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Effect of seedling age and water depth on morphological and physiological aspects of transplanted rice under high temperature

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Abstract: To study the effect of high temperature, rice seedlings 20, 30, 40 and 50 d were kept at 5, 10, 15 and 20 cm water depth in a water pool. Meteorological findings indicated that water temperature varied up to 10 cm but became stable below this depth. Deep water inflicted higher tiller mortality, minimal increase in dry weight of aerial parts and leaf area, decrease in root length, and decrease in root dry weight especially at 20 cm water depth and produced an unbalanced T/R ratio (top versus root dry weight). However, deep water tended to increase plant length. These parameters, however, excel in shallow water. Older seedlings, with the exception of root dry weight, could not perform well compared to young seedlings in all physiological and morphological aspects. The study revealed that seedlings, particularly young ones, stand well in shallow water and can cope with high temperature.

Key words: Rice, High temperature, Seedling age, Water depth
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INTRODUCTION

Rice (*Oryza sativa* L.) is one of the most important crops in Pakistan. It is the third largest crop in terms of area and production after wheat and cotton. Although rice in Pakistan is consuming large acreage, Pakistan is still far behind other rice producing countries. The average yield is very low (2 t/ha) as compared to Egypt (8.4 t/ha) and USA (6.6 t/ha). There are many reasons for this low yield. The most important are high temperature (40–50 °C), low humidity at the time of transplanting, use of seedlings of unsuitable age, and use of different water levels by farmers to counter the negative effect of high temperature injury during transplanting. The combined effect of these factors (high temperature, seedling age and water depth) usually produces high seedling mortality just after transplanting.

High temperature (32−40 °C) at harvesting results in decrease in panicle weight and increase in the number of empty grains in ten cultivars (Zakria *et al*., 2002). Morita *et al*.(2002) noted a decrease in average grain weight during high temperature during the day and night. Thanomthin *et al*.(2002) observed a decrease in spikelet of four rice cultivars named Sasanishiki, Koshihikari, Milyang 23 and IR-13, due to high temperature of 30 °C from 800−1600 h at heading stage. It was observed that root growth was significantly adversely affected by higher temperature while at lower temperature root development was severely restricted (Ogasawara *et al*., 1998).

The correct age of seedlings used for transplanting is of primary importance for uniform stand and seedling establishment, as Padalia (1980) stated "half of the success of rice cultivation depends upon the seedling". Nursery management is an integral part of transplanted rice (Lal and Roy, 1996). The technical-know how on rice seedlings (morphology and physiology) play a pivotal role at transplanting due to the pronounced effect of temperature and water depths at that time (De Datta, 1981). Quayyum *et al.*(1981) used 10–40 d old seedlings grown in submerged conditions and observed an increase in internodal length with the increase in seedling age.

The transplanting depth of rice seedlings has noticeable effect on the growth of rice. Kanzaki *et al.*(2001) observed a pronounced effect on harvest index and Single Photon Avalanche Diode (SPAD) value due to an increase in phytotocicity (Cafenstrole) at a shallow water depth of 1 cm. Rice yields and harvest index were observed to be reduced in shallow water depth (5 cm) compared to deep-water depth of 20 cm (Williams and Angus, 1994). Sinha (2002) showed that fewer grains per panicle and lower grain weight in IR-42 occurred under submerged conditions. Adak and Gupta (2002) observed that rice cultivars showed significant reduction in yield under submergence compared to those grown under normal conditions.

It is important to select suitable age rice seedlings contributing towards increased rice production and resolve the problem posed by higher temperature and water depth inflicting seedling mortality. This has resulted in low population per unit area just after transplanting as well as causing huge economic losses to the farming community in arid Pakistan. The present endeavour is, therefore, to determine the appropriate seedlings age and water depth at high temperature conditions during transplant time. This will help farmers achieve increased rice production.

MATERIALS AND METHODS

An experiment was conducted in pots in a glasshouse at Tsukuba International Centre (Japan International Cooperation Agency (JICA)), Japan during the rice-growing season.

