statistical tests for the data are shown in Table 2.

cowpea and peanut at Kokeyai, which was the driest location. Legumes emerged well after shallow sowing, perhaps because soil in the seed zone approximately 5 cm underneath the soil surface had adequate water for seedling emergence in these trials. In contrast, deep-sown legumes did not emerge as well because of adverse effect from increased soil strength or higher soil water content on seed germination and/or emergence. Mahdi *et al.* (1998) reported that sowing wheat at 12 cm decreased seed emergence and led to reduced seedling vigour. Increasing sowing depth below 5 cm reduced seedling emergence of Japanese chestnuts (*Castanea crenata*) (Seiwa *et al.*, 2002) because a greater fraction of seed reserves were exhausted before the emergence of seedling. Similarly, Banks and Gilmour (1979) suggested that 4 to 6 cm was a more reliable sowing depth for germination and emergence than 8 to 12 cm for soybean planted in the dry season when the soil water at that level was adequate. By contrast, Siddique and Loss (1999) suggested that sowing at 10-cm depth improved crop establishment in faba bean and chickpea, both large-seeded legumes, but only in fields which had soil water stored below 4 cm. Such differences in results of studies may be related to seed size in relation to planting depth, soil strength and soil water around and below the seed.

Growth and yield

Yield and harvest index of legumes did not differ meaningfully among sowing depths. Growth of deep-sown legumes was mostly similar to or lower than shallow-sown legumes as reflected in total shoot dry weight. The exception was soybean in Kokeyai at 9 WAS where deep-sown legume had higher shoot dry weight than shallow-sown legume. Kokeyai had the lowest soil water content in the topsoil, and soybean is the most sensitive of the grain legumes to water stress (Wright, 1994). Deep sowing might help soybean roots to penetrate into deeper soil profile to access more water. Buakum *et al.* (2012) found that deep-sown legume crops (approximately 15 cm) in sands with receding water table depth had deeper and finer root systems than shallow-sown crops (approximately 5 cm).

By contrast with the present results, Chantron (1983) reported that growth and yield of peanut in the dry season without any irrigation after sowing at 10- and 15-cm depths were significantly higher than at 5-cm depth. Peanut in that study was grown in a field where topsoil water content was lower than PWP between 12 and 15 WAS . Chantron (1983) argued that deep sowing allowed the root system to utilize soil water at greater depth in the field where there was 1–1.5-m water table depth. Jintrawet *et al.* (1983) also reported that deep sowing (approximately 10–15 cm) facilitated root exploration for water in deep soil layers which in turn promoted growth and yield for peanut cultivation after rice harvesting at locations with soil water content of 0–10 cm, which dropped below PWP late in the growing season. Furthermore, Polthanee (2001) found that peanut grown after rice in the dry season of Northeast Thailand after deep sowing (15 cm) gave the highest growth and yield when soil water content at 0–15 cm fell below PWP 10 WAS.

The above-referred studies had lower water table depth and lower soil water content than the three sites in the present study. Collectively, these results suggest that deep sowing leads to better growth and yield of legume crops when topsoil dries out to PWP within 10 weeks of sowing. On the other hand, it was not necessary to sow seeds deep at locations with a shallow and slowly receding water table. For example, Khongmorn (1994) reported that crop growth rates of cowpea, peanut and soybean after deep sowing (approximately 10–15 cm) in Kokeyai were lower in a field with shallow water table depth (54–75-cm underneath soil surface) than with deep water table depth (101–145 cm), especially late in the growing season (at 10–12 WAS) (Figure 5). Water table depths in Kokeyai, Samjan and KKU in the present study were intermediate between the deep water tables and the shallow water tables in Kokeyai in 1989–1990 (Figure 6). Soil texture affects capillary rise from a water table with greater water rise in clay than in sand (Hillel, 1998). Clay contents in this study (3–16% clay) and in the study by Khongmorn (1994) (6–10% clay) were similar, so in the studies there was no expected significant difference in capillary rise of water from the water table. The shallow-sown legumes grew well in the present study in the dry season without irrigation because soil water contents throughout the soil profile of all locations were in the available range throughout the growing season.

