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Growth and Yield of Rice (*Oryza sativa* L.) as affected by Cultivars, Seeding Depth and Water Deficits at Vegetative Stage

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Abstract: This study investigates the effects of different seeding depths and water stress on growth and yield of direct-seeded rice. The experiment was a 3×2×2 factorial in a randomized complete block design with four replications. The main factors (03) were seeding depths (0, 1 and 5 cm), water level (well watered and water stress at 30 days after seeding (DAS) and rice cultivars (Pathum Thani 1 and Suphan Buri 1). Above-ground biomass and root length density were significantly affected by rice cultivars, seeding depths and water stress. The Suphan Buri 1 had a higher above ground biomass and root length density than the Pathum Thani 1. At the first 7 days of water stress, maximum above-ground biomass was obtained at 1 cm seeding depth. But at a later stage, the highest above ground biomass was observed with a seeding depth of 5 cm at both 60 and 90 days after seeding. The greatest root length density was obtained at a seeding depth of 5 cm. Grain yield was significantly affected by seeding depths and water stress. The highest grain yield was obtained in 5 cm seeding depths compared with other low depth under water stress at vegetative stage (30 DAS). It was concluded that yield loss under water stress at vegetative stage may be compensated for by increasing seeding depth above shallow depth levels.

Key words: Above-ground biomass, relative water content, root length density, seeding depth, water deficit

INTRODUCTION

Water stress is a major cause of low yield of rice grown in the rainfed lowlands (Sharma and De Datta, 1994), an ecosystem that accounts for about 25% of the world's rice-growing area, but where in Asia, the average grain yield is only 2.3 t ha^{-1} (Maclean, 1997). The relatively low yield of rainfed lowland rice may be partly due to drought stress. Drought is a major limitation for rice production in rainfed ecosystems (Kamoshita *et al*., 2000). In Northeast Thailand, direct seeding by broadcasting after tillage plowing is used and it is begun after rainfall when the soil is moist (Pandey *et al*., 2000). However, with the early planting of direct-seeded rice (DSR), plants are normally subjected to water stress during the vegetative growth stage, due to unpredictable rainfall in the region. Therefore, vigorous root and shoot growth may provide better drought tolerance during the vegetative growth stage. Sowing seeds or drilling seeds may more easily avoid water stress by deep rooting and seeds sown by this method are often damaged by birds and rats.

Indeed, shallow sowing is a traditional practice in some countries (Tully and Rassam, 1985). In Syria, for example, farmers usually commence sowing after rain when the surface soil is moist and hence, do not need to sow more deeply than 3 cm. Thus, planting must be delayed until significant rainfall occurs; in some cases planting is incomplete if the rain is excessive, restricting access to the field as it happens in particularly wet years (Mahdi *et al*., 1998).

Direct seeding requires a drill that will effectively penetrate untilled soil and place the seed at the optimum depth for rapid plant emergence. Therefore, sowing depth is also an important factor in crop management practices (Campbell *et al*., 1991; Kirby, 1993). The deeper seeding depth may be higher the root length density in the deep soil layer than shallow depth.

Shallow hardpans are very common in the rainfed lowlands and appear to impede root penetration by about 60-80% (Wade, 1996). Increased soil strength under reduced soil moisture in the subsoil of rain-fed lowlands makes it difficult for roots to gain access to deep soil

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moisture. Under such conditions, roots with higher penetration ability have an advantage for absorbing water from deeper soil layers. However, deep sowing can have an adverse effect on seedling emergence and grain yield unless cultivars adapted to deep sowing are used (Kirby, 1993). Several studies of pot experiments rigorously illustrated the dynamic changes of soil water content in relation to root growth in rice (Azhiri-Sigari *et al.*, 2000). Also, differences among rice cultivars exist in deep root development; they affect the cultivar difference in the extraction of soil water and the rice plant's water status under water stress.

Rice better able to penetrate hardpans have access to more water and should be more able to avoid drought in rainfed lowland environments. The development of a deep root system results from several physio-morphological responses linked to both shoot and root growth (Araki *et al.*, 2002). Deep root systems are often quantified using different parameters by different researchers, such as rooting depth (Araki *et al.*, 2000) and length or weight of deep roots. Therefore, this study investigates the effects of different depths of sowing, water deficit and rice cultivars on growth and yield of direct-seeded rice.

