Australian Journal of Crop Science
3(5):278-286 (2009)
ISSN: 1835-2707

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Effect of conventional, SRI and modified water management on growth, yield and water productivity of direct-seeded and transplanted rice in central Thailand

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Abstract

Innovations in water saving technologies are the foremost needs in today's rice production as water has become the most limiting resource in agriculture. This study was conducted for evaluating conventional, system of rice intensification (SRI) and modified water management methods in direct-seeded and transplanted rice in order to determine the best water management practice that increases grain yield and water productivity. A 2x3 factorial experiment, where two methods of establishment [viz. direct seeding and transplanting with 8 day old seedlings (TPR)] and three water management methods [viz. conventional water management (CWM), two-week irrigation followed by two-week non-irrigation (2W-2N) and one-week irrigation followed by three week non-irrigation (1W-3N)], was conducted in a randomized complete block design with four replicates. Soil moisture contents at 0-15 cm and 15-30 cm soil layers reached near the lower levels of the readily available water (RAW) during non-irrigation periods in 2W-2N and 1W-3N, but never depleted below RAW level. There were interactions between establishment method and water management for leaf area index (LAI), root parameters, yield and yield components, harvest index and water productivity. Conventional water management was inferior to 2W-2N and 1W-3N, and direct seeding and transplanting had no difference. Overall results showed that there are greater benefits of water saving, yield and net income with 1W-3N water management combined with direct seeding over SRI and CWM and transplanting for 120-day old Suphan Buri 1 hybrid.

Key words: Direct seeding, transplanting, irrigation, non-irrigation, Suphan Buri 1

Introduction

Rice is the staple food of more than a half of the world population (Vijayakumar et al., 2006; Sinha and Talati, 2007). The demand for rice increases with increasing population, and is expected to rise by a further 38% within the next 30 years (Satyanarayana, 2005). The availability of fresh water is one of the major constrains for increasing rice production in Asia (Lampayan *et al.*, 2003). About 80% of the available water resources world-wide is used by the agricultural sector (IFPRI, 1995; Sujono, 2007) and of which irrigated rice makes the highest demand. Currently, on-farm availability of fresh water is reducing due to many reasons (Uphoff, 2006). Future predictions indicate that two million ha of fully irrigated and thirteen million ha of partially irrigated lands in Asia during wet season would experience a "physical water scarcity", and 22 million ha of irrigated lands in the dry season would face "economic water scarcity" by 2025 (Tuong and Bouman, 2003). This will necessitate and encourage research on alternative measures for reducing water use and increasing the efficiency of water use in order to ensure food security.

Madagascar Rice Production System- MRP is a centuries-old technique that was developed for saving water in irrigated rice production (Laulanié, 1993), and was recently revamped as System of Rice Intensification (SRI) (Uphoff and Randriamihariosa, 2002). This system alternates irrigation for two weeks (called "wetting") followed by suspending irrigation for the two weeks (called "drying"), and collectively referred to as "alternative wetting and drying" (AWD). The AWD is continued until flowering and after which the field is inundated to a 2-3 cm

Table 1. Soil characteristics in the research plots at the Agricultural Systems Research Farm

Soil characteristics	Characterization/ quantification
Texture	Clay
Sand	26.90(%)
Silt	29.38(%)
Clay	43.72(%)
Bulk density	1.17 g/cm^3
pH (H_2O) 1:1	7.2
EC	0.12 mS/cm
Organic C	3.36 %
Total N	0.1%
Available P	4.39 ppm
Exchangeable K	294.56 ppm
Field capacity	60 mm
Permanent wilting point	29 mm

depth until full dough stage, and then drained to facilitate grain drying. This practice enables farmers to save irrigation water by 25-50% and also getting higher yields and more profits than conventional rice production (CRP) (Uphoff, 2006). The yield levels as high as 8 to 10 t/ha have been reported with SRI, but mostly below 5 t/ha in CRP (Uphoff and Randriamiharisoa, 2002; Uprety, 2004). The suspension of irrigation for two weeks promotes deep root growth thus facilitating rice plants to explore deep soil layers for water and nutrients (Clark *et al.*, 2002), which appeared to be the main contributing factor for higher yields (Fukai and Kamoshita, 2004) and higher water productivity than CRP (Tuong and Bouman, 2003) and profits. The SRI is becoming popular in Asia at present. As far as the need for increasing rice extent and yields are concerned, there is a need for continuation of further research to save water and develop other technological interventions beyond what is practiced in SRI. Therefore, this study was conducted to determine effects of reducing the irrigation period and extending the length of non-irrigation period on growth and yield of rice in order to further conserve irrigation water beyond SRI practices while increasing or maintaining rice yields.

