Effects of Sowing Depths on Growth and Rooting Patterns of Cowpea and Mungbean in a Deep Sand with Shallow Water Table

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ABSTRACT: In some dry-season cropping areas of northeast Thailand, farmers can grow selected annual legumes without irrigation by deep seeding. This cropping system seems to depend on capillary water rising from a shallow water table and seems to be suitable for peanut and cowpea but not other legumes. Seedlings planted by deep seeding might produce more roots under the seed position and could facilitate plants to absorb more water in deep soil because their roots were closer to water table. The present experiment was set up to investigate the differences of growth and rooting patterns between cowpea and mungbean planted at different sowing depths in a sandy soil with a shallow water table. Cowpea and mungbean seeds were sown in soil columns either shallow (~5 cm) or deep (~15 cm) with wet or dry soil over the seeding position. Shoot dry weight of legume plant did not differ consistently between seeding depths but shallow seeding generally increased root: shoot ratio and root length at 6 WAS. Percentage of root length in subsoil (>15 cm) ranged from 21 % to 80 % and 76 % to 99 % for legume plant after shallow and deep seeding, respectively. However, growth of legume plant after shallow and deep seeding did not significantly differ in this study because water was non-limiting for plant growth throughout the 6 weeks growth period. By contrast the percentage of roots of deep-seeded legumes in subsoil increased to 46%. Cowpea and mungbean with relatively dry soil above the seeding position had a bigger and deeper root system than the wet soil in both species. Cowpea had greater shoot growth than mungbean and its root system was bigger and deeper than mungbean. Greater depth of cowpea roots increased access to soil moisture supplied in deep soil layers due to the standing water table. This characteristic might explain the suitability of cowpea for growing on sand soils in the dry season without irrigation.
Keywords: seeding depth, root system, legume, receding soil moisture

Introduction

Most farmers in northeast Thailand are low income landholders who face diverse agricultural and resource problems (Lovelace et. al., 1988). One potential strategy to increase farm income per hectare per year is to practice double cropping. Some interesting double cropping systems in northeast Thailand have been evolved growing the minor crop in the dry season without irrigation, e.g. peanut after rice in Surin and sesame before rice in Bureerum provinces.

In the dry season, some farmers in northeast Thailand grow selected annual legumes without irrigation, by deep seeding (approximately 10-15 cm from soil surface) in the paddy field with shallow water table (Jintrawet et al., 1983). Growth of such dry season legume after rice might depend on capillary water rising from the shallow water table and seems to be suited only for peanut and cowpea but not for the other legumes.

During the dry season, crop establishment may enhance by increasing sowing depth at the certain locations where the topsoil dries out and residual moisture and capillary water is available in the subsoil (Siddique and Loss, 1999). Deep sowing promoted root growth to deeper soil layer to explore more water (Polthanee, 2001). Polthanee (2001) found that peanuts after deep seeding (15 cm) in the dry season had deeper root system and also gave highest growth and yield. Deep sowing let the root system to utilize the soil water efficiently at a greater depth (Chantron, 1983; Ehsanullah et al., 1999). However, deep sowing (> 10 cm) could reduce growth and yield of peanut (Rao and Reddy, 1985; Nambiar and Srinivasa Rao, 1987) even though seed was placed closer to the stored moisture in the soil profile. Pistachio seedlings showed greater dry weight allocation to the stem, at the expense of the roots after deep sowing (Sewia et al., 2002; Gholami et al., 2007). Differential survival of crops in the dry season without irrigation might be related to root system differences among crop species in deeper soil layers. Pandey et al. (1984) found that cowpea and peanut had higher root densities at 0.4 to 0.8 m soil depths than soybean or mungbean so peanut and cowpea roots had greater capability to extract water from deeper soil profile and continuously sustain an adequate water uptake. In addition, Benjamin and Nielsen (2006) reported that field pea and chickpea had a greater proportion of their root systems deeper in the soil profile than soybean, which could lead to better use of stored soil moisture. However, previous studies were performed at shallow sowing depth. There is still limited direct evidence on the root distribution patterns of different legumes and their response to deep sowing and topsoil water level when there is a standing water table in the upper 1 m of the soil profile.