The experiment was designed to analyse the effect of seedling age and water depth on the subsequent growth of transplanted rice plants under high temperature conditions.

Experimental design

The pot experiment was carried out in Randomized Complete Block Design (RCBD) with split plot design having 3 replications. Water depths 5, 10, 15 and 20 cm were used as the main plot factor, while 20, 30, 40 and 50 d seedlings were transplanted into sub-plots, comprising a total of 16 treatments.

Seed preparation

Rice variety IR-44 was used for the experiment. The selected seeds were soaked in a salt solution of specific gravity (1.13), then rinsed and treated for 24 h with ×200 solution of Healthied, a fungicide, and then soaked in continuously replaced water for 24 h till the seeds got swollen and ready to sprout.

Nursery preparation

A nursery bed was prepared in a glasshouse to raise healthy and vigorous seedlings. Accurately weighed seeds were sowed 60 g/m^2 in 4 raised nursery beds in upland conditions. The seedbeds were raised 10 cm and had waterways on all sides and between the beds. Fertilizer, 15, 20 and 18 g/m^2 each of N, P_2O_5 and K_2O were applied to the nursery beds. Irrigation water was applied by sprinkling as and when needed. Seeds were planted at 10-day intervals (July 15 and July 25) and (August 5 and August 15). All the seedlings were transplanted on September 5, 2002.

Cultivation method

The seedlings from treatment, viz. 20, 30, 40 and 50 d, were uprooted carefully with minimum damage to the roots on the day of transplanting. Two days before transplanting, Wagner pots were filled with equal amounts of soil. Three seedlings/hill, three hills/pot were planted. These pots were filled to different water depths randomly on a stair arrangement (Fig.1). The seedlings were then transplanted in these pots, with their original numbers of tillers. Layout of experimental plan is shown in Fig.2. Data were recorded for all the plants after the lapse of experimental period of 14 d. All of the 48 pots were taken

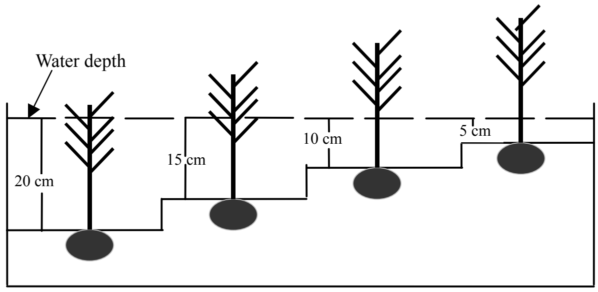

Fig.1 Arrangement of pots on stairs in water pool

from the pools. The pots were carefully washed with tap water to remove the soil from the roots of the plants.

Observations

1. Meteorological data: The glasshouse temperature was kept high during the daytime by closing the doors and windows to create a tropical condition. Meteorological data were recorded twice a day (8.00 h and 14.00 h) during the entire experimental period of 2 weeks. The relative humidity was measured at 14.00 h.

2. Measurements: Growth characteristics such as plant length, root length, leaf area, dry weight of aerial parts, and root dry weight of different age seedlings were recorded at the time of transplanting (Table 1). The percentage increase/decrease in various parameters of the rice plants relative to initial characteristics of the seedlings at the time of transplanting was calculated. In the same way, dry weight of aerial parts versus roots (T/R ratio) was computed to find the seedling condition under high temperature stress.

RESULTS AND DISCUSSION

Meteorological findings

Air temperature affected the water temperature from the surface to 10 cm, whereas the deeper water showed a very stable response. It was revealed that soil temperatures were almost stable at all water depths. In a glass house, air temperature was kept as high as 40 °C to 50 °C, which correspondingly increased the water temperature directly up to 41 °C to a 5 cm water depth. Lowest temperature (15 °C) at nighttime was recorded, at less than 5 cm depth, higher water temperature (25 °C to 27 °C) was noted. Nishiki (1987) reported that temperature inside deep water is higher at night and lower during daytime compared to water temperature at the normal water level.