Materials and methods

This experiment was conducted during the dry period from December, 2007 to May, 2008 at the Agricultural Systems Research Farm, Asian Institute of Technology, located in the Central Region of Thailand (14° 04' N latitude, 100° 37' E longitude and at 2.27 m above mean sea level).

The climate is tropical humid with distinct wet and dry seasons. The dry condition prevails from November to early-April of the following year.

The soils belonged to Rangsit series which is characterized by deep, very fine clayey and extremely acid sulphate with pH of 4.5-4.9, and suitable for rice culture. The soil characteristics are shown in the Table 1.

A 2x3 factor factorial experiment comprised of two methods of establishment [viz. direct seeding and transplanting] and three water management methods [viz. conventional water management–CWM, two-week irrigation followed by two-week non-irrigation – 2W-2N, and one-week irrigation followed by three-week non-irrigation –1W-3N], tested in a Randomized Complete Block Design with four replicates.

Experimental plots (8m x 4m) were prepared by adopting conventional land preparation techniques. Plots were demarcated and then hydraulically isolated with 0.5 m wide earthen bunds and covering with black plastic sheets which was extended vertically downward to a depth of 0.5 m to avoid seepage across plots. The hard pan was at 0.4 m depth. Cattle manure was applied to each plot at the rate of 10 t/ha at two weeks before puddling.

The non-photosensitive 120-day old rice hybrid Suphan Buri 1 recommended for the central plain under irrigation facilities by the Thailand Department of Agriculture (DOAT) was used. Rice was established manually. Pre-soaked and pre-germinated seeds were planted in DSR, and eight-day old seedlings were transplanted in TPR at 25cm x 25cm spacing and 3.2 x 10^5 plants/ha as per treatments. In order to provide similar weather conditions for plants in both direct-seeded rice (DSR) and transplanted rice (TPR), the direct seeding was done first and seedlings obtained from nursery were transplanted on the 8th day in TPR plots. Plots were irrigated in the first week to support establishment. Each plot was applied with di-ammonium phosphate (N 21% and P 23%) at the rate of 188 kg/ha at one week after establishment. Potassium was not applied as soil was rich in K. Nitrogen (N) was top dressed at 91 kg/ha at 25 days after establishment and at panicle initiation. Plots were maintained with a water level of 3-5 cm during irrigation period. Indicator scales were set up in each plot to observe water level. Irrigation following non-irrigation was continued for specified periods as per treatments up to flowering. Thereafter water level was maintained above soil level until grains reached hard dough stage, i.e. two weeks before harvesting, and then drained out to facilitate grain drying.

Hand weeding was regularly adopted to control weeds, while insect pests were controlled with integrated pest management (IPM) practices. Golden apple snails -GAS (*Pomacea canaliculata*) were managed by applying copper sulfate during seedling stage at 6.25 kg/ha as recommended by the DOAT. In

Table 2. Monthly average weather parameters during 2007-2008

Month	RF, mm	Min. Temp. ^{o}C	Max. Temp. ^{o}C	RH %		SR, MJ m^{-2} d^{-1}
				7.00 a.m.	2.00 p.m.	
December	-	21.8	33.5	85	51	21.9
January	-	20.9	33.1	87	45	18.3
February	10.2	22.5	33.0	86	57	16.3
March	1.70	25.0	35.6	90	62	20.3
April	14.5	28.5	35.5	89	59	20.2
May	16.6	25.8	34.5	87	65	18.6

Table 3. Effect of establishment method X water management method interaction on different phenological stages, shoot growth parameters and root length density at 0- 15 cm and 15-30 cm soil layers