The present experiment was set up to investigate the differences of rooting patterns between cowpea and mungbean at different sowing depths in a sandy soil with a shallow water table.

Material and method

Experimental design

The experiment was conducted in pot experiment located at the Field Crop Research Station, Department of Plant Science and Agricultural Resources, Faculty of Agriculture, Khon Khaen University, during May 4 to June 18 2007.

A 2x2x2 factorial design in completely randomized design with 4 replications was used. Cowpea and mungbean seeds were sown at two depths, approximately 5 cm (called shallow sowing) which was the common seeding depth (Dungan and Ross, 1957; Martin and Leonard, 1965) and approximately 15 cm (referred to as deep sowing). We selected cowpea (*Vigna unguiculata* c.v. 'KKU 264 R') as the test species which previously grew well with deep sowing and no irrigation in farmers' fields, plus mungbean (*Vigna radiata* c.v. 'U-thong 1') which did not grow well in the dry season without irrigation (Pandey et al., 1984). In addition to the sowing depth treatment, cowpea and mungbean soil over the seeding position was either kept moist or allowed to dry.

Column management

Soil in the column (25 cm diameter polyvinyl chloride (PVC) pipe) was packed in 3 layers; 0-15, 15-30 and greater than 30 cm depth. The soil in each layer was obtained from soil at the same depth from a Baan Samjan paddy field, Khon Kaen province. Soils were analysed for soil texture by the hydrometer method, for pH by 1:2.5 H_2O, organic matter by Walkley and Black wet oxidation, total N by a micro-Kjeldahl method, extractable P by Bray II and exchangeable K and Ca by using 1 M ammonium acetate extraction at pH 7. Physical and chemical properties of the soil are presented in **Table 1**.

In both seeding depth treatments, we placed seeds in the column at 90 cm from column bottom but soil column height of shallow and deep seeding were different. Cowpea and peanut with deep seeding and shallow seeding were set in the long columns with either 105 or 92.5 cm soil column height. The soil over the seeding position was loosely filled after seed placement. Water height in containers depended on soil water condition over seeding position. Water in container was 2 cm above the column bottom in the dry soil condition (i.e. water table was 88 cm below the seed position) and 46 cm above the bottom in wet soil condition (i.e. the water table was 44 cm below the seed position). Water was filled in the container at the base of the column to allow capillary water uptake to imitate a shallow water table.

The depth of the wetting front of soil in each column was traced through the experiment as follows. A wires wrapped with absorbent paper was inserted through the soil to 30 cm depth and left for 2 hours and then removed. The wetting front depth was measured by observing the depth to moisture on the paper covering the wire.

The 15-15-15 chemical fertilizer (N: P_2O_5: K_2O) was applied at the rate equivalent to 156 kg ha^{-1}. Seed was treated with Captan at the rate 5 mg kg^{-1} seed to protect from seed rots and dampling-off diseases. The seedlings were then thinned to one plant per pot at 2 weeks after sowing. Pests and diseases were adequately controlled during the growing season.

Data collection

Shoot and root growth and rooting pattern with depth of cowpea and mungbean were assessed 4 and 6 weeks after seeding (WAS). Roots were analyzed for length and surface area by WINRHIZO Pro 2004a software (REGENT Instruments Inc., QC, Canada). A 3-way ANOVA was used to examine the effect of seeding depth, legumes and soil water condition over the seeding position. To test for effects of root depth on root length density, a 4-way ANOVA was used with root depth treated as a repeated measures variable. Each sampling date was analysed as a separate experiment. Calculation procedures of statistical analysis were done using STATISTIX-8.

Table 1 Physical and chemical properties of soil packed in columns.