MATERIALS AND METHODS

A pot experiment was conducted in sandy loam soil at Agronomy Farm of Khon Kaen University, Khon Kaen Province Thailand (16°26'N 102°50' E above sea level 204 m), from December 2003 to April, 2004. The experiment was a 3 x 2 x 2 factorial in a randomized complete block design with four replications and each treatment was replicated three times. The main factors (03) were seeding depths (03), water level (02) and rice cultivars (02). Three seeding depths were used: 0, 1 and 5 cm. The two water treatments were as follows: (1) well-watered; (2) water stress at vegetative stage. The seeds of two cultivars (photoperiod insensitive), the Pathum Thani 1 and Suphan Buri 1, were provided by the Pathum Thani 1 and Suphan Buri 1 Rice Research Center, respectively (Rice Department, Ministry of Agriculture and Cooperatives, Thailand).

Soil (Typic Halaquepts) was collected from a paddy soil, which were located in Ban Muang, Khon Kaen Provinces, Thailand and represent the soil type of rice fields. Soil sample was air-dried, sieved (>2 mm) and before put in the plastic pots. Chemical characteristics of soil are 4.56 pH (1:2.5 w/v water), 5.8 g kg^{-1} organic matter content (Walkey and Black, 1934), 250 mg kg^{-1} total N (Bremner, 1960), 14 mg kg^{-1} available P (Bray and Kurtz, 1945) and 33 mg kg^{-1} exchangeable K (1 N ammonium acetate pH 7 extraction (Schollenberger and Simon, 1945)). In this study, a plastic pot of 25 cm in diameter and 60 cm in height was used as an experimental unit and 25 kg of dry soil was put in each pot. The soil was then wetted to field capacity before planting. Prior to potting, the soils were mixed with a basal dressing of the following nutrients: 30 g N (NH_4NO_3), 30 g P ($Ca(H_2PO_4)_2$ and 15 g K (KCl) pot^{-1}. Urea at 192 g ($(NH_2)_2CO$) pot^{-1} was applied to all pots as top dressing at the panicle initiation stage. Rice was grown in open greenhouse during December, 2003-April, 2004 (season temperatures ranged between 13 and 19°C at night and between 23 and 36°C during the day). Fifteen seeds were sown in each pot at a specific depth (0, 1 and 5 cm), that later maintained five plants.

In this experiment, there were 144 pots; three replicate of 12 treatments were randomly assigned to each block (four blocks). Three replicates were used with each treatment acting as a replicate. Among the 36 pots in each block, three served as irrigated control for each cultivar for each time point. Two stress treatments were imposed: (1) well-watered and (2) water stress at 30 DAS in three pots. So, there were three replicates for each treatment in each block. Thirty six pots in each block were maintained for two rice cultivars. All pots, five plants were maintained per pot. At 30 DAS, 18 pots were water maintains as control for two rice cultivar and the other 18 pots were subjected to drought stress by withholding water for two cultivars.

A water deficit condition, plants were subjected to vegetative drought at 30 DAS. Water was withheld until pots reached 30% of Filed Capacity (FC) or leaf wilting was observed and then reapplied. The soil water status was monitored by measuring daily drought pot weight and re-watering was done at the end of days stress period. The weight of pots with plant material was measured daily and moisture lost was replenished. Moisture lost was taken as the amount of water transpired. The experiment was terminated after 7 days, when cultivars could be separated into tolerant and intolerant of water deficit according to a visual score (leaf wilting or soil moisture in pot reach until 30% FC). During the course of drought, all tillers were retained on each plant, but measurements were made on the main shoot of one plant. The plant was used for recording relative water content (RWC). The youngest fully expanded leaf was determined during midday (10.00-11.30) at before drought and the end of days stress period. RWC was determined by the standard method (Barr and Weatherley, 1962). Leaves were detached from each treatment, replicate and genotype and were cut weighed immediately to record fresh weight (FW), followed by dipping half of their portion in distilled water for 4 h. The leaves were blotted to wipe off excess water, weighed to record fully turgid weight (TW) and subject to oven dried at 80°C for 48 h to record the dry weight (DW). RWC was calculated according to the following equation (Barr and Weatherley, 1962):

