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STUDY OF AGE OF SEEDLINGS AT TRANSPLANTING ON GROWTH DYNAMICS AND YIELD OF RICE UNDER ALTERNATING FLOODING AND SUSPENSION OF IRRIGATION OF WATER MANAGEMENT

G.A. Sanjeewanie Ginigaddara and S.L. Ranamukhaarachchi*

Asian Institute of Technology, Thailand

Abstract

Age of seedlings at transplanting is considered for influencing grain yield in water scarce rice production systems, primarily by laying the foundation for determining the number of panicles at harvest. This experiment investigated plant growth, yield and yield components of rice when transplanted at varying ages under alternating flooding and suspending irrigation in water management for saving water. In a greenhouse study, nine ages of seedlings starting from 4 to 12 days were transplanted in pots and the performance of each age was compared with a direct-seeded crop in a completely randomized design with five replicates.

Soil moisture content (SMC) in the 0-15, 15-25 and 25-50 cm soil layers were monitored. SMC reached near the lowest level of readily available water (RAW), but never reached below RAW during the first suspension of irrigation in all the treatments. However, SMC reached PWP in the 15-25 cm soil layer at the second period of suspension of irrigation.

The number of tillers, leaf area per hill, plant height and above ground non-grain biomass did not differ between direct-seeded rice (DSR) and transplanted rice (TPR) with 4-12-day old seedlings. Maximum tillering occurred between 5 and 6 weeks after establishment in all age groups of seedlings. However, root depth, total root length, root dry weight and shoot to root ratio were significantly greater in DSR than TPR. Age of seedlings at transplanting had a significant effect on number of productive tillers per hill, filled grains per panicle, panicle length, 1000-grain weight, grain yield and panicle setting rate. However, harvest index was not significantly affected.

Establishment of rice by direct seeding and transplanting up to 12 days did not differ in handling the transplanting shock and resuming normal growth phase rapidly. And also, there was no difference in the tillering potential and the growth dynamics of seedlings of all ages used, but 9-day old seedlings had higher yield under alternating flooding and suspending irrigation compared to other ages of seedling and water management.

Introduction

Seedling age at transplanting is an important factor for uniform stand of rice (Paddalia, 1980) and regulating its growth and yield (Bassi *et al.*, 1994). Tillering is an important agronomic trait which finally determines the number of panicles, grains and grain yield per unit land area (Li *et al.*, 2003). Tillering dynamics of the rice plant greatly depends on the age of seedling at transplanting (Pasuquin *et al.*, 2008). There is an in-built pattern of physiological development in the rice plant which puts out tillers regularly and sequentially which is described in terms of *phyllochrons.* Berkelaar (2001) reported that for maximum tillering, the plant has to complete as many *phyllochrons* as possible during its vegetative phase. Each tiller produces another two *phyllochrons* later under favorable growing conditions (Singh *et al.*, 2007). When a seedling is transplanted carefully at the initial growth stage, the trauma of root damage caused during uprooting is minimized following a rapid growth with short *phyllochrons*.

Mobasser *et al.* (2007) observed that when seedlings stay for a longer period of time in the nursery beds, primary tiller buds on the lower nodes of the main culm become degenerated leading to reduced tiller production. When the seed is not planted too deep, tillering starts early in about fortnight from sowing in case of direct seeding. But, transplanted rice takes little longer time period to start tillering as it first needs more time to recover from transplanting shock. When rice seedlings are transplanted at the right time in terms of age, tillering and growth proceed normally (Mobasser *et al.*, 2007), and only a fewer tillers are produced during vegetative period leading to poor yield if transplanting is delayed.

The age of seedlings at transplanting is an important criterion in rice production as it primarily contributes to the number of tillers produced per hill. In the system of rice intensification (SRI), single seedlings are transplanted at a wider spacing (25cm x 25cm) than conventional rice production (Latif, 1995). Stoop *et al.* (2002) reported that young seedlings

* Corresponding Author, *Email*: ranamuka@gmail.com

below 10 days of age are transplanted in SRI, which produce higher number of tillers than normal rice production systems, which contribute to higher grain yields (Krishna *et al.*, 2008). Same authors noted that rice seedlings transplanted before commencing the fourth *phyllochron* retained their higher tillering potential than that of seedlings of more than 14 days old. In recent studies of Makarim *et al*. (2002), 14-day old seedlings have performed better than transplanting 21- to 23-day old seedlings. McHugh *et al.* (2002) and Thiyagarajan *et al* (2002) observed highest yields with 8 -15 days old seedlings transplanted at 25 hills m^{-2} in Madagascar and with 10-day old seedlings in Sumatra. Krishna and Biradarpatil (2009) observed high grain yields of 3.25 t ha^{-1} with 12-day old seedlings than 8-, 16- and 25-day old seedlings and the yield decline of seedlings of latter three ages was primarily attributed to the reduction in the number of tillers.