The present results define the water tables and soil water drying conditions that favour deep versus shallow sowing of legumes in sandy paddy fields after rice. These findings have relevance to a wide range of sandy paddy fields in Northeast Thailand, Laos, Cambodia and Vietnam.

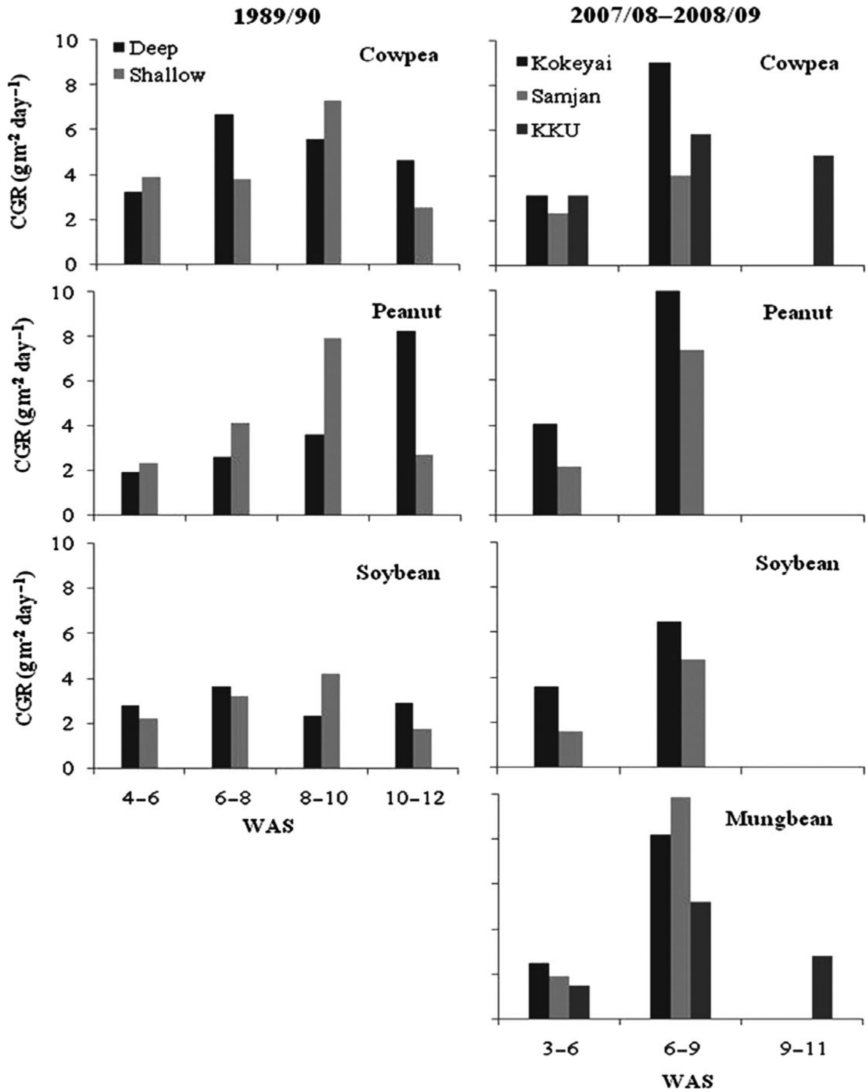

Figure 5. Crop growth rate (CGR) of cowpea, peanut, soybean and mungbean after deep sowing (~15 cm) on paddy fields with deep (Deep) or shallow (Shallow) water tables in Kokeyai in 1989–1990 (Khongmorn, 1994) and in Kokeyai, Samjan and KKU in 2007–2008–2008–2009.

CONCLUSIONS

Although deep sowing helps legume roots penetrate deeper in the soil profile to explore water, it also delayed seedling emergence and consequently reduced growth and yield of crops at sites with available water in the topsoil throughout the growing season. Thus, deep sowing was not beneficial for the dry season cropping in field conditions with shallow water table and adequate stored soil water for crop growth.