$$\text{RWC (\%)} = [(\text{FW}-\text{DW})]/(\text{TW}-\text{DW})]\times 100$$

At the end of drought period, two plants were root sampled by extracting three soil cores per pot using a coring tube at a distance of 5 cm. Kamoshita *et al.* (2000) found that seedling vigor may allow faster development of deep roots before or during the early stages of drought, thus, accelerating water extraction and maintaining growth during drought The sampling positions were located in the center above the plant in each pot. A soil core was divided into three, 5 cm sections (0 to 5 cm, 5 to 10 cm and 10 to 15 cm). Root length will be determined using a WinRHIZO Pro software (2004). Root-Length Density (RLD) was calculated as the ratio of root length (cm) and soil volume (cm^{-3}) (Bland, 1989).

Two plants were sampled from ground level to the highest leaf in each pot for leaf area and biomass determination, at 60 and 90 DAS. Plant samples were dried at 80°C for 48 h and weighed to obtain biomass. At maturity, seed yield was determined from two plants in each pot. All yields are expressed on dry grain (about 14% moisture) basis (Dingkuhn and Le Gal, 1996). Plants were considered mature if all grains had turned yellow and most could not be dented. At this stage (ca. 20% moisture), the earliest grains began to shatter whereas late grains were solid but could still be dented (Dingkuhn and Le Gal, 1996). Yield components were determined from the pants in twenty panicles in the each pot (Dingkuhn and Le Gal, 1996). Tillers and panicles were counted, oven-dried and divided into straw and filled and unfilled grain. Fractions were weighed and subsequently, 1000 filled and 1000 unfilled grains separated and also weighed to determine grain and spikelet number for bulk samples. Weeds were controlled manually. No diseases were observed. Data statistical analysis was performed using statistics 8 software (Anonymous, 2003).

RESULTS

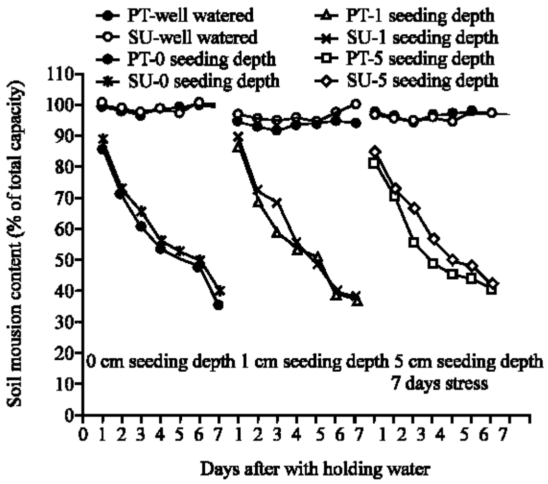

Fig. 1: Soil moisture regime during water stress imposed at 30 Days after Seeding (DAS)

Table 1: Effect of seeding depth, water level and rice cultivar on above-ground biomass

	Above-ground biomass (g plant^{-1})		
Treatments[1]	7 days stress period[2]	60 DAS[3]	90 DAS
Seeding depth (cm)			
0	2.89b	23.14c	31.82c
1	4.48a	28.66b	39.41b
5	3.39b	34.35a	47.22a
	**	**	**
Water level			
Well-watered	3.91a	31.32a	43.06a
Water deficit	3.26b	26.11b	35.90b
	**	**	**
Cultivar			
Pathum Thani 1	3.04b	24.31b	33.42b
Suphan Buri 1	4.14a	33.13a	45.55a
	**	**	**
SD×W[4]	ns	**	*
SD×C	*	ns	ns
W× C	*	ns	ns
CV (%)	22.63	25.01	25