The age of seedlings at transplanting and its influence of determining total and productive tillers and the ability of the resulting plants to perform under induced water stress conditions with its physiological and adaptation mechanisms and giving rise to high grain yield are some of the key expectations of water saving rice production systems. This has been a topic of discussion based on three aspects: 1) What age of tillering would be most appropriate with respect to obtaining optimum number of productive tillers that eventually determine the magnitude of the yield, as the number of productive tillers is a yield determinant; 2) In terms of convenience of handling seedlings during uprooting and transplanting, as primarily a transplanting of rice is considered as a way of minimizing the rice-weed competition, sizeable seedlings are required to facilitate for inundation of the rice field immediately after transplanting to a sufficient depth and to reduce very fine land preparation and near perfect leveling for water management; and 3) With the introduction of water saving rice production such as "Madagaskar Rice Production System", which was later revived with some modifications as "System of Rice Intensification – SRI", as a climate change adaptation measure when water became more and more a limiting resource and for exploring the physiological potentials of rice seedlings on tillering to increase the number of productive tillers for increasing grain yield, there was a need to identify the best age(s) of seedlings for transplanting. However, there are many different arguments on this subject although rice has been grown for thousands of years. Therefore, growth dynamics including tillering pattern and its contribution to final grain yield under water saving irrigation was felt worthy of further investigating in detail under absolute conditions. This study was conducted to determine the effect of age of seedlings of rice at transplanting on the ability of recovery of seedlings from transplanting shock, tillering behavior of seedlings, and growth dynamics and overall yield potential of rice plants under alternating flooding and suspension of irrigation (AFSI). As the water saving rice production is currently becoming popular in Asian countries, the results of this study will be helpful in deciding the seedling age of transplanting, that can contribute to high tiller production, optimum planting density and increasing grain yield.

Materials and Methods

Location

The experiment was conducted in pots in a green house at the Agricultural Research Farm of the Asian Institute of Technology, Thailand (Latitude, 14.04'N, Longitude 100.37'E and ASL, 2.27m) from August, 2008 – February, 2009.

The soil belonged to Rangsit series with deep, very fine clayey texture and pH (H_2O) of 4.5-4.9. Soils had total N 1200 ppm [Kjeldahl method (Bremner, 1982)], available P 16.81 ppm [Bray II method (Bray and Kurtz, 1945)] and exchangeable potassium 156.4 ppm [ammonium acetate extraction method (Ryan *et al.*, 2001)] before commencing the experiment. Organic matter content was 3% [Walkley – Black method (Nelson and Sommers, 1982)] and electrical conductivity of 0.18 mS cm^{-1} [at 1.5 sample solution (Ryan *et al.*, 2001)]. Mechanical analysis of the soil using the hydrometer method (Day, 1965) showed clay, silt and sand fractions of 49.38, 26.87 and 23.75 percent, respectively. Bulk density was 1.29 g cm^{-3}.

Treatments

Nine different ages of rice seedlings, viz. 4, 5, 6, 7, 8, 9, 10, 11, 12 days old were used for transplanting and compared with direct seeding under alternating flooding and suspension of irrigation in pots. The rice variety was Suphan Buri 1, a non-photosensitive variety with a maturity period of 120 days and recommended to Central Plains of Thailand. The pots were provided with alternating two-week flooding to inundate to approximately 4 cm above soil surface followed by suspension of irrigation for two weeks until flowering, thereafter inundated the soils to an approximate depth of 5 cm from flowering to hard-dough stage followed by draining water to support grain drying. Treatments were arranged in a complete randomized design with five replicates.

Large cylindrical containers with a diameter of 0.6 m and height of 0.8 m were used as pots due to the need of retaining sufficient content of moisture for rice plants to survive during suspension of irrigation. Of every pot, holes of 2.5 cm diameter were made downward at 15, 25 and 50 cm heights from the top for taking soil samples to determine soil moisture contents at predetermined time periods after suspending irrigation. These holes were fixed up with PVC pipe sockets containing removable caps. At the bottom of the pot, a hole with a diameter of 5 cm was made and a PVC pipe with a removable cap was fixed up to facilitate retaining water during flooding and draining during the suspending of irrigation. Pots were filled with cow dung-added (at the rate of 10,000 kg/ha) and well-ploughed paddy soils to the top and left for two weeks, during which pots were daily irrigated to settle down the soil before commencing the study. The final height of soils was adjusted to 10 cm from the top of the pot by adding more soils, and each pot finally had soils to the height of soil at 0.7 m.

Rice was established manually in all the pots. Twenty four-hour pre-soaked and pre-germinated seeds were dibbled to 1 cm depth in pots assigned to direct-seeded treatment and for remaining pots seedlings were produced for transplanting. Therefore, sufficient seeds were established in a separate nursery prepared using the same soils in the greenhouse to obtain 4- to 12-day old seedlings for transplanting treatments. Corresponding to transplanting treatments, seedlings were uprooted from the nursery starting from 4^{th} day onwards until 12^{th} day and transplanted in pots at two seedlings per hill. The spacing of 25cm x 25cm was provided, and accordingly there were four rice hills in each pot. One pot was considered as one replicate and five replicates were used for each treatment. Pots were arranged with 30 cm spacing between pots in rows. Pots were irrigated daily for one week to facilitate the establishment of transplanted seedling before adhering to the irrigation management schedule. One week after transplanting, one vigorously growing seedling was retained and the second seedling was removed. Nitrogen (N) and phosphorus (P) were applied at the rate of 30 and 16 kg/ha using di-ammonium phosphate (16-20-00) as basal dressing by calculating on per planting hill basis. But potassium (K) was not applied as soils were rich in K. As top dressing, N was applied at the rate of 42 kg/ha twice: the first application at 25 days after establishment (DAE) to overlap with active tillering and the second at 50 DAE to coincide with panicle initiation (PI).

During flooding period of two weeks, the water level was maintained approximately up to 4 cm in each pot by daily irrigation. Once the two-week suspension of irrigation started, the bottom-most PVC valve in each pot was kept opened until the end of suspension of irrigation period. Pots were regularly hand-weeded. No serious pests other than leaf rollers were observed during the cropping period and leaf rollers were manually collected and destroyed. All sides of the greenhouse were kept opened to facilitate free air circulation as well as to avoid temperature rises in the day time. At flowering, nylon nets were laid down on all four sides to avoid bird damage on panicles.