		Phenological stage			Shoot growth parameters			RLD, cm/cm^{3}	
Establis-hment method	Water mgt. method	Beginning Flowering	50% flowering	Harvest	LAI at flowering	Total tillers at harvest no./hill	Total biomass t/ha	at 0-15 cm soil layer	at 15-30 cm soil layer
DSR	CWM	78 ± 0	86 ± 0	115 ± 0	4.6 ± 0.2	19.8 ± 2.4	4.5 ± 0.1	3.5 ± 0.5	0.6 ± 0.1
	2W-2N	79 ± 0	88 ± 0	115 ± 0	4.3 ± 0.5	18.8 ± 1.0	5.1 ± 0.1	2.9 ± 0.1	0.8 ± 0.0
	1W-3N	79 ± 0	87 ± 0	113 ± 0	3.2 ± 0.8	21.8 ± 1.9	5.7 ± 0.3	2.8 ± 0.1	0.9 ± 0.1
TPR	CWM	84 ± 0	91 ± 0	120 ± 0	2.9 ± 1.0	17.3 ± 1.7	3.8 ± 0.2	2.7 ± 0.1	0.4 ± 0.1
	2W-2N	85 ± 0	92 ± 0	119 ± 0	3.1 ± 0.2	20.8 ± 0.9	3.8 ± 0.0	2.6 ± 0.1	0.8 ± 0.0
	1W-3N	85 ± 0	92 ± 0	118 ± 0	3.5 ± 0.4	18.3 ± 0.5	4.5 ± 0.2	2.6 ± 0.0	0.9 ± 0.0
LSD(0.05)		0	0	0	0.9	2.3	0.3	0.3	0.1
Analysis of variance									
Source of variation	DF								
EM	1	216.00***	130.67***	130.67***	4.20*	6.56***	10.67*	1.11***	0.06***
WM	2	2.67***	4.67***	8.67***	0.48	1.75***	5.17	0.37***	0.34***
EM*WM	2	0.00	0.67***	0.67***	1.96*	0.15*	17.17**	0.19*	0.01 *
Error	18	0.00	0.00	0.00	0.28	0.03	2.36	0.05	0.00
CV%		0.00	0.00	0.00	16.09	3.94	7.91	7.50	6.48

EM- Establishment method; WM- Water management method; DSR – Direct- seeded rice; TPR –Transplanted rice; CWM – Conventional water management; 2W-2N - two weeks irrigation followed by two weeks non-irrigation; 1W-3N- one week irrigation followed by three weeks non-irrigation; RLD = Root length density

addition, suction point of the irrigation pump was covered with a fine plastic mesh to prevent tiny GAS entering with irrigation water.

Experimental observations

Time for commencement and 50% of plants reaching flowering and maturity was recorded. Soil moisture contents (SMC) at 0-15 and 15-30 cm layers were estimated at three day intervals from the time of suspension of irrigation using gravimetric method (Gardner and Klute, 1982). Soil moisture contents at the field capacity (FC) and the permanent wilting point (PWP) was determined in each plot at the beginning using pressure plate method (Cassel and Nielsen, 1986). Eight plants were used for estimating leaf area per hill and length and width method (Yoshida, 1981).

To estimate yield parameters, eight rice hills were randomly selected from each plot and total number of tillers and panicles per hill, filled and unfilled grain number per panicle, and 1000-grain weight (at 14% moisture content) were recorded. Grain yield was measured in an area of 6m x 2m in each plot leaving 1.0 m border area at 14% moisture content. In addition, all non-grain materials in the same area were harvested at the ground level, fresh weights were recorded, samples were oven–dried at 80^{o}C for 72 hours (i.e. to a constant weight) and dry weights were recorded. Using this information, total fresh weights were converted to dry weights. The spikelet sterility percentage was determined by dividing the number of unfilled grains per panicle by the total number of grains per panicle and multiplying by 100 (Yang *et al.*, 2008).