Soil depth (cm)	Physical properties					
	Sand (%)	Silt (%)	Clay (%)	Texture	FC[1/] (%)	PWP[2/] (%)
0-15	85.0	10.0	5.0	Loamy sand	6.76	1.85
15-30	85.0	12.5	2.5	Loamy sand	7.04	1.11
> 30	87.5	10.0	2.5	Loamy sand	6.06	0.66
Soil depth (cm)	**Chemical properties**					
	pH	Total N (%)	Extr.P (mg kg^{-1})	Exch.K (mg kg^{-1})	Exch.Ca (mg kg^{-1})	Exch. Mg (mg kg^{-1})
0-15	5.95	0.140	5	29	261	24
15-30	5.10	0.063	3	12	151	13
> 30	6.20	0.027	2	12	83	8

[1/] FC: field capacity

[2/] PWP: permanent wilting point

Results

Wetting front of soil column during growing season

After shallow seeding, the wetting front ranged from 1.7 to 3.1 cm below the soil surface in the treatment designated as having dry soil over the seeding position and 0 to 1.0 cm below the soil surface in the wet soil. After deep seeding, wetting front ranged from 7.9 to 11.2 cm below the soil surface in the dry soil and 1.0 to 2.8 cm below the soil surface in the wet soil. Wetting fronts of the dry soil were lower than the wet soil by 2.2 and 7.8 cm after shallow and deep seeding, respectively (Figure 1).

Shoot and root growth

Legumes after shallow seeding had higher root: shoot ratio at both sampling date and total root length at 6 WAS than legumes after deep seeding (Table 2). Meanwhile, deep-seeded legumes had higher shoot dry weight at 6 WAS and root length in subsoil at both sampling date than shallow-seeded legumes.

Shoot dry weight of cowpea was greater than mungbean by 177 % and 229 % at 4 and 6 WAS, respectively. Cowpea also had higher root: shoot ratio at 4 WAS and root length in subsoil at 6 WAS than mungbean (Table 2).

At 4 WAS, root: shoot ratio, shoot dry weight, total root length and root length in subsoil of legumes in the dry and wet soil were not significantly different (Table 2). At 6 WAS, legumes in the dry soil had higher root: shoot ratio, shoot dry weight, and root length in subsoil than in the wet soil.

Root: shoot ratios of all shallow-seeded legumes in both soil conditions were higher than deep-seeded legumes at 4 WAS (Figure 2a). At 6 WAS, root: shoot ratios of cowpea and mungbean in the dry and wet soil were not significantly different. In the dry soil, shallow-seeded mungbean at 6 WAS had greater root: shoot ratio than deep-seeded plants (Figure 2). But interaction between seeding depth, legume, and soil moisture condition of root: shoot ratio were not significantly different at both sampling dates (Figure 2a).

After shallow and deep seeding, shoot dry weight of cowpea and mungbean in the dry and wet soil at 4 WAS were not significantly different (Figure 2b). In the dry soil at 6 WAS cowpea after shallow seeding had greater shoot dry weight than deep seeding but shoot dry weight of mungbean after shallow and deep seeding were not significantly different (Figure 2b). In the wet soil, cowpea and mungbean after deep seeding had more shoot dry weight than shallow seeding at 6 WAS.

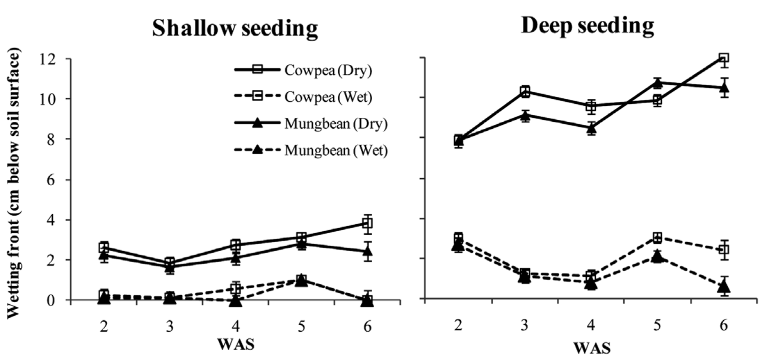

Figure 1 Wetting front (cm below soil surface) during growing season in pots in which cowpea and mungbean were seeded shallow (2.5 cm) and deep (15 cm) with wet and dry soil over the seeding position. Values are means of 4 replicates. Bars where visible represent standard errors of means.