*,**Indicate significance at $p \leq 0.05$ and $p \leq 0.001$, respectively, ns: Not significantly different ($p > 0.1$), [1]Means followed by a common letter in the row and column are not significant at 5% ($p = 0.05$), [2]7 days stress period after water deficit, [3]DAS: Days after seeding, [4]SD: Seeding depth (cm), W: Water level, C: Rice cultivar; PT: Pathum thani 1, SU: Suphan buri 1

Soil moisture: At the vegetative stage, when stress was imposed at 30 DAS, it took 7 days for rice plants to reach leaf wilting (Fig. 1). Both cultivars reached the same level of stress and there was no significant difference between the cultivars in terms of water loss. The rice cultivars showed susceptibility to a vegetative stage stress within 7 days when stress was imposed at 30 DAS. They exhibited rolling symptom on the fourth day after stress at soil moisture around 40% FC (Fig. 1).

Above-Ground Biomass (AGB): Used rice cultivars, seeding depths and water treatments significantly affected AGB at all rice stages and the interaction between rice cultivar and seeding depths, cultivar and water stress on AGB at 7 days water stress, seeding depth and water treatments on AGB at 60 and 90 DAS (Table 1). The rice cultivar Suphan Buri 1 gave the highest AGB, followed by Pathum Thani 1 at all stages (Table 1). The

Table 2: Interaction effect of seeding depth×water level, seeding depth×cultivar, and water level×cultivar on above-ground biomass

Seeding depth x Water level[1]

Seeding depth	Water level	Above-ground biomass (g plant^{-1}) 7 days stress period[2]	60 DAS[3]	90 DAS
0	Well-watered	3.36a	26.91b	36.99ab
1	Well-watered	1.94a	27.51b	37.83ab
5	Well-watered	3.43a	39.54a	54.37a
0	Water deficit	2.42a	19.37c	26.64c
1	Water deficit	4.02a	29.81b	40.98a
5	Water deficit	3.36a	29.15b	40.08a
		ns	**	**

Seeding depth (cm)×Cultivar[4]

Seeding depth	Cultivar	Above-ground biomass (g plant^{-1}) 7 days stress period [2]	60 DAS [3]	90 DAS
0	PT	2.00c	16.05a	22.04a
1		3.85b	26.20a	36.03a
5		3.25b	30.68a	42.19a
0	SU	3.78a	30.26a	41.58a
1		5.09a	31.12a	42.79a
5		3.55b	38.01a	52.26a
		**	ns	ns

Water level×Cultivar

Water level	Cultivar	Above-ground biomass (g plant^{-1}) 7 days stress period [2]	60 DAS [3]	90 DAS
Well-watered	PT	3.59a	19.84a	39.55a
Water deficit		2.48b	19.34a	27.28a
Well-watered	SU	4.23a	33.87a	46.57a
Water deficit		4.05a	32.38a	44.52a
		**	ns	ns

*,**Indicate significance at $p \leq 0.05$ and $p \leq 0.001$, respectively, significantly different ($p>0.1$), [1]Means followed by a common letter in the row and column are not significant at 5% ($p = 0.05$), [2]7 days stress period after water stress, [3]DAS: Days after seeding, [4]PT: Pathum Thani 1, SU: Suphan Buri 1

greatest AGB was obtained at the 1 cm seeding depth (4.48 g plant^{-1}) at 30 DAS. But at a later stage, the highest AGB was observed with a seeding depth of 5 cm depth at both 60 and 90 DAS, producing 31.35 and 47.22 g plant^{-1}, respectively, followed by the 3 cm seeding depth (Table 1). For interaction treatments was shown in Table 2. The interaction between seeding depth and water treatment showing the highest AGB at 60 DAS was observed with rice sowing at 5 cm depth at well-watered. The lowest AGB was observed at 0 seeding depth when rice suffered water stress (Table 2). The cultivar SU had a higher AGB than PT when at shallow depths (0 and 1 seeding depths) at 30 DAS (Table 2). Under water deficit, the highest AGB was observed with SU (Table 2).