Root parameters were recorded from five consecutive plants in a row soon after harvesting. A soil core with the diameter of 15 cm and depth of 30 cm was taken 10 cm away from the base of each selected plant hill. The soil in the core was divided into 0-15 cm and 15-30 cm layers and roots were then carefully washed with running water on a mesh (6.4 per cm) and the total root length in each soil core at 0-15 cm and 15-30 cm depth was measured using a meter ruler and the grid line intersect method (Bohm, 1979). Root dry weights were recorded after oven-drying the roots at 80°C for 72 hours to a constant weight. Soil was then dug vertically downward as a trench to a depth until all roots were visible, and root depth was measured and recorded. Root length density (RLD) was calculated.

Volume of water applied at each irrigation and throughout the growing season was recorded by measuring the discharge, time duration and height of the water level. The rainfall, solar radiation, relative humidity and temperature of the site were recorded throughout the cropping period. The water productivity (WP) [grain yield (kg)/total water input (m^3)] and harvest index (HI) [grain yield/biomass yield (kg/ha) (Holliday, 1960)] were calculated. Analysis of variance (ANOVA) was performed and Fisher's Protected Least Significant difference (LSD) was used for mean separation (Steel and Torrie, 1980).

Results and discussion

Weather condition

The weather data during the study showed that solar energy ranged from 18.28 to 21.92 MJ m^{-2} d^{-1}, maximum temperature (Max. Temp.) from 33.03 to 35.60°C, minimum temperature (Min. Temp.) from 20.9 to 28.51°C, relative humidity 45 – 90 % and rainfall from 0 to 16.58 mm (Table 2). Since the experiment was conducted during regular dry period, rainfall did not interfere with the alternate irrigation and non-irrigation treatments during vegetative period.

Soil moisture contents

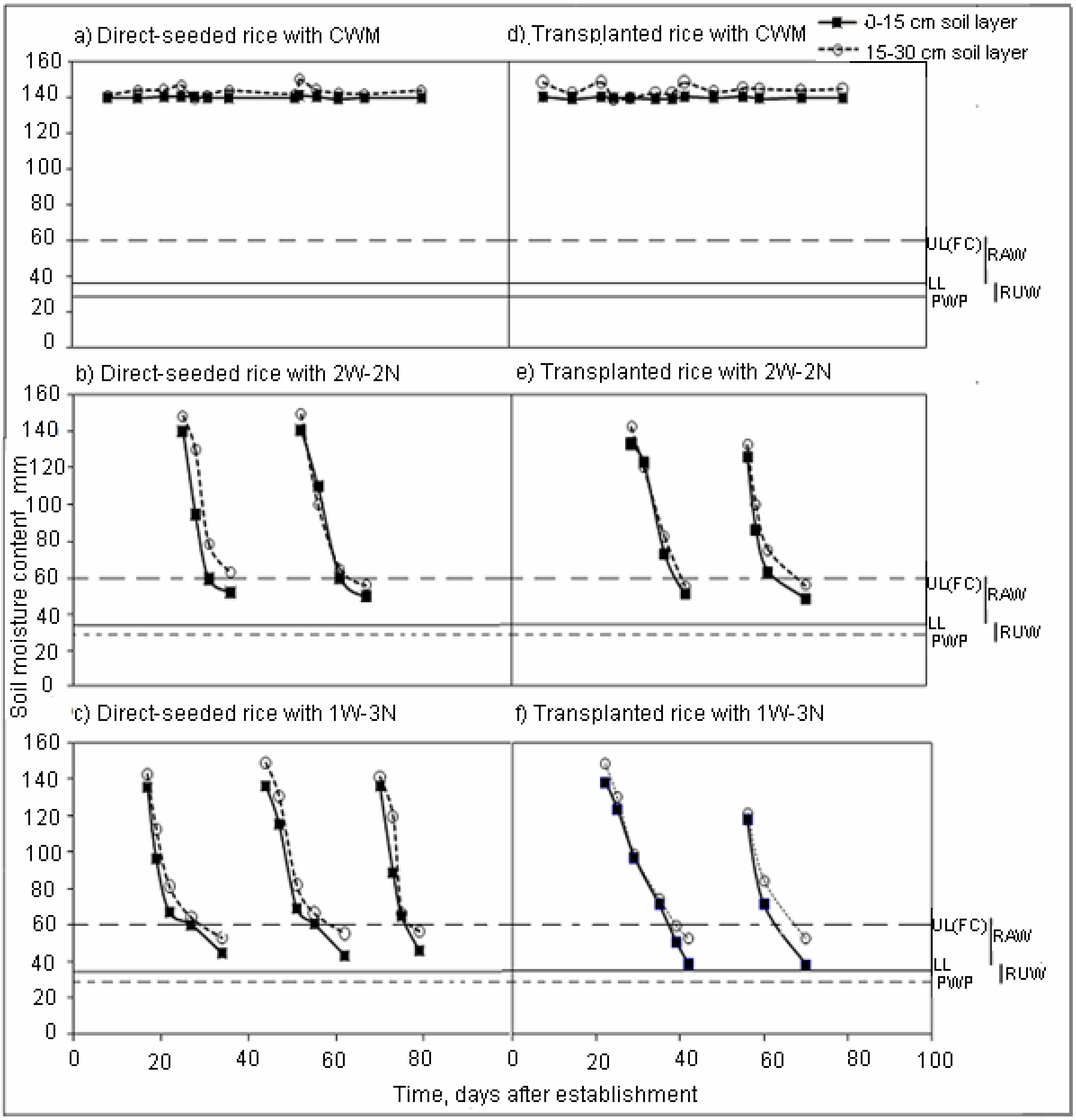
The variation of SMC at 0-15 cm and 15-30 cm depths during the study under different treatment combinations is presented in Fig.1. Suspension of water was adopted twice in all the treatments, except in DSR with 1W-3N which received three suspensions during vegetative period.