Experimental observations and data analyses

The time to reach key phenological stages, tiller counts, leaf area, shoot and root dry weights, and yield per rice hill and its yield parameters and soil moisture contents (SMCs) at 0-15, 15-25 and 25-50 cm were recorded during the experiment. Time from establishment to 50% of the plants to reach maximum tillering, flowering and maturity were recorded. The number of tillers per hill, plant height and leaf area per hill was recorded at maximum tillering and 50% flowering. Total leaf area was estimated using length and width method with undisturbed sampling technique (Yoshida, 1981).

At harvest, the root depth, total root length and root dry weight were measured by turning the pots upside down and exposing the soils. Root depth was measured down to the end of the deepest root. For total root length, root systems were first separated by washing with running water on a mesh of size 6.4 squares/cm until all the soils disappear from the root mass. Then roots were oven-dried at 70^{o}C until a constant weight reached and root dry weight recorded. The total root length was estimated using a representative sample from each root system using a meter ruler and grid-line intersect method (Bohm, 1979).

Yield data were obtained from all four hills in each treatment and replicate. Number of total and productive tillers (bearing panicles) per hill, filled and un-filled grains per panicle, and 1000-grain weight were recorded. Filled and un-filled grains were gathered from nine selected panicles representing primary, secondary and tertiary tillers from each hill, and their weights and moisture contents (Grainer II PM 300) recorded. Later the grain yields were converted to 14%, the equilibrium moisture content during storage.

Soil moisture content (SMC) at the field capacity (FC) and the permanent wilting point (PWP) were determined at the beginning of the study using the pressure plate technique (Cassel and Nielsen, 1986). Later, SMCs at 0-15, 15-25 and 25-50 cm layers were determined at three-day intervals during each period of suspending irrigation with gravimetric method (Gardner and Klute, 1982) using disturbed sampling. Soil samples obtained at flowering were analyzed for total N, available P, exchangeable K, organic matter, pH and EC using methods mentioned in section 2.1 to examine any variations, if existed. Solar radiation and temperature within and outside the greenhouse were daily recorded thrice a day in the morning (08:00 hrs), noon and evening (18:00 hrs). Daily mean solar energy ranged from 268 – 877 MJ m^{-2} d^{-1} outside and 181-596 MJ m^{-2} d^{-1} inside the greenhouse. Daily mean temperature ranged from 26.2 – 34.3^{o}C outside and 27.6 – 39.0^{o}C inside the greenhouse.

Shoot: root ratio was calculated using shoot and root dry weights. Panicle setting rate (Vergara, 1979), Harvest Index (Donald, 1962), spikelet sterility percentage (Yang *et al.*, 2008) and tillering rate (Yoshida, 1981) were also calculated.

Analysis of variance (ANOVA) was performed for data and Fisher's Protected Least Significant Difference (LSD) was used for mean separation (Steel and Torrie, 1980).

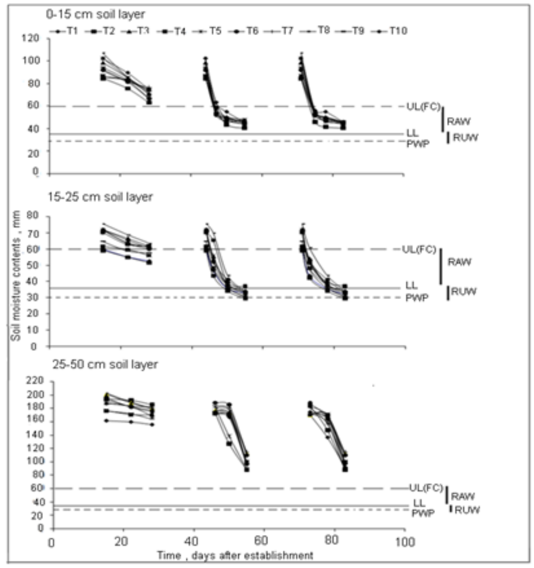
Results

Soil moisture

Average SMCs at FC and PWP were 58 and 28 mm, respectively where as available water content (AWC) was 30 mm in all three soil layers. The variation of SMCs at 0-15, 15-25 and 25-50 cm depths during the study in different treatments is presented in Figure 1. Irrigation was suspended three times in all the treatments.

Soil moisture depletion pattern during suspension of irrigation was similar in all the treatments (Figure 1). The depletion was slow in the first time of suspension of irrigation and fast in the later suspensions during vegetative phase. This is due mainly to increased water consumption with increased number of tillers and roots and leaf area per hill. The rate of depletion from saturation to FC was faster in 15-25cm soil layer compared to other two layers and the contributing factor could be the distribution of major part of the root system in this layer. The rate of depletion of water as shown in the slopes of response lines was faster from FC to lowest limit of RAW than from the latter to PWP. There was no noticeable depletion of SMC below lowest limit of RAW in 0-15cm and 25-50cm soil layers. Slaton *et al.* (1990) too observed a greater root length density (RLD) of rice in 20-30cm soil layer than the other layers.

Figure 1. The variation of soil moisture content in 0-15, 15-25 and 25-50 cm soil layers in different treatments during suspension of irrigation periods.



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

When the actual age from days after germination (DAG) of rice plant is considered, there was a delay in reaching specific growth stages in TPR, except for the appearance of first tiller with 4-day old seedlings and DSR (Figure 2). These differences would be attributed to the time period required for root system to recover from the damage due to uprooting and to commence its normal functions after transplanting. As the seedlings spend a part of their vegetative period in the nursery, the balance period plus the recovery period together show the time taken for reaching specific growth stage after field establishment by transplanting to be shorter in TPR, but in reality, TPR takes a longer period to reach specific growth stages. But seedlings transplanted at 4 and 5 days after emergence showed the shortest time to reach each growth stage, which is probably attributed to the rapid recovering ability after uprooting from the nursery.