Table 3: Effect of seeding depth, water level and rice cultivar on root-length density at 7 days after water stress, and relative water content

Treatments[1]	Root-length density (cm cm^{-3}) 0-5 cm	5-10 cm	10-15 cm	Relative water content (%) Before[2/]	4 day	7 day
Seeding depth (cm)						
0	3.62a	0.34b	0.16b	94.81a	72.02a	65.14a
1	3.14b	1.15a	0.19a	98.82a	70.87a	61.52a
5	1.61c	1.42a	0.23a	93.68a	76.02a	67.28a
	**	**	ns	ns	ns	ns
Water level						
Well-watered	2.95a	1.05a	0.18a	97.82a	75.01a	70.01a
Water deficit	2.63b	0.89a	0.20a	93.73a	70.93a	59.28b
	*	ns	ns	ns	ns	*
Cultivar						
Pathum Thani 1	2.77a	0.95a	0.17a	97.61 a	74.81a	64.40a
Suphan Buri 1	2.81a	0.99a	0.22a	93.96 a	71.13a	64.88a
	ns	ns	ns	ns	ns	ns
CV (%)	15.41	57.13	50.23	7.62	7.85	18.77

*,**Indicate significance at $p \leq 0.05$ and $p \leq 0.001$, respectively, ns: Not significantly different ($p>0.1$), [1]Means followed by a common letter in the row and column are not significant at 5% ($p = 0.05$), [2]Before: Rice before subjected water stress, 4 days and 7 days after water stress

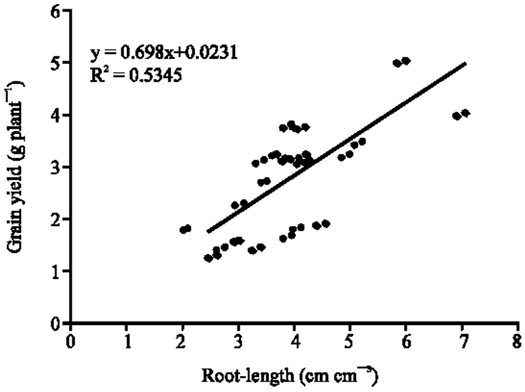

Fig. 2: Relationship between total root-length density at 37 days stress period and grain yield

Root-Length Density (RLD): The RLD observed at 7 days water stress was not significantly affected by the rice cultivars and among water treatments, but the treatments became significantly different between seeding depths at 0 to 5 cm and 5 to 10 cm soil depths and with no interaction (Table 3). The RLD at 0 cm and 1 cm seeding depths, producing 3.62 and 3.14 cm cm^{-3}, respectively, were higher than at 5 cm seeding depth (Table 3). However, with a soil layer of 10 to 15 cm soil depth, the majority of roots were found at 5 cm sowing depth (Table 3).

Relative Water Content (RWC): The RWC was not significantly affected by rice cultivars, different seeding depths or water stress, but the treatments were only significantly different among water treatment on RWC at 7 days after water deficit (Table 3). The plants grown well-watered had higher the RWC (70%) than plants that suffered water deficit (59.28%). Although, the RWC was not significantly affected by seeding depth, the trend of RWC when observed at 7 days after water stress was maintained better, at 67.28% with rice sowing at 5 cm depth, than the other shallow depth (Table 3). There was

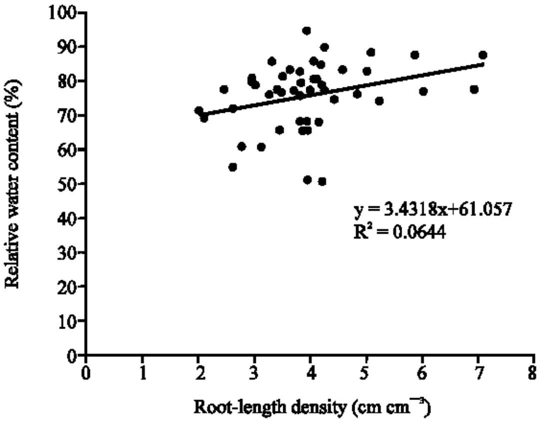

Fig. 3: Relationship between relative water content and total root-length density at 7 days stress period

Table 4: Effect of seeding depth, water level and rice cultivar on yield component and seed yield