The CWM had always its water level near or above FC (i.e. in the saturation range). In the saturation range, the depletion of SMC to FC was faster in DSR than TPR in both soil layers in all water management treatments. But within the available water range, TPR had faster depletion than DSR. The depletion was also relatively faster in 0-15 cm layer than 15-30 cm layer of the profile. But SMCs in neither of the water management methods nor the establishment methods reached below the lowest limit of readily available water (RAW) during non-irrigation period. Treatment with 1W-3N water management had greater depletion than 2W-2N, and this was due to its longer non-irrigation period, and in TPR over DSR could be due to the variable root formation. Naklang et al. (1996) too confirmed this information using IR-2 rice variety. McDonald *et al.* (2006) reported that in dry–down periods, the TPR showed greater depletion of SMC than that of DSR in the upper layer. However, rice plants in both water management and establishment methods were not subjected to severe water stress in this study.

Growth performances

A significant interaction between establishment method and water management method existed for the time taken to reach beginning and 50% flowering and maturity (Table 3). Flowering commenced earlier in DSR than TPR, and also in CWM within each establishment method than both in 2W-2N and 1W-3N. The same difference existed even up to 50% flowering and maturity. The differences could have been associated with time required to establish the root system of transplanted seedlings as suggested by McDonald *et al.* (2006). In the current study, there was no drastic variation observed in reaching phenological stages within each method of establishment. This shows that rice has not been exposed to severe water stress, as water stress leads to growth plasticity, and shortening the time interval between phenological stages (Puckridge and O'Toole, 1980; Turner *et al.*, 1986; Inthapan and Fukai, 1988).

There was a significant interaction between establishment method and water management for LAI at flowering, tiller number per hill, above-ground non-grain biomass at harvest and RLD (p=0.05) (Table 3). DSR had higher LAI than TPR in all water management treatments, except 1W-3N (Table 3). The LAI was highest in CWM in DSR, moderate in 2W-2N and lowest in 1W-3N. In TPR, the reverse was observed. The higher LAI in DSR was attributed to increased number of tillers per hill in the CWM method. Similar results were reported by Dingkuhn *et*



UL - Upper limit of water availability (Field Capacity) ; LL - Lower limit of water availability ;
RAW - Readily available water ; RUW - Readily unavailable water ; PWP - Permanent wilting point

Fig 1. Behaviour of SMC in direct-seeded and transplanted rice during the period of suspension of irrigation as influenced by the interaction between water management method and establishment method.