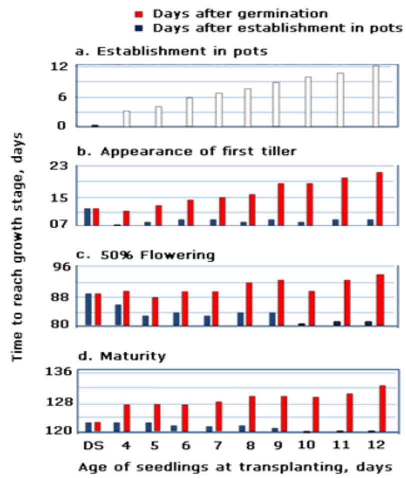
Time to reach phenological stages

The time to reach first tiller appearance, 50% flowering and maturity is shown in Figure 2. The number of days from field establishment to 50% flowering and maturity was significantly different between direct-seeded rice (DSR) and transplanted rice (TPR) (Figure 2). The first tiller appeared in DSR in 12 DAE, while 7 DAE in TPR with 4-day, and 9 DAE with 11- and 12-day seedlings (Figure 2). Similarly, 10-day old seedlings completed flowering (in 80 DAE) earlier than all other treatments, while DSR took the longest time (89 DAE) (Figure 2), and the difference was 9 days. Rice transplanted with 10- to 12-day old seedlings matured earlier (120 DAE) than DSR ($p=0.05$).

Effect of age of seedlings at transplanting on growth parameters

Number of total and productive tillers: The age of seedlings had significant effects on the number of total and productive tillers/hill at harvest, but the effect was insignificant at maximum tillering (MT) and at flowering ($p=0.05$) (Table 1). Rice transplanted with 5-day old seedlings had the highest number of tillers at MT, and flowering, both total (Table 01) and productive tillers (Table 04) at harvest than all others. In contrast, the DSR reported the lowest number of tillers at maximum tillering, at flowering and at harvest (Table 01) and productive tillers at harvest (Table 4).

Figure 2. Effect of seedling age at transplanting on time to appear first tiller, to 50% flowering and maturity



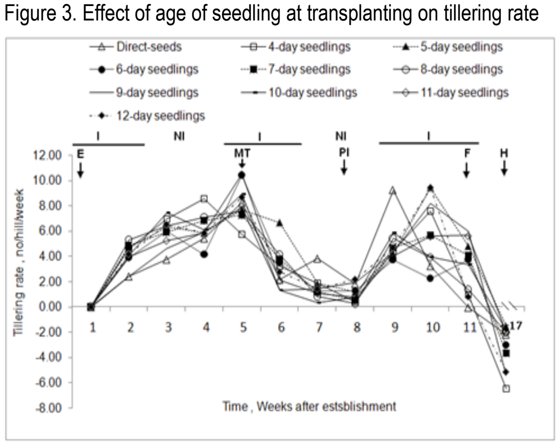
Tillering rate: The tillering rate refers to the change in the number of tillers per hill during each week. There was an increase in tillering rate up to 5 weeks from establishment to the time of MT in all treatments, except that 4-day old seedlings after 4th week (Figure 3). Of 4-day old seedlings, there was a remarkable drop in the tillering rate from 4 to 8 weeks, which was followed by another rise from 8 to 10 weeks, and thereafter followed by a sharp decline until the harvest. Of all plants including DSR, tillering rate dropped after 5th week and again increased after 8 to 9 week in DSR and TPR of 6, 8 and 10 day old seedling. The rest had increasing tillering rates until 10th week. The negative tillering rate occurred due to lesser number of tillers produced in the plant after the flowering as well as death of latter formed tillers.

Table 1. Effect of seedling age at transplanting on tiller production

Treatment 1/		Tiller production, No/hill		
		At max tillering	At flowering	At maturity
DSR		25.9 ± 2.8	40.1 ± 5.4	37.9±2.2 b
TPR				
4-day old		31.2 ± 4.9	44.6 ± 6.5	38.2±4.1 b
5-day old		33.0 ± 8.4	52.6 ± 6.7	51.1±6.8 a
6-day old		29.3 ± 5.6	40.3 ± 8.8	37.2±2.7 b
7-day old		29.8 ± 5.4	44.6 ± 8.9	40.9±1.8 b
8-day old		31.4 ± 4.7	42.4 ± 6.4	40.4±4.1 b
9-day old		23.5 ± 4.6	43.9 ± 4.9	38.4±4.3 b
10-day old		28.2 ± 2.5	42.0 ± 4.4	40.1±6.2 b
11-day old		28.7 ± 4.7	44.6 ± 7.3	42.6±1.8 b
12 -day old		29.4 ± 1.9	46.4 ± 6.1	41.2±3.8 b
LSD (p=0.05)		ns	ns	5.9
Analyses of Variance				
Source of variation	DF	Mean squares		
Treatment	9	30.39	51.87	63.96**
Error	30	40.50	65.64	17.04
CV%		16.85	18.35	10.12

1/ DSR – Direct-seeded rice; TPR – Transplanted rice

Figure 3. Effect of age of seedling at transplanting on tillering rate



Plant height: Seedling age had no effect on plant height at maximum tillering, but a significant effect was found at PI (p=0.05) (Table 2). TPR with eight-day old seedlings had the highest plant height, and which were not significantly greater than the rest, except those established with 4, 6, 9 and 12-day old seedlings. The lowest plant height was in TPR with 6- and 9-day old seedlings and DSR.