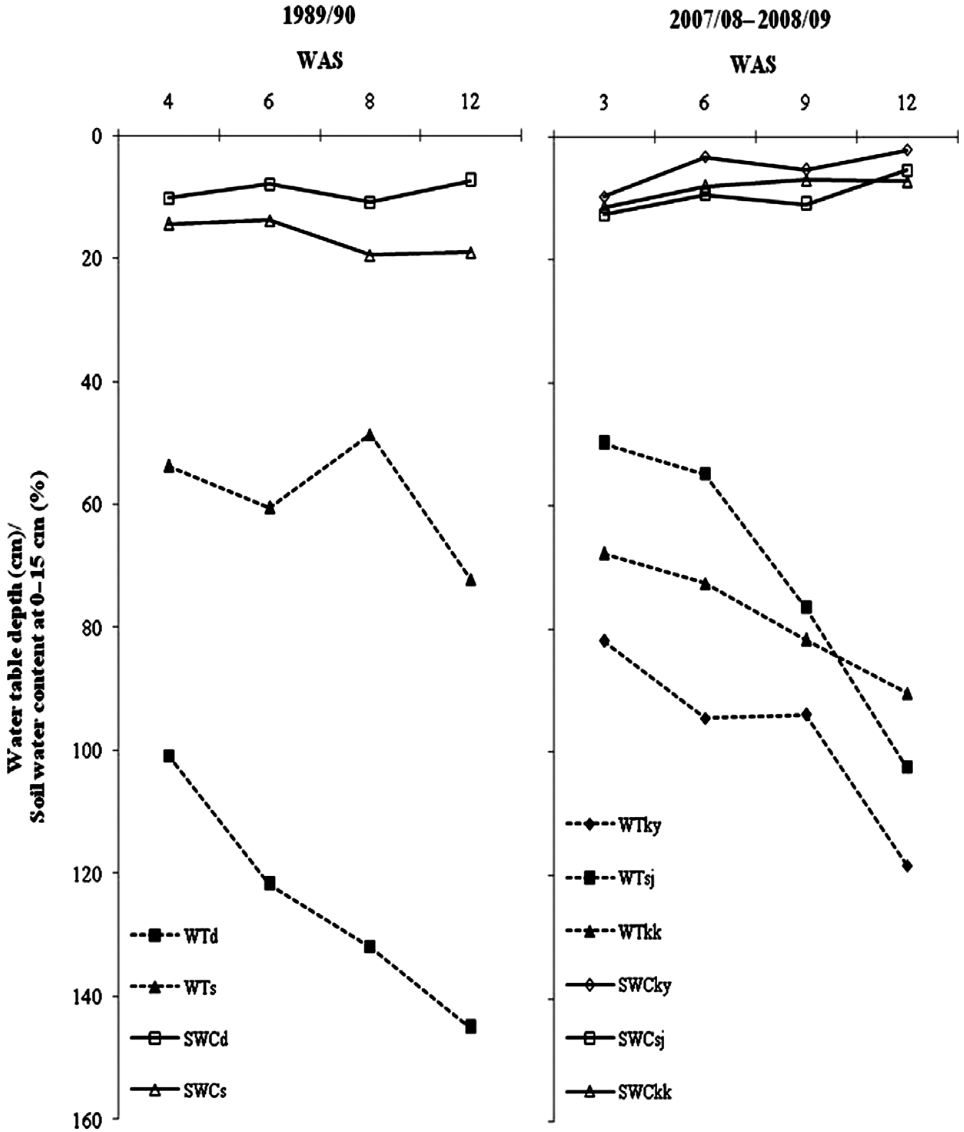

Figure 6. Water table depth (deep – WTd; shallow – WTs) and soil water content (0–15 cm) (deep – SWCd; shallow – SWCs) in paddy fields in Kokeyai in 1989–1990 (Khongmorn, 1994) and Kokeyai (WTky), Samjan (WTsj) (both in 2007–2008) and KKU (WTkk) (in 2008–2009). Soil water content (0–15 cm) labels as follows: Kokeyai (SWCky), Samjan (SWCsj) and KKU (SWCkk).

Sandy rice fields that can support satisfactory yield of legume crops in the dry season without irrigation by shallow sowing should maintain soil water content at 0–15-cm depth greater than PWP throughout the growing season.

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