At 4 weeks after seeding, total root length of mungbean in the dry and wet soil were not significantly different (**Figure 2c**). Total root length of cowpea after deep seeding increased by more than 6.3 and 26.3 times relative to shallow seeding in the dry and wet soil, respectively. Total root length of shallow-seeded legumes were higher than deep-seeded legumes in both soil conditions at 6 WAS (**Figure 2c**).

Percentage of root lengths in subsoil (RLS) of all shallow-seeded legumes were lower than deep-seeded legumes regardless of soil water level over the seeding position (**Figure 2d**). At 4 weeks after seeding, RLS ranged from 75% to 99% after deep sowing but declined to 21% to 53% for legumes after shallow seeding. Percentage of root lengths in subsoil at 6 WAS ranged from 33% to 80% and 84% to 99% for legumes after shallow and deep seeding, respectively (**Figure 2d**).

Distribution of roots with soil depth

Seeding depth and soil moisture over the seeding position did not significantly affect distribution of roots with soil depth at both harvesting dates (**Figure 3**). Root length density with soil depth of cowpea was greater than mungbean (**Figure 3**). Soil level at 15-30 cm had higher RLD than 2.5-15, 30-45, 0-2.5, 45-60, 60-75, 75-90, and 90-105, respectively (**Figure 3**).

Cowpea had greater RLD and deeper roots than mungbean at every sampling date (**Figure 3**). The dry and wet soil had no effect to RLD distribution of mungbean but cowpea in the dry soil had a deeper root system than in the wet soil at 4 and 6 WAS.

Table 2 Effect of seeding depth, legume species, and soil water condition above the seeding position on root: shoot ratio, shoot dry weight, total root length and percentage of root length in subsoil (> 15 cm) of cowpea and mungbean seeded shallow (2.5 cm) or deep (15 cm) with wet and dry soil over the seeding position at 4 and 6 weeks after seeding. Values are means of 4 replicates.

Treatment	Root: shoot ratio		Shoot dry weight ($g\ plant^{-1}$)		Total root length ($m\ plant^{-1}$)		Root length in subsoil (%)	
	4 WAS	6 WAS	4 WAS	6 WAS	4 WAS	6 WAS	4 WAS	6 WAS
Seeding depth (D)								
Shallow	0.348	0.23	3.05	19.1	53	472	41	48
Deep	0.259	0.192	3.81	25.5	96	165	91	92
SEM	0.013**	0.018*	0.64^{ns}	1.0**	23^{ns}	32**	8**	5**
Legume (L)								
Cowpea	0.332	0.228	5.04	34.2	64	296	71	75
Mungbean	0.274	0.194	1.82	10.4	85	341	61	65
SEM	0.013**	0.018^{ns}	0.64**	1.0**	23^{ns}	32^{ns}	8^{ns}	5**
Soil moisture (M)								
Dry	0.304	0.245	3.02	25.5	62	305	70	78
Wet	0.303	0.176	3.84	19.1	87	332	62	63
SEM	0.013^{ns}	0.018**	0.64^{ns}	1.0**	23^{ns}	32^{ns}	8^{ns}	5**
SEM								
D x L	0.018^{ns}	0.025^{ns}	0.90^{ns}	1.4^{ns}	32*	44^{ns}	12^{ns}	7^{ns}
D x M	0.018^{ns}	0.025^{ns}	0.90^{ns}	1.4**	32^{ns}	44^{ns}	12^{ns}	7^{ns}
L x M	0.018^{ns}	0.025**	0.90^{ns}	1.4**	32^{ns}	44^{ns}	12^{ns}	7^{ns}
D x L x M	0.026^{ns}	0.036^{ns}	1.27^{ns}	2.0**	46^{ns}	63**	18^{ns}	9**