Leaf area per hill: There was a significant effect of seedling age at transplanting on leaf area per hill at maximum tillering, but not at flowering (Table 2). At maximum tillering, the highest leaf area was in rice transplanted with 5-day old seedlings, while, the lowest was in DSR (0.35 m^2/hill). All TPR had leaf area per plant ranging from 20% in rice transplanted with 12-day old seedlings (0.42 m^2/hill) to 80% with 5-day old seedlings (0.63 m^2/hill) compared to DSR (0.34 m^2/hill). In both methods of establishment planting spacing was 25cm x 25cm, although TPR had a higher leaf area per hill. At flowering, leaf area was not significantly different between DSR and TPR, and also among different age groups of seedlings used in TPR.

Above-ground non-grain biomass

Neither DSR nor TPR with different seedling ages had significant influence on the above-ground non-grain biomass at harvest (p=0.05) (Table 3). The non-grain biomass values ranged from the lowest of 124.7 g/hill in DSR to the highest of 144.8 g/hill in TPR with 5-day old seedlings.

Root characteristics

The total root length (TRL), total root dry weight (TRD) root depth (RD), and shoot: root ratio (SRR) at harvest had significant differences among treatments (Table 3). All parameters, except SRR, were highest and significantly greater in DSR than all transplanted treatments. Although the height of pots was 0.8 m, all plants had developed their roots down to the bottom of the pots, and the higher values more than 0.80 m was due to further development of roots at the bottom of pots. The total root length (TRL) showed a decline in TPR compared to DSR, and also within TPR the lowest root length was in rice plants that were transplanted with older seedlings, i.e. 12-day old seedlings having the lowest root length. Total root dry weight (TRD) too followed the same trend as TRL. In contrast to root depth, TRL and TRD, shoot: root ratio (SRR) was greater in all TPR treatments than DSR, and within TPR, the highest SRR was in 12-day old seedlings (29.1) and the lowest in 4-day old seedlings. Decreased root dry weight with increasing the seedling age at transplanting - i.e. delaying the time of seedlings in the nursery – contributed to the increased SRR.

Table 2. Effect of seedling age at transplanting on plant height and leaf area per hill

Treatment 1/		Plant height, m		Leaf area, m^2/hill	
		At maximum tillering	At panicle initiation	At maximum tillering	At flowering
DSR		1.12 ± 0.01	1.19 ± 0.04 cd	0.35±0.01 d	1.08±0.15
TPR					
4-day old		1.17 ± 0.03	1.21 ± 0.01 bcd	0.52±0.08 b	1.16±0.16
5-day old		1.13 ± 0.03	1.23 ± 0.03 abc	0.63±0.07 a	1.33±0.18
6-day old		1.13 ± 0.03	1.19 ± 0.03 d	0.49±0.08 cb	1.08±0.24
7-day old		1.18 ± 0.03	1.25 ± 0.03 ab	0.50±0.02 b	1.19±0.24
8-day old		1.16± 0.03	1.27 ± 0.03 a	0.52±0.05 b	0.90±0.14
9-day old		1.10 ± 0.05	1.19 ± 0.01 d	0.39±0.08 d	1.10±0.38
10-day old		1.16 ± 0.03	1.24 ± 0.04 ab	0.48±0.00 cb	1.06±0.11
11-day old		1.15 ± 0.03	1.23 ± 0.04 abcd	0.52±0.02 b	1.12±0.19
12 -day old		1.13 ± 0.03	1.21 ± 0.02 bcd	0.42±0.04 cd	1.12±0.16
LSD (p=0.05)		ns	0.04	0.08	ns
Analysis of variance					
Source of variation	DF	Mean squares			
Treatment	9	23.01	28.70**	0.026***	0.048
Error	30	12.82	8.87	0.003	0.043
CV%		3.12	2.44	11.21	18.57

1/ DSR – Direct-seeded rice; TPR – Transplanted rice

Effect of age of seedlings at transplanting on yield and yield components

Seedling age at transplanting had significant effects on the number of panicles (productive tillers) per hill, grains per panicle, weight of 1000-grains and total grains per plant (Table 4).

Number of panicles per hill

The lowest panicle number per hill was in both DSR and TPR with 4-day old seedlings (Table 4). The highest panicle number per hill was in TPR with 5-day old seedlings followed by 11-day and 10-day old seedlings, but there were no significant differences among them. When the number of panicles per hill was compared with the number of tillers/hill at flowering, there was a clear reduction in the number of tillers that produced panicles. This value was 32.4% for DSR, 37.4% and 28.3% for TPR with 4- and 5-day old seedlings, respectively, and decreased further with the use of seedlings of 6-day old onwards. However, there was an increase in the same value with 12-day old seedlings used for transplanting.

Table 3. Effect of seedling age at transplanting on different root parameters, above ground non-grain biomass and shoot: root ratio at harvest

Treatment 1/	Above ground non- grain biomass, g/hill	Total root length cm/hill	Total root dry weight g/hill	Root depth, cm	Shoot: Root ratio
DSR	124.7 ± 4.7	264.7 ± 30.7 a	14.7 ± 3.8 a	97.3 ± 5.7 a	8.9± 2.1 d
TPR					
4-day old	128.5 ± 19.7	231.6 ± 14.5 b	11.7 ± 0.9 b	80.9 ± 1.5 bc	10.9 ± 0.9 cd
5-day old	144.8 ± 13.9	208.8 ± 12.5 bc	10.6 ± 2.0 bc	79.6 ± 1.2 c	13.6 ± 1.5 c
6-day old	132.2 ± 9.8	179.6 ± 26.5 d	8.9 ± 0.9 cd	82.2 ± 2.5 bc	14.8 ± 1.5 c
7-day old	142.6 ± 14.7	174.8 ± 18.6 d	7.1 ± 1.1 de	82.6 ± 3.8 bc	20.7 ± 2.1 b
8-day old	137.6 ± 11.8	186.6 ± 18.7 cd	6.9 ± 0.4 de	84.9 ± 4.1 b	19.7 ± 1.6 b
9-day old	130.4 ± 19.8	164.2 ± 5.4 de	5.9 ± 0.5 ef	80.9 ± 2.2 bc	21.9 ± 1.6 b
10-day old	133.6 ± 15.3	163.9 ± 7.9 de	5.0 ± 0.2 ef	82.8 ± 5.2 bc	26.7 ± 4.3 a
11-day old	134.4 ± 7.5	146.7 ± 16.1 e	4.7 ± 0.3 f	80.1 ± 2.1 c	29.0 ± 2.8 a
12-day old	140.8 ± 18.3	142.0 ± 22.6 e	4.9 ± 0.9 ef	78.2 ± 1.1 c	29.1 ± 6.1 a
LSD (p=0.05)	ns	27.3	2.2	4.8	4.1