Percent increase in plant length

Water depth and seedling age significantly affected plant length, but their interaction was found to be not significant (Table 2). Deeper water compared to shallow water resulted in longer plants. It was also noted that younger seedlings gained more plant length than older ones. The deep water tended to increase plant length. This tendency was directly related to the increasing inter-node length at the upper part of the culm and by deep-water stress and high air temperature there. Similar findings were reported by Quayyum *et al.*(1981). Purba (1993), Sugai *et al.*(1998) and Gun (1999) emphasized that increase of culm length is positively correlated with deep water. The higher increase in plant length in young seedlings could be due to less root damage during uprooting, as their root length was shorter than that of older ones. This resulted in full utilization of the root structure in absorption of nutrients and their upward flow in young

Replication I — Seedling age (d)

Water depth (cm)				
10	30	50	20	40
15	40	20	30	50
20	30	50	20	40
5	40	30	20	50

Replication II — Seedling age (d)

Water depth (cm)				
15	50	30	20	40
20	30	20	50	40
10	40	20	50	30
5	40	20	50	30

Replication III — Seedling age (d)

Water depth (cm)				
15	40	50	30	20
5	30	20	50	40
20	20	30	50	40
10	30	50	20	40

Fig.2 Experimental layout of different water depths and seedling ages

Table 1 Growth characteristics of various seedlings at the time of transplanting

Seedling age at transplanting time (d)	Aerial parts			Roots	
	Length (cm)	Leaf area (cm^2)	Dry weight (g)	Length (cm)	Dry weight (g)
20	28.0	17.46	0.05	5.64	0.01
30	39.3	42.7	0.15	8.35	0.018
40	48.2	133.69	0.60	15.0	0.054
50	61.85	157.01	0.84	16.9	0.056

seedlings produce vigorous plants at later growth stages. The older seedlings might have utilized their stored carbohydrates for repairing damaged roots in early growth stages, so their percent increase in plant length was slower than that of the younger ones.

Percent increase in dry weight of aerial parts

The recorded data on dry weight of aerial parts are presented in Table 3. Water depth and seedling age significantly affected the dry weight of aerial parts with their interaction being found statistically not significant. Water depths data showed minimal increase in dry weight of aerial parts of plants in deep water. Seedling ages data showed that only the youngest seedling of 20 d gained more aerial parts dry weight as compared to that of all older seedlings, which depicted a not significant increase in dry weight. This indicated that more rapid growth occurred in young seedlings at the end of the experimental period of 14 d. Higher dry weight of aerial parts occurred in shallow water than in deep water. Deep water tended to inhibit tillering due to the submerged conditions and reduced leaf area during early rooting stages. It was found true by Ohe and Mimoto (1999). It was also observed that higher daytime water temperature produced heavier plants (more dry matter). This is in agreement with Matsushima *et al.*(1968) who reported that daytime water temperature is higher than nighttime water temperature, and that the dry matter is always heavier than that during nighttime.

Percent increase in root length

The data on root lengths indicated that water depth and seedling age affected root lengths significantly (Table 4). The interaction of the two factors was found to be statistically not significant. Data revealed that higher increase in root length occurred in shallow water. It is evident that seedling of all ages gained more root length in shallow water, with more pronounced root length gain observed in younger seedlings.

Percent increase in root dry weight

Root dry weight is one of the most important criteria for measuring the growth after transplanting.

Table 2 Effect of different water depths and seedling ages on increase in plant length (%) 14 d after transplanting under high temperature conditions

Water depth (cm)	Percent increase in plant length				
	Seedling age (d)				Mean*
	20	30	40	50	
5	29.8	25.5	39.7	25.0	30.0b
10	60.7	34.9	41.8	24.0	40.3ab
15	57.1	32.3	48.7	31.5	42.4a
20	61.9	37.4	49.4	32.6	45.3a
Mean*	52.4a	32.5b	44.9a	28.3b	

*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: Water depth: $Rp2$=10.45, $Rp3$=10.81, $Rp4$=10.99; α=0.05, d.f.=6; Seedling age: $Rp2$=11.34, $Rp3$=11.86, $Rp4$=12.13; α=0.01, d.f.=24. Rp is the abbreviated word for Duncan multiple Range Test value that is used to compare two values for significance