SEM, Standard error of mean

ns, Non- significant, *, ** Significant at the 0.05 and 0.01 probability levels respectively

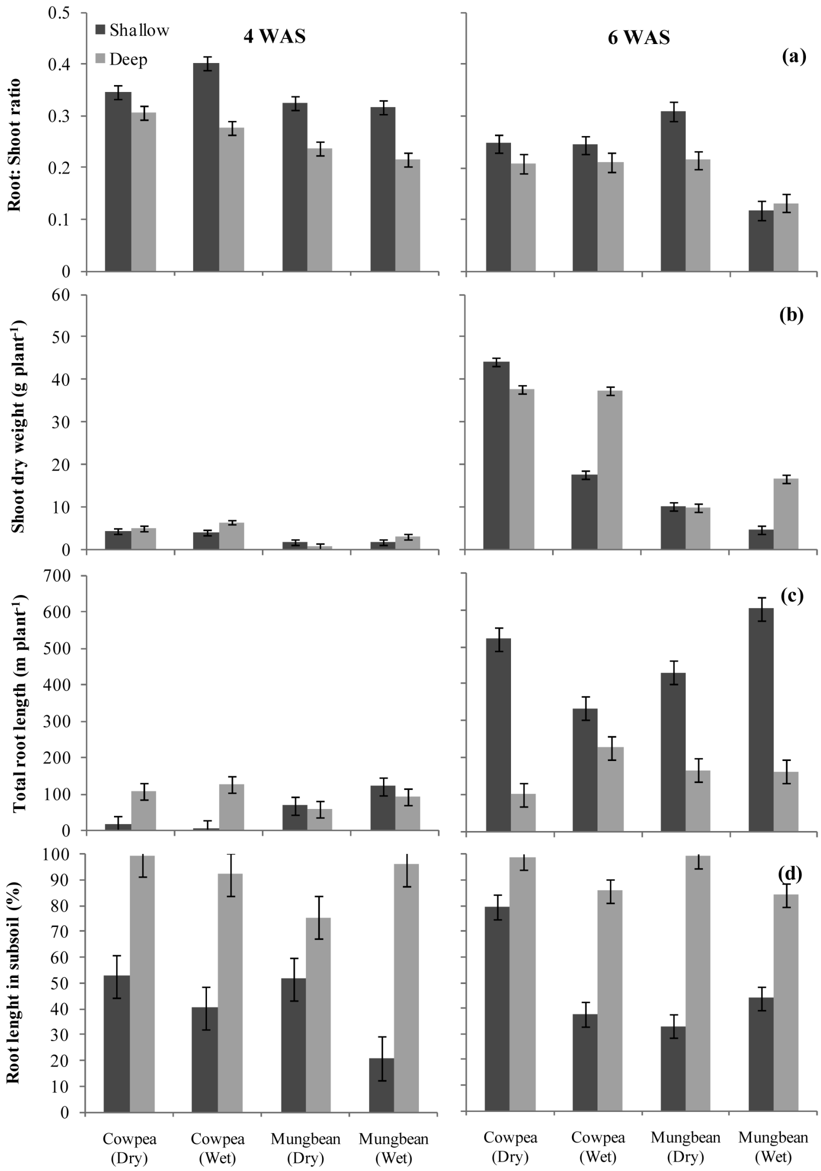

Figure 2 Interaction of seeding depth, legume species, and soil water condition above the seeding position on root:shoot ratio (a), shoot dry weight (b), total root length (c) and percentage of root length in subsoil (> 15 cm) (d). Cowpea and mungbean were seeded shallow (2.5 cm) or deep (15 cm) with wet and dry soil over the seeding position. Values are means of 4 replicates. Vertical bars represent standard errors of means. Statistical tests for the data are shown in Table 2.