Table 4. Effect of establishment method X water management method interaction on the number of panicles per hill and filled grains per panicle, grain yield, harvest index (HI) and water productivity (WP)

Establi-shment method	Water Mgt. Method	Panicles no./hill	Filled grains no./panicle	1000-grain wgt. g	Spikelet sterility %	Grain yield t/ha	Harvest Index	WP kg/m^3
DSR	CWM	17.8 ± 2.4	127.0 ± 15.2	27.5 ± 0.6	10.8 ± 5.7	5.9 ± 0.8	0.57 ± 0.03	0.34 ± 0.04
	2W-2N	17.8 ± 1.5	107.8 ± 06.6	27.9 ± 0.9	11.2 ± 0.9	4.7 ± 0.3	0.48 ± 0.01	0.39 ± 0.02
	1W-3N	19.8 ± 1.3	128.8 ± 04.3	26.6 ± 1.1	09.4 ± 4.0	6.7 ± 0.2	0.54 ± 0.02	0.67 ± 0.02
TPR	CWM	19.3 ± 1.7	126.5 ± 09.1	27.6 ± 1.1	07.9 ± 2.8	5.3 ± 0.6	0.58 ± 0.02	0.30 ± 0.03
	2W-2N	19.5 ± 0.6	132.5 ± 11.3	26.8 ± 0.8	07.9 ± 2.9	6.8 ± 0.7	0.64 ± 0.02	0.59 ± 0.06
	1W-3N	17.3 ± 0.9	129.3 ± 05.6	26.8 ± 0.2	06.2 ± 1.2	6.1 ± 0.4	0.58 ± 0.02	0.64 ± 0.40
LSD(0.05)		2.2	14.1			0.8	0.003	0.057
Analysis of Variance								
Source of variation	DF							
EM	1	1.50	16.67	0.48	57.84	0.58	0.029***	0.013**
WM	2	3.79	405.13***	1.68	6.98	1.29*	0.001	0.220 ***
EM*WM	2	9.13*	125.79***	1.15	0.09	4.96***	0.012***	0.037***
Error	18	2.22	24.08	0.72	13.13	0.27	0.004	0.002
CV%		8.20	4.28	3.11	40.66	8.79	3.860	7.910

EM- Establishment method; WM- Water management method; DSR – Direct- seeded rice; TPR –Transplanted rice; CWM – Conventional water management; 2W-2N - two weeks irrigation followed by two weeks non-irrigation; 1W-3N- one week irrigation followed by three weeks non-irrigation; WP = Water productivity

al. (1990) and San-Oh *et al.* (2008). In contrast Zheng *et al.* (2004) reported that SRI practices have shown higher LAI than conventional rice production systems. The number of tillers was highest in DSR receiving 1W-3N which was significantly greater than the rest of treatments, except 2W-2N in TPR. Plots receiving water frequently had lower tiller production than 1W-3N. This agrees with the findings of Dingkuhn *et al.* and Schnier et al. (1990) who reported higher tiller density in DSR than TPR. According to Gupta *et al.* (1976) and Hossain *et al.* (2002), intermittently irrigated rice produced more adventitious tillers during recovery after the re-irrigation. The highest above-ground biomass was in DSR receiving 1W-3N which was significantly greater than the rest. However, 1W-3N had always a higher biomass in both DSR and TPR (p=0.001). Dingkuhn *et al.* (1990), Schnier et al. (1990) and Tuong *et al.* (2002) also reported similar results, where DSR maintained significantly higher above ground biomass than TPR. This difference was attributed to higher tiller number in DSR with intermittent irrigation (Murthy and Murthy, 1984).

The RLD was greatly reduced in the 15-30 cm soil layer compared to 0-15 cm. Within each method of establishment, CWM had significantly higher RLD than other water management methods. In 15-30 cm layer, RLD significantly increased with increasing the duration of suspending irrigation. The highest RLD was in the treatment 1W-3N in 15-30 cm layer. The RLD variation between DSR and TPR under CWM compared to intermittently irrigated plots agrees with the findings of Samson *et al.*, (2002) and Wang *et al.*, (2009), while decrease in the RLD with increasing soil depth agrees with Lilley and Fukai (1994).