Analysis of Variance

Source of variation	DF	Mean squares				
Treatment	9	165.43	5958.14***	45.27***	116.38***	215.08***
Error	30	207.38	356.39	2.32	11.08	8.23
CV%		10.67	10.13	18.87	4.01	14.69

1/ DSR – Direct-seeded rice; TPR – Transplanted rice

Number of filled grains per panicle

The highest number of filled grains per panicle was in TPR with 9-day old seedlings (236 grains) followed by 11-day old seedlings (232 grains), but difference was not significant (p=0.05). The lowest number was recorded in TPR with 10-day old seedlings, although the same treatment had the third highest number of panicle bearing tillers/hill. The number varied drastically across treatments and followed no specific pattern.

1000-Grain weight

Thousand-grain weight showed significant differences among treatments, but varied in a narrow range (Table 4). The value was highest in TPR with 4-day old seedlings and lowest with 12-day old seedlings. DSR had moderate values of 25.27 g/1000 grains.

Total grain weight per hill

Except in rice transplanted with 4-day old seedlings, TPR had higher total grain weight per hill than DSR (Table 4). The highest total grain weight per hill was in TPR with 9-day old seedlings (161 g/hill), the main contributing factor was increased filled grain number per panicle, while the variation of the other yield parameters was marginal. Although grain yields were greater in TPR, a specifically noticeable trend related to age of seedlings at transplanting could not be found. There was a 2% decline in the total grain weight in rice transplanted with 4-day old seedlings, and 10-15% increase with 5-12-day old seedling with exceptions of 9-day old seedlings producing 27% higher grain weight per hill and 10-day seedlings producing 4%. The latter was attributed to the decrease in filled grain number per panicle (186.5 grains/panicle). Seedling ages of 5 to 8 days gave 10-11% grain yield increases per hill, and 11 and 12 days a 15% increase.

Table 4. Effect of seedling age on grain yield and yield parameters

Treatment 1/	Productive tillers, number/hill 2/	Filled grains, number/panicle	Grain weight, g/1000 grains	Total grain weight g/hill
DSR	27.1 ± 2.6 e (32.4)	212.2 ± 25.9 abcd	25.27 ± 0.52 dc	126.3 ± 04.58 d
TPR				
4-day old	27.9 ± 2.1 de (37.4)	204.8 ± 9.9 cd	26.85 ± 0.77 a	124.0 ± 11.29 d
5-day old	37.7 ± 5.2 a (28.3)	209.6 ± 8.4 abcd	25.13 ± 1.12 cd	140.5 ± 04.89 bc
6-day old	30.3 ± 4.7 cde (24.8)	224.1 ± 10.6 abc	24.91 ± 0.59 cd	138.9 ± 03.99 bc
7-day old	30.9 ± 1.1 cde (30.7)	212.0 ± 13.6 abcd	26.25 ± 0.58 ab	142.7 ± 06.39 bc
8-day old	33.1 ± 1.6 abc (21.9)	207.9 ± 18.5 bcd	24.71 ± 0.29 cd	142.7 ± 09.29 bc
9-day old	32.1 ± 4.4 bcd (26.8)	236.3 ± 4.1 a	25.20 ± 0.42 cd	161.0 ± 12.53 a
10-day old	35.7 ± 4.0 ab (15.0)	186.5 ± 33.7 d	24.62 ± 0.48 cd	131.4 ± 14.06 dc
11-day old	36.4 ± 1.8 ab (11.7)	232.9 ± 27.8 ab	24.62 ± 0.48 bc	145.6 ±0 3.61 b
12-day old	33.3 ± 1.9 abcd (28.2)	219.3 ± 06.7 abc	24.44 ± 0.43 d	146.0 ± 06.95 b
LSD (p=0.05)	4.7	26.8	0.9	0.6
Analysis of variance				

Source of variation	DF	Mean Squares			
Treatment	9	48.49 ***	838.04*	2.24 ***	463.40 ***
Error	30	10.66	344.64	0.39	73.13
CV%		10.07	8.65	2.47	6.11

1/ DSR – Direct-seeded rice; TPR – Transplanted rice; 2/ Value within parenthesis shows the percent reduction in the tillers bearing panicles at harvest compared to the total number of tillers produced at flowering

Table 5. Effect of seedling age on spikelet sterility, panicle setting rate and harvest index