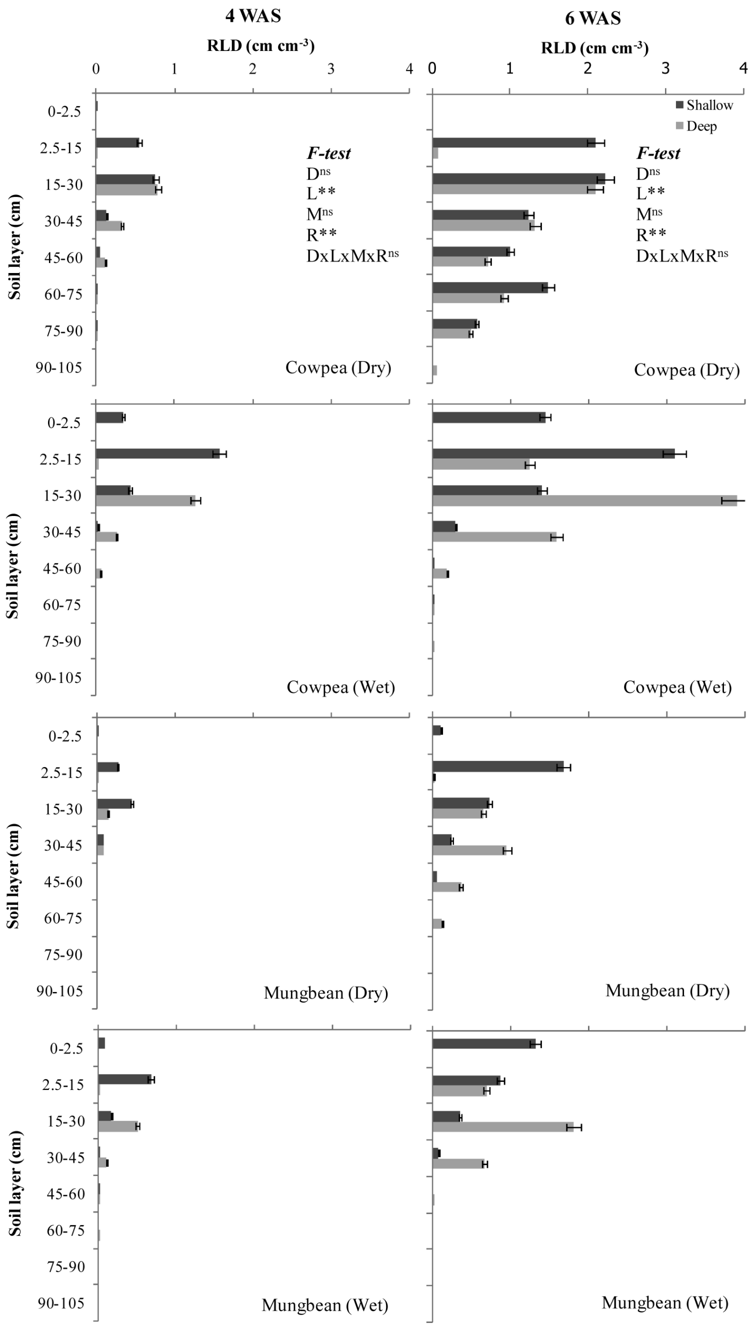

Figure 3 Root length distribution (RLD, cm cm^{-3}) with soil depth of cowpea and mungbean seeded shallow (2.5 cm) or deep (15 cm) with wet and dry soil over the seeding position at 4 and 6 weeks after seeding (WAS). Values are means of 4 replicates. Vertical bars represent standard errors of means. ***F-test***, the significant of F-test for effects of seeding depth (D), legume (L), topsoil moisture (M), root depth (R), and interaction of DxLxMxR.ns, Non- significant, *, ** Significant at the 0.05 and 0.01 probability levels respectively