Table 3 Effect of different water depths and seedling ages on increase in dry weight of aerial parts (%) 14 d after transplanting under high temperature conditions

Water depth (cm)	Percent increase in dry weight of aerial parts				
	Seedling age (d)				Mean*
	20	30	40	50	
5	188.1	150.4	134.3	83.2	139.0a
10	185.2	106.7	77.2	49.7	104.7ab
15	89.6	52.8	94.8	50.4	71.9bc
20	105.9	18.3	47.5	40.6	53.1c
Mean*	142.2a	82.0b	88.4b	56.0b	

*Means followed by a common letter in the column and row are not significant at the 5% (P=0.05) by Duncan's Multiple Range Test: Water depth: $Rp2$=46.56, $Rp3$=48.68, $Rp4$=49.86; α=0.01, d.f.=24; Seedling age: $Rp2$=46.56, $Rp3$=48.68, $Rp4$=49.86; α=0.01, d.f.=24

Root dry weight data are presented in Table 5. Statistically significant differences were observed in root dry weight gain caused by both water depth and seedling age. Water depth data indicated that only the 20 cm water level had negative effect on root dry weight, while the influence of all other water levels was found to be not significant. On the other hand, older seedlings gained a significantly higher increase in root dry weight than younger ones, indicating their higher root activity than the younger seedlings. The interaction between water depths and seedling ages appeared to be not significant. Root length tending to decrease in deep water could be due to reduced oxygen levels. On the other hand, root length was very long in young seedlings compared to older ones due to physiologically more active root and shoot growth. Root dry weight tending to reduce with deep water could be due to reduction of leaf area, which in turn decreases photosynthesis causing reduced flow of carbohydrates from leaves to the roots. On the other hand, older seedlings tending to increase in root dry weight could be due to comparatively bigger vegetative portion (leaves), which translocated more photosynthate to the root in older seedlings in the early rooting stage. These results are accord with the findings of Hoshikawa (1975), who stated that transplantion of rice seedlings into deep water causes very poor rooting, while longer seedlings perform better than small ones in deep water stress because they have more breathing portion out of the water.

Percent increase in leaf area

The data on increase in leaf area is presented in Table 6. The interaction of water depth and seedling age significantly affected leaf area. Seedling of all ages in 15 cm and 20 cm water depths showed no significant differences in percent increase in leaf area indicates a stable trend at these water depths. Water depth data revealed that 20 d old seedlings produced more leaf area than seedlings of all other ages in 5 and 10 cm water depth. Older seedlings' leaf area tended to decrease in deep water. This was due to the submergence of leaves under deep water and higher tiller mortality in older seedlings. The leaf mortality and small tillers were the major reasons for the reduction of leaf area. These results are supported by the findings

Table 4 Effect of different water depths and seedling ages on increase in root length (%) 14 d after transplanting under high temperature conditions

Water depth (cm)	Percent increase in root length				
	Seedling age (d)				Mean*
	20	30	40	50	
5	207.3	211.4	68.9	46.0	133.4a
10	290.1	167.5	73.3	55.8	146.7a
15	154.1	131.5	66.7	67.7	105.0ab
20	124.6	115.6	31.1	46.0	79.3b
Mean*	194.0a	156.5a	60.0b	53.8b	

*Means followed by a common letter in the column and row are not significant at the 5% (P=0.05) by Duncan's Multiple Range Test: Water depth: $Rp2$=42.83, $Rp3$=44.75, $Rp4$=45.83; α=0.01, d.f.=24; Seedling age: $Rp2$=85.65, $Rp3$=89.50, $Rp4$=91.66; α=0.01, d.f.=24

Table 5 Effect of different water depths and seedling ages on increase in dry weight of roots (%) 14 d after transplanting under high temperature conditions

Water depth (cm)	Percent increase in root dry weight				
	Seedling age (d)				Mean*
	20	30	40	50	
5	455.6	529.6	1015.9	792.9	698.5a
10	448.1	519.3	867.1	764.4	649.7a
15	237.0	535.8	978.9	800.1	638.0a
20	311.1	198.4	509.1	548.8	391.8b
Mean*	363.0b	445.8b	842.7a	726.6a	