Treatment 1/	Spikelet sterility %	Panicle setting rate	Harvest index
DSR	15.55± 5.32	71.4 ± 04.8 e	0.47 ± 0.02
TPR			
4-day old	13.25 ± 5.06	73.5 ± 04.5 de	0.46 ± 0.02
5-day old	15.39 ± 2.11	73.7 ± 05.4 de	0.48 ± 0.02
6-day old	11.62 ± 3.13	81.6 ± 11.7 abde	0.49 ± 0.01
7-day old	16.17 ± 3.72	75.5 ± 03.9 cde	0.47 ± 0.05
8-day old	14.33 ± 4.59	82.4 ± 05.0 abcd	0.48 ± 0.02
9-day old	10.93 ± 0.48	83.3 ± 06.3 abc	0.51 ± 0.01
10-day old	12.01 ± 4.24	89.4 ± 04.5 a	0.49 ± 0.03
11-day old	12.78 ± 4.57	85.1 ± 01.9 ab	0.50 ± 0.01
12-day old	17.76 ± 1.47	81.0 ± 03.4 bcd	0.47 ± 0.01
LSD (p=0.05)	ns	8.2	ns
Analysis of variance			

Source of variation	DF	Mean squares		
Treatment	9	27.09	136.44**	0.0009
Error	30	14.414.44	32.49	0.0006
CV%		25.89	7.15	5.02

1/ DSR – Direct-seeded rice; TPR – Transplanted rice

There was no significant effect of seedling age at establishment of rice on spikelet sterility, which ranged from 10.9% in TPR with 9-day to 17.76% with 10-day old seedlings (Table 5).

The panicle setting rate which was calculated by dividing the number of panicles per hill by total number of tillers at harvest was highest in TPR with 10-day old seedlings, but lowest in DSR, and the difference was significant (p=0.05) (Table 5).

Although it was not very much obscure, there was a trend of increasing the favourable parameters and decreasing unfavourable ones when transplanted with

9-11 day seedlings. This is shown by its highest harvest index; although there were no significant differences existed among the age at transplanting or direct seeding (Table 5).

Discussion

Tillering influences grain yield of rice as it is closely linked to the final panicle number produced per unit area of cultivated land (Quyen *et al.*, 2004). Pasuquin *et al.* (2008) reported that tiller production could be optimized by transplanting seedlings at younger ages compared to direct seeding. The maximum number of tillers produced by the rice plant is inversely proportional to the length of the *phyllochron* (Katayama, 1951; Nemato *et al* 1995), which is dependent upon the extent of stresses. Wider spacing, availability of solar radiation, medium temperature, soil aeration, and nutrient supply promote shorter *phyllochrons* which increase the number of tillers in the rice plant (Anon, 2004). Transplanting too creates a certain degree of stress, by which the rate of *phyllochron* development after transplanting would be depressed (Mimoto, 1981; Yamamoto *et al.*, 1995). Younger seedlings could relieve the transplanting stress in a shorter period of time compared to that of older seedlings (Sato, 1956; ; Yamamoto *et al.*, 1998) due to the higher nitrogen content in the former (Yamamoto *et al.*, 1998), and the plants' ability to faster resumption of the rate of *phyllochron* development (Anon, 2004). Higher endosperm nutrient contents during 2nd and 3rd *phyllochrons* support faster recovery of younger seedlings, and when seedlings transplanted after 4th *phyllochron* stage take little longer time for recovery from the transplanting schock (Hoshikawa *et al.*, 1995; Ota, 1975; Yamamoto *et al.*, 1995; Yamamoto *et al.*, 1998). Krishna and Biradarpatil (2009) found that rice plants experience shorter *phyllochrons* and increasing number of tillers when seedlings of less than 12 days are transplanted (two leaf stage).

In contrast, Pasuquin *et al.* (2008) observed absence of transplanting shock with 7-21 day old seedlings. In the current study, the number of tillers in TPR did not differ significantly among different seedling ages up to flowering. This may be due to less shock the TPR have undergone after transplanting and the ability of plants to resume their *phyllochron* development soon after transplanting. According to Dingkuhn *et al.* (1990 and 1991), lower tiller production in TPR is commonly caused by transplanting shock as compared to DSR. Such a difference in tiller production could not be observed further when there is a low transplanting shock to rice plants as shown in this study.

Pasuquin *et al.* (2008) observed that there was no significant difference in duration from transplanting to the emergence of the first tiller for seedling ages ranging from 7 to 21 days. The current results agree with his findings. Direct–seeded rice took four more days than transplanted rice to produce the first tiller. In TPR, tillering may be initiated before transplanting, yet it remained unexpressed due to delayed field establishment. Therefore, once transplanted, TPR usually reaches tillering in the field earlier than DSR.

The rate of tiller production in rice is faster from establishment to maximum tillering (35-40 days of age) and slower thereafter, but tiller production continues until flowering (Vergara, 1979). The same pattern was observed in the current study too (Figure 2). Huang *et al*. (1996) and Quyen *et al.* (2004) observed that the tillers that started late grew at a slower rate, died off due to insufficient supply of assimilates and nutrients and mutual shading. As observed by Wu *et al.* (1999), young tillers in transplanted rice began to die off after 48 DAE. On the other hand the tillers produced at the latter part of the growth of the rice plant were too small and flowered late. These lately produce panicles ripen late and could not mature along the earlier formed panicles and hence becoming unproductive (Vergara, 1979). A negative tillering rate of rice after flowering was observed in Figure 2 in this study, and it was due to the death of adventitious tillers formed after panicle initiation (PI) in the peripheral circle of the rice plant. The tillers that remained alive until the end of the maturity period were also unproductive. The plants accelerated the tiller production with re-irrigation after the suspension of irrigation period. The rate of increase in tiller number after PI and re-irrigation could be due to the formation of adventitious tillers. According to Zhong *et al.* (2002) the reduction of tillering rate at PI could be due to rapid increase in the leaf area and its shading effects; this was prominent at leaf area of 3.66- 4.11. They also mentioned that light quantity and/or quality at the base of the hill where tiller buds and young tillers are formed control tiller production.