Higher RLD in top soil layer indicates the plants' tendency to absorb water whenever available, while in deeper profiles indicates relative tendency to tap deeper soil layers in situations of reduced water availability in the upper soil layers. Root depth significantly varied due to method of establishment and water management, but there was no interaction between two factors. The DSR had a higher root depth (56.8 cm) than TPR (50.8 cm) (p=0.05), and increasing the length of non-irrigation period increased root depth (1W-3N = 72.9 cm; 2W-2N = 55.4 cm and CWM = 32.5 cm). This may be due to depletion of water with increasing the duration of suspension of irrigation, and the promotion of entry of oxygen into deeper soil profiles promoting root growth to such layers (Tuong *et al.*, 2002; Samson *et al.* (2002).

Yield and yield parameters

There was a significant interaction between method of establishment and water management on the number of panicles per hill and filled grains per panicle, and grain yield, but had no significant effect on 1000-grain weight and spikelet sterility (Table 4).

There was an increasing trend of the number of panicles in DSR with increasing the period of non-irrigation with the highest panicles number resulting in 1W-3N, though the difference was insignificant within same method of establishment (Table 4). In TPR, the same water management had the lowest panicle number per hill. On the other hand, the water management 1W-3N had a significantly greater panicle number in DSR than TPR. The filled grain number per panicle was lowest in 2W-2N in DSR, while highest in TPR (Table 4). Both 1000-grain weight and spikelet sterility % did not show significant differences among treatments, but their slight variations would have contributed to the differences in final grain yield among treatments (Table 4). Soga and Nozaki (1957) and Yoshida (1981) too reported that 1000-grain weight remained stable as far as there was no water stress during grain filling, and Ashraf *et al.* (1999) and Trillana *et al.* (2001) reported grain weight to be the least affected by the environment.

Grain yield was significantly greater in DSR with 1W-3N and 2W-2N in TPR than the rest of water management tested, with no significant difference between the two values. Results indicated the possibility of extending the non-irrigation period up to three weeks for Suphan Buri 1 hybrid of rice. McDonald *et al.* (2006) and Sinha and Talati (2007) also observed lower yields under CWM compared to intermittently irrigated rice. The non-existence of the variation of the spikelet sterility could be attributed to the low water stress in rice plants faced during the growth period (Fig. 1).

There was a significant interaction between establishment method and water management for HI and WP (Table 4). In this study, the highest HI was associated with 2W-2N in TPR and CWM in DSR. The 1W-3N in DSR had a second highest grain yield in this study and at the same time moderate HI due to high biomass production. Therefore, HI appears to be unsuitable as an indicator of productivity of different water management practices. Within establishment methods, 1W-3N had the highest WP, but the DSR had a higher overall WP. This shows that TPR needed more water compared to DSR as its root system is well distributed in the upper payers. These findings agree with the findings of Mann *et al.* (2004) who also reported that higher water requirement of TPR than DSR. Therefore, DSR would be fairly a good option for using water efficiently in rice production. This provides valuable information for saving water and solving looming water crisis in rice production (Mann *et al.*, 2004).

The net income was highest from 1W-3N in DSR (958 US $), moderate from 2W-2N in TPR (791 US $) and lowest from CWM in TPR (271 US$) and 2W-2N in DSR (459 US$). Reduction of net income from CWM in TPR and 2W-2N in DSR was due to lower yields than the rest of the water management treatments. Water management 1W-3N combined with DSR gave 21% higher net income compared to 2W-2N in TPR, and contributory factors were high grain yield, and reduced cost of labour for establishment and irrigation, but increased cost of weeding restricted further increase in the net income.

Conclusion

Direct seeding coupled with water management of one-week irrigation for initial seedling growth and weed suppression, followed by alternating one-week irrigation and three-week non-irrigation until flowering and thereafter irrigation until dough stage of rice gives higher grain yield, water productivity and net income compared to conventional water management as well as the practices specified in the SRI.

Acknowledgements

Authors thank the financial assistance by Norwegian Government for the graduate studies of the first author at the Asian Institute of Technology, Thailand.

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