Treatments[1]	Panicle plant^{-1}	Spikelet panicle^{-1}	1,000 weight grains (g)	Seed yield (g plant^{-1})
Seeding depth (cm)				
0	18.91b	73.03c	25.52a	18.01c
1	19.30b	86.38b	25.33a	30.67b
5	22.66a	98.85a	25.63a	40.39a
	ns	**	ns	**
Water level				
Well-watered	21.21a	94.30a	25.48a	32.28a
Water deficit	19.35a	77.88b	25.50a	27.09b
	ns	**	ns	*
Cultivar				
Pathum Thani 1	20.60a	85.72a	25.36a	29.32a
Suphan Buri 1	19.96a	86.45a	25.62a	30.06a
	ns	ns	ns	ns
SD×W [2]	ns	**	ns	ns
SD×C	ns	**	ns	ns
W×C	ns	**	ns	ns
CV (%)	19.76	10.58	3.36	28.07

*,**Indicate significance at $p \leq 0.05$ and $p \leq 0.001$, respectively, ns: Not significantly different ($p>0.1$), [1]Means followed by a common letter in the row and column are not significant at 5% ($p = 0.05$) by Duncan's Multiple Range Test. [2]SD: Seeding depth (cm), W: Water level, C: Rice cultivar, PT: Pathum Thani 1, SU: Suphan Buri 1

Table 5: Interaction effect of seeding depth x water level, seeding depth x cultivar, and water level x cultivar on spikelet per panicle

Seeding depth (cm) x Water level[1]

	Spikelet per panicle		
Seeding depth	Well-watered	Water deficit	Mean
0	73.37d	72.69d	73.03
1	99.07b	73.70d	86.39
5	110.45a	87.25c	98.85
Mean	94.3	77.88	

Seeding depth x Cultivar

	Spikelet per panicle		
Seeding depth	PT [2]	SU	Mean
0	73.35c	72.71c	73.03
1	87.08b	85.69b	86.39
5	96.74a	100.96a	98.85
Mean	85.72	86.45	

Water level x Cultivar

	Spikelet per panicle		
Water level	PT	SU	Mean
Well-watered	97.66a	90.93a	94.29
Water deficit	73.79c	81.96b	77.87
Mean	85.73	86.45	

[1]Means followed by a common letter in the row and column are not significant at 5%, ($p = 0.05$) by Duncan's Multiple Range Test. [2]Rice cultivar is PT: Pathum Thani 1 and SU: Suphan Buri 1

a linear relationship between the total RLD at 7 days water stress and grain yield (Fig. 2). There was also a relationship between the total RLD at 30 DAS of rice and the RWC at 7 days after water stress (Fig. 3).

Seed yield (g plant^{-1}): The type of rice cultivar did not significantly affect seed yield (g plant^{-1}), number of spikelet (grains) per panicle and the 1000-seed weight (g), but seeding depths and water stress significantly affected grain yield. Interaction treatments were shown in Table 4. The number of spikelet per panicle was greater for the 5 cm seeding depths than for the 0 and 1 cm seeding depths (Table 4). The average number of spikelet per panicle was 98.85 for the 5 cm seeding depths, followed by 86.38 for the 1 cm seeding depth. The highest grain yield was obtained in the 5 cm seeding depth treatments, followed by 1 cm seeding depth (Table 4). In contrast, 0 cm seeding depth led to the significantly lowest grain yield (Table 4). Number of spikelet per panicle and grain yields was higher when observed for well-watered treatments than for water deficit. For interaction treatments was shown in Table 5. The highest of number spikelet per panicle was observed in well-watered treatment with sowing at 5 cm seeding depth. However, under water deficit, rice sowing at 5 cm seeding depth had the highest spikelet per panicle compared with a shallow seeding depth (0 and 1 cm seeding depth) (Table 5). The largest number of spikelet per panicle was observed in well water, while Suphan Buri 1had higher spikelet per panicle than Pathum Thani 1 for the rice that suffered water stress at the vegetative growth stage (Table 5).