Discussion

Shoot growth of legumes did not differ consistently among seeding depths, but shallow seeding generally increased root growth as reflected in root: shoot ratio, and overall root length at 6 WAS. For percentage of root in subsoil (>15 cm), roots of cowpea and mungbean after deep seeding were mainly distributed in the subsoil but only 45% of roots of shallow-seeded legumes were in subsoil. That is with deep sowing the roots emerged most densely under and near the seed placement position. The greater proportion of roots of deep-seeded legumes in subsoil than topsoil, would facilitate better growth and survival in dry seasons without irrigation when the plants depend mainly on capillary water rising from a shallow but gradually declining water table. The higher root distribution in the subsoil would be expected to enhance drought tolerance and thus stabilize pod yield and harvest index of legume plants under water-stress conditions (Songsri et al., 2008). Barraclough et al. (1989) reported that little root growth of winter wheat occurred in the topsoil during drought but there was compensatory growth in the subsoil provided that nitrogen fertilizer was given. However, growth of legumes after shallow and deep seeding did not significantly different in this study presumably because there was not a limiting water supply for plant growth throughout the short 6-week growing period. Indeed, from a summary of six field experiments conducted in northeast Thailand with deep sowing of peanut on sandy soils with shallow water tables, Buakum et al. (under review) concluded that deep sowing was superior to shallow sowing for crop yield only when topsoil water stress occurred.

The root system of cowpea was larger and deeper than mungbean. In the dry season without irrigation, the depth of rooting might have a major influence in determining the potential supply of soil water that is available to the crop (Gregory, 2006). Greater depth of cowpea roots on the sandy soil profile can increase access and use of soil moisture in deep soil layers (Matsui and Singh, 2003). This character might explain why cowpea can grow well in the dry-season without irrigation on sandy soils that have a shallow standing water table after rice harvest (Buakum et al., under review). Sangakkara et al. (2001) reported that cowpea had a more extensive root system than mungbean, a characteristic of a drought-tolerant species, and this trait facilitates the extraction of moisture from dry soils. However, poorer growth of mungbean as compared to cowpea could also be due to other factors. The pH of soil in column was rather low, ranging between 5.10 and 6.20 and could inhibit mungbean growth because it does best on fertile sandy loam soils with a pH between 6.2 and 7.2 (Oplinger et al., 1997). In contrast, low pH and poor soils should not affect cowpea growth because it performs well on a wide variety of soils even where soil pH is in the range 5.5 to 6.5 (Davis et al., 2003). Indeed, it can tolerate very acid soil with pH between 5.0 and 5.5 (Metcalfe and Elkins, 1980).

Legumes seeded with dry or wet soil over the seed position had similar shoot growth and overall root growth but differences in root distribution. Legumes in the dry soil had larger and deeper root systems than the wet soil especially cowpea in the later harvesting date at 6 WAS. Relatively dry soil condition induced plants to develop more extensive root system. Dry topsoils have range of effects on root system depending on the exact circumstances including increases in lateral root production, the depth of rooting, and total root length and dry weight when compared with well watered plants (Gregory, 2006). Buakum et al. (under review) found that while deep sowing helped legume roots penetrate deeper in the soil profile to explore for water, deep sowing also delayed seedling emergence and consequently reduced growth and yield of crops on soils that remained wet. Thus, it is not necessary to sow seeds deep in field conditions with shallow water table and adequate stored soil water for crop growth (Buakum et al., under review).

Furthermore, in this experiment, we kept water in columns with wet soil over the seed position at higher level than in the dry soil. Soil column length for legumes grown in wet soil was much lower than that in the dry soil treatment. Therefore, the legumes in the wet soil might have experienced waterlogging condition at later growth stage either before or at 6 weeks after seeding.

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