*Means followed by a common letter in the column and row are not significant at the 5% (P=0.05) by Duncan's Multiple Range Test: Water depth: $Rp2$=183.39, $Rp3$=191.72, $Rp4$=196.35; α=0.01, d.f.=24; Seedling age: $Rp2$=183.39, $Rp3$=191.72, $Rp4$=196.35; α=0.01, d.f.=24 of Gun (1999) who reported that under deep-water conditions, the leaf area was reduced to 23%, which was related to the reduction of tiller number and the leaf area per tiller.

Top versus root dry weight (T/R ratio)

The top versus root dry weight (T/R ratio) is one of the representative characteristics of balanced and strong seedlings. The data on T/R ratio presented in Table 7 showed significant differences regarding water depths and seedling ages, although their interaction was found to be not significant. Water depth data indicated that water depths of 5, 10 and 15 cm produced a very balanced T/R ratio and are statistically at par with each. The very high T/R ratio noted at water depth of 20 cm indicated an unbalanced T/R ratio. On the other hand seedlings of all other ages were significantly lower in producing a balanced T/R ratio as compared to 40 d old seedlings. Lower T/R ratios indicate more root dry weight as compared to that of aerial parts. This indicates balanced and strong seedlings. At the end of the experimental period, deep water caused unbalanced T/R ratio, while a small balanced T/R ratio in older seedlings might be due to fast root growth during the early rooting period.

CONCLUSION

Water temperature conditions were unstable from the surface to 10 cm water depth but became stable below this depth. However, where water depth conditions were adversely affecting a number of parameters under study. Deep water, induced higher tiller mortality, minimal increase in dry weight of aerial parts, and root length, and negatively affected root dry weight and produced an unbalanced T/R ratio. However, deep water increased plant height. Seedlings of all ages performed well in shallow water except older seedlings, which performed acceptably well in submerged conditions regarding few parameters. It is, therefore, concluded that seedlings (morphologically and physiologically) established adequately in shallow water and can withstand high temperature under such conditions.

Table 6 Effect of different water depths and seedling ages on increase in leaf area (%) 14 d after transplanting under high temperature conditions

Water depth (cm)	Percent increase in leaf area				
	Seedling age (d)*				Mean
	20	30	40	50	
5	110.9a	50.5bc	90.2ab	16.3c	67.0
10	174.0a	47.5b	42.5b	18.7b	70.7
15	18.1a	13.6a	49.0a	24.6a	26.3
20	–4.0a	–14.2a	14.3a	7.0a	0.8
Mean	74.7	24.3	49.0	16.7	

*The data followed by a common letter in the column are not significant at the 5% (P=0.05) by Duncan's Multiple Range Test: Water depth: $Rp2$=65.06, $Rp3$=68.39, $Rp4$=70.18; α=0.05, d.f.=24; Seedling age: $Rp2$=65.06, $Rp3$=68.39, $Rp4$=70.18; α=0.05, d.f.=24

Table 7 Effect of different water depths and seedling ages on dry weight aerial parts vs roots (T/R ratio) 14 d after transplanting under high temperature conditions

Water depth (cm)	T/R ratio				
	Seedling age (d)				Mean*
	20	30	40	50	
5	2.6	3.3	2.4	3.0	2.8b
10	2.7	2.8	2.0	2.7	2.6b
15	2.8	2.1	2.0	2.6	2.4b
20	2.5	3.4	2.7	3.3	3.0a
Mean*	2.7a	2.9a	2.3b	2.9a	

*Means followed by a common letters in the column and row are not significant at the 5% (P=0.05) by Duncan's Multiple Range Test: Water depth: $Rp2$=0.39, $Rp3$=0.43, $Rp4$=0.44; α=0.05, d.f.=24; Seedling age: $Rp2$=0.39, $Rp3$=0.43, $Rp4$=0.44; α=0.05, d.f.=24

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