The second cycle of suspension of irrigation period coincided with PI of rice crop in all the treatments. During this period, SMC of 15-25 cm soil layer reached near PWP, but in the 25-50 cm layer was still above PWP (Figure 1). The roots grown deeper than 15-25 cm layer had the access to soil moisture in the 25-50 cm soil layer, thus compensating the water shortage developed during the second cycle of suspension of irrigation. This hypothesis was supported by the absence of wilting symptoms of the rice plants at this stage. Therefore with the progress in time deeper root penetration not only exposed the plants to acquire water from deeper profiles, but also to access nutrients that are available in such profiles.

Leaf area is an important plant trait which is directly linked with the rate of photosynthesis and crop yield. Total leaf area present at flowering greatly affects the amount of assimilates available to the panicles (De Datta, 1981). In the current study, there was no significant difference in leaf area per hill among treatments at flowering. This confirms that the rice seedlings transplanted from 4 to 12 days of age did not face distinguishable stresses among the treatments. The highest leaf area of TPR with 5-day old seedlings was mainly due to the highest number of tillers, and similar observation was reported by San-Oh *et al.* (2008) too.

The plant height is an important morphological character that primarily helps to avoid potential competition by weeds (Nyarko and De Datta, 1991). Although too short and too tall plant heights cause many disadvantages, a compromised height of a rice cultivar always offers benefits. The height is a varietal character, but is often regulated by environmental conditions (Yoshida, 1981). Gani *et al.* (2002) reported that rice transplanted with 7- and 14-day old seedlings had greater plant heights than that of 21-day old seedlings. However, there was no significant variation in plant height among the different ages of seedlings transplanted in this study.

Roots, being an integral part of the rice plant, have various adaptive mechanisms in response to soil water stress conditions in the acquisition of nutrients and water (Yamauchi *et al.*, 1996). The plants produce deep and extensive root system in response to water stress and support extraction of water from deep soils (Fukai and Cooper, 1995; Kamoshita *et al.*, 2004; Kato *et al.*, 2007), and increase nutrient uptake and maintain competitiveness with weeds (Richards, 2008). The alternate irrigation and its suspension ensured deeper growth of the root system and access to water and nutrients uptake which ensuring optimum growth and high grain yield (Zhi, Undated). Therefore, deeper root growth is a sign of moisture shortage experienced by rice plants (Fageria *et al.*, 2005). In the current study, deep and extensive root system was found in the AFSI water management. The DSR had significantly deeper and longer root system with greater dry mass and hence a lower shoot: root ratio than all TPR treatments (Table 3). This could be attributed to a) undisturbed growth of roots and b) availability of relatively longer time period for root growth of DSR compared to TPR. Sharp and LeNoble (2002) noted that shoot growth is restricted by roots during water stress. This agrees with Osaki *et al.* (1997) who mentioned that the growth of roots is assumed to be iterating with the shoot growth. This is because shoots are more sensitive to water stress than roots.

Pasuquin *et al.* (2008) reported that rice transplanted with 7-day old seedlings (2-leaf stage) had a higher yield compared to that of 14- (5-leaf stage) and 21-day old seedlings (7-leaf stage). Furthermore, McHugh *et al.* (2002) reported that 8-day old seedlings had a positive correlation with grain yield. In the current study, 9-day old seedlings (2-leaf stage) gave the highest total grain weight (161.03g per hill, equivalent to 8.05 t/ha), while the lowest was in DSR (126.32 g/hill, equivalent to 6.2 t/ha) and 4-day old seedlings (124.02 g/hill, equivalent to 6.12 t/ha), and the difference being 37g/hill (1.3 t/ha) between DSR and 4-day old seedlings. The difference in total grain weight per hill between the highest (8-day old) and next highest in 12-day old seedlings was 18.67g (0.88 t/ha). Farmers sometimes complain on handling difficulties with very tiny young seedlings. The current study shows that seedlings aged between 5 and 12 days could be conveniently used without significant yield reductions under AFSI water management.

The panicle setting rate (PSR) is an important parameter in estimating yield potential of rice. Improved rice varieties normally have PSR above 75% (Vergara, 1979). In the current study, TPR with 6- to 12-day seedlings had above 75% PSR, while DSR and TPR with 4- and 5-day old seedlings had less than 75%. Therefore, PSR could be considered as a favourable index for selecting suitable age of the seedlings for transplanting.

Spikelet sterility is an indicator of hardships experienced by the rice crop during the period from pollination and fertilization of ovules to physiological maturity (Yoshida, 1981). This could result due to nutrient deficiencies (Yoshida, 1981), water stresses (Ekanayake *et al.*, 1989) and many other causes (Jagadish *et al.*, 2007) during flowering to physiological maturity. There was no water stress experienced by rice plants after flowering as water was retained in the rice pots. Spikelet sterility of less than 25% and its insignificant differences among treatments also confirmed the absence of unfavourable stresses due to transplanting with seedlings of different ages and nutrient deficiencies (results were not presented) in the current study.

The differences in harvest index (HI) among TPR at all ages were not significant from DSR. This explains the non-variability of grain and shoot biomass among the treatments regardless of the method of establishment adopted and age of seedlings transplanted.

Conclusions

The current study showed no variation among the direct-seeding and transplanting with 4- to 12-day old seedlings of rice with respect to tillering potential and growth dynamics under alternate flooding and suspension of irrigation method of water management in a pot study in central Thailand. Although total grain weight per hill had somewhat wider variation among seedling ages, the opportunities may exist to reduce the differences by reducing planting spacing and increasing density which would also help to increase harvest index. The transplanting shock can be minimized with seedlings of less than 12-days, and 9-day old seedlings offered the highest total grain weight.

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