DISCUSSION

Changes in the soil moisture characteristic curves brought about by paddling accepted the duration that available water was accessible for different crop establishment methods (Tuong *et al*., 2002). In the 5 cm seeding depth, rice reached to 30% of field capacity (FC) at 7 days stress period later than the other seeding depth (Fig. 1), indicating that soil water in the topsoil was available for rice for a longer period than rice sowing at the shallow depth. Similarly, at the end of the stress period, available water remained around 37% FC for the 5 seeding depth while the 0 and 1 seeding depth soil moisture reached 40% FC after 7 days of stress. They exhibited rolling symptom on the fourth day after stress at soil moisture around 40% FC (Fig. 1). In this experiment, rice sowing at 5 cm depth appears to have the longest roots compared to shallow sowing depth, since, the deepest roots of both cultivars reached a deep depth in soil layer of water deficit at the vegetative stage (Table 3). In another study, Urasaki *et al*. (2002) also observed that some roots of Nipponbare cultivar had reached depths of more than 70 cm by 50 DAS, where a hardpan existed in the topsoil layer at the experimental site.

The ability of the plant to survive severe water deficits depends on its ability to restrict water loss through the leaf epidermis after the stomata have attained minimum aperture. Decline in stomatal conductance and transpiration rate at reduced water potentials were similar in rice and wheat and these both were reduced to one-fourth of control plants on last day of stress. This is consistent with the results of Dingkuhn *et al*. (1989) in rice. Relative water content (RWC) measures the water content of a leaf relative to the maximum amount that the leaf can take under full turgidity and hence is considered as an appropriate measure of plant water status under stress. RWC was closely associated with the lengths of roots of rice seedlings (Fig. 3). Both the Pathum Thani 1 and Suphan Buri 1 relied more on soil water from deeper layers in response to reduction in the moisture content of surface soil. Interestingly, RWC at 4 and 7 days after water deficit tended to be greater in the Suphan Buri 1 than in Pathum Thani 1 under drying of the surface soil when rice was sown at 5 cm depth (water deficit at 30 DAS). This would be primarily due to higher root length density at the 10 to 15 cm depth in the Suphan Buri 1 than in Pathum Thani 1 (Table 3).

These results suggest that the deeper root development of Suphan Buri 1 gave this cultivar an advantage over the Pathum Thani 1 under conditions of intermittent drought. This supports the results of Kamoshita *et al*. (2000) in a pot experiment, where genotypes with a higher root length density at a depth of 30 to 40 cm extracted more soil water from deeper soil during drought. This suggests the possibility that the rice plants continued to take up some soil water from the surface layer in the experiment. However, the soil water content of soil in the surface layer might be affected by a larger amount of soil evaporation in the field experiment with water deficit and longer drying period than the pot experiment.

In the present study, the rice cultivars also differed in above-ground biomass. The cultivar Suphan Buri 1 showed higher above-ground biomass than the Pathum Thani 1. Total above-ground biomass might also affect canopy water use when the surface soil was relatively wet, considering rapid soil moisture depletion along the soil profile with Suphan Buri 1 compared with Pathum Thani 1 cultivars at 30 DAS. The differences among the cultivars in total above-ground biomass and hence, in transpirational demand may confuse the effect of the rooting pattern on the extraction of soil water during the drying period (Lilley and Fukai, 1994).

Thus, the advantages offered by a deep root system depend not only on the severity of the drought conditions but also on shoot size, which determines the potential amount of soil water that is extracted during water stress that can occur in upland or lowland rainfed rice. Indeed, our experiment shows superior plant characteristics than deep root development and total above-ground biomass associated with plant water status or leaf relative water content during the drying period (Table 3, Fig. 3). A deep sowing depth at 5 cm depth has been found to maintain higher leaf water potential during drought stress. If sown deep at 5 to 7 cm, it could catch up at later growth; it may avoid risks of seeds drying out before germination at low depths and exhaustion of seedling reserves when seeds are placed too deep in the soil. Although, this experiment showed no significant difference between rice cultivars regarding grain yield, we found that the Suphan Buri 1 cultivar had a higher root length density, greater above-ground biomass and better relative water content of seedlings than the Pathum Thani 1 resulting in the highest grain yield (Table 4).

Long root length density was considered an important characteristic of rice cultivars for successful establishment of seeds sown deep in the soil and for grain yield (Fig. 2). This may result from the cultivar's ability to maintain a relatively good water status, since plant water status during reproductive stages is closely associated with both spikelet sterility (Garrity and O'Toole., 1994) and spikelet formation and abortion due to differences in physiological metabolism, such as a greater translocation of assimilates to young panicles (Saini and Westgate, 1999). Shallow sowing at 0 or 1 cm was also not optimum and gave consistently poorer establishment and lower yield than at 5 cm seeding depth.

In present experiment, sowing at about 5 cm into moist soil offers a better opportunity for the crops to develop the longest root length density. This may mean that rice better tolerates a short drought period and is able to increase crop yield because of better establishment (above ground biomass) compared with seed planted shallow (0-1 cm). Sowing depth is also an important factor in crop management practices (Campbell *et al*., 1991;

Kirby, 1993). Campbell *et al.* (1991) found that deeper sowing (below 8 cm) is also disadvantageous and leads to reduced yield. Hadjichristodoulou *et al.* (1977) also found that, in Cyprus, wheat and barley planted at 5 cm produced significantly more yield (79% in wheat, 82% in barley) than did the same crops planted at 15 cm. It is found that, for deep seeding depth, it might be expected that roots from plants starting from 3 cm deep in the soil might seek out moisture deeper in the profile. Thus, it is surmised that the top 3 cm of the soil dried out so quickly that these roots either dried out or found it difficult to penetrate the drier soil near the surface. To dry the soil to 6 cm, however, would take 3-4 days assuming diffusion-limited soil evaporation, allowing the roots more time to

In present study, there was a significant in above ground biomass between rice cultivars when vegetative stage drought at 7 days after water stresses (Table 1). This would be primarily due to higher root length density at the 5 seeding depth in the Suphan Buri 1 than the Pathum Thani 1 (Table 3). These results suggested that the deeper root length of the Suphan Buri 1 gave this cultivar an advantage over the Pathum Thani 1 under vegetative stage drought. This supports the results of Kamoshita *et al.* (2004) in a pot experiment, where genotypes with a higher root length density at a depth of 30 to 40 cm extracted more soil water from deeper soil under drought. Lilley and Fukai (1994) suggested that the differences among the rice cultivars in above ground biomass may confuse the effect of rooting pattern on the extraction of soil water during the drying period. Then, the advantage offered by a deep root system depends not only on the severity of the drought conditions but also on above ground biomass under the water stress that can occur in vegetative stage drought.

Genotypic variation for maintain higher leaf water potential during drought stress has been well documented in upland rice (Jongdee *et al*., 2002). In the present study, there was no significant difference between cultivars for relative water content at the vegetative stage drought (Table 3). But, there was a significant difference seeding depth for root length density at the 7 days after water stress (Table 3). Also, this experiment found a significant linear relationship between root length density and seed yield under drought stress (Fig. 2.) and less in relationship between relative water content and yield (Fig. 3). This root length density might be associated with increased seeding depth, thus, improved water conductivity. Resulting rice seeding depth at 5 cm had greater number of spikelet per panicle and seed yield than other seeding depths under drought stress (Table 4).

In the present study, there was no found significant difference between cultivars for yield and yields component (Table 4). The Suphan Buri 1 had a greater the number of spikelet per panicle and seed yield than the Pathum Thani 1 when rice seeding at 5 cm depth and under drought stresses (Table 5). This is maybe indicate that the difference between the cultivars is consistent across environments. Fischer and Maurer (1978) concluded that wheat cultivar yield averaged across drought levels is an appropriate summary of cultivar differences under drought in each particular experiment. When water stress was imposed during vegetative stage, rice seeding at 5 cm depth was affected to longest root length density and less reduces the number of spikelet per panicle.

Present results indicated that deep root development of rice was primarily advantageous for soil water extraction and plant water stress during water stress and that the advantages of a deep root system were affected by total above-ground biomass, which had strong effects on plant water status under erratic rain-fed conditions.

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