Environmental Effects on the Resistance of Rice Seedlings to Complete Submergence[1]

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ABSTRACT

The survival of rice seedlings (*Oryza sativa* L.) after complete submergence in water decreased with increased duration of submergence; with increased depth, temperature, and turbidity of water; and with increased rates of N fertilization. Survival increased with high light intensity and plant carbohydrate content. Factors that influence the survival of submerged plants also determine the amounts of N and carbohydrate in the plant.

Additional index words: **Temperature, Light intensity, Turbidity, Nitrogen, Carbohydrate content.**

IN many monsoon areas the rice plant (*Oryza sativa* L.) is completely submerged for a day to a week during its early growth. In some seasons the plant may be submerged several times. These inundations may destroy the rice crop. This paper reports a study that was conducted at the International Rice Research Institute to determine the tolerance of rice plants to complete submergence, as influenced by duration of submergence, temperature, depth and turbidity of water, light intensity, and N level of the soil.

MATERIALS AND METHODS

Two experimental lines of rice, "early-short 'Peta'" and "early-tall 'Peta'", were used. The Peta lines were obtained by crossing Peta, a tall indica cultivar, and 'Taichung Native 1,' a short indica cultivar, and then backcrossing to Peta three times. Pregerminated seeds were sown in rows in porcelain trays, each containing 5 kg Maahas clay soil, 5 g ammonium sulfate (21% N), 2 g solophos (20% P_2O_5), and 2 g muriate of potash (60% K_2O). Each tray had eight rows, with 10 seedlings per row. Both short and tall Peta lines were sown together in a tray or separately, depending upon the experiment. Ten days after sowing, the seedlings were submerged in a tank. At the time of submergence the tips of the short Peta and the tall Peta seedlings were about 15 cm and 10 cm below the surface of the water, respectively. Each treatment was replicated twice.

In pot experiments seedlings were grown in porcelain trays for 10 days and then transplanted into porcelain pots, each containing 6 kg Maahas clay soil, 4 g ammonium sulfate, 2 g solophos, and 2 g muriate of potash. Four seedlings were planted in each pot. Each treatment consisted of five pots.

Total N was determined by the semi-microkjeldahl method. Total sugars and total starch were determined by the Anthrone method (6).

To obtain turbid water Maahas clay that had been passed through a 2 mm sieve was added to the water. The water was stirred continuously to keep soil particles in the turbid tank evenly distributed.

The soil suspension resulted in a light intensity at the base of the seedlings that was only 55% of that at the water surface, as measured by the Toshiba light meter. The water temperature was kept at 30 C in both tanks. Water temperature of the tanks was kept constant by a double-acting thermostat that controlled the heater and the flow of the cold water through the plastic tubing attached along the sides of the tank.

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RESULTS AND DISCUSSION

Length of Submergence

Short Peta and tall Peta seedlings growing in porcelain trays were submerged for 2, 4, 6, 8, 10, and 12 days. The percentage of plant survival was recorded 7 days after each treatment. Figure 1 shows the condition of the plants 19 days after the start of the treatment. Leaves of plants that were submerged for 6 to 12 days remained green while submerged but turned brown upon exposure to air. New leaves, which were much shorter than older leaves, were formed later on some plants.

More than 80% of the plants survived 6 days of submergence (Fig. 2). The percentage of survival decreased sharply after 6 days of submergence. Survival rates at 8, 10, and 12 days of submergence, however, were not significantly different from each other.

Temperature of Water

Seedlings of short Peta were submerged for 10 days in water at 25 and at 30 C. At 30 C 64% survived, while 93% survived at 25 C (Table 1). Plants elongated more slowly at 25 C and they remained dark green after removal from water. Little growth occurred while the plants were submerged, and the amount of growth in the two temperature treatments was the same. Of the plants that survived, however, those submerged at 25 C recovered faster. Since the plants at 25 and 30 C had the same quantity of starch and sugar, the faster recovery at 25 C might have been caused by a difference in the amount of green leaves. More leaves dried at the tips at 30 than at 25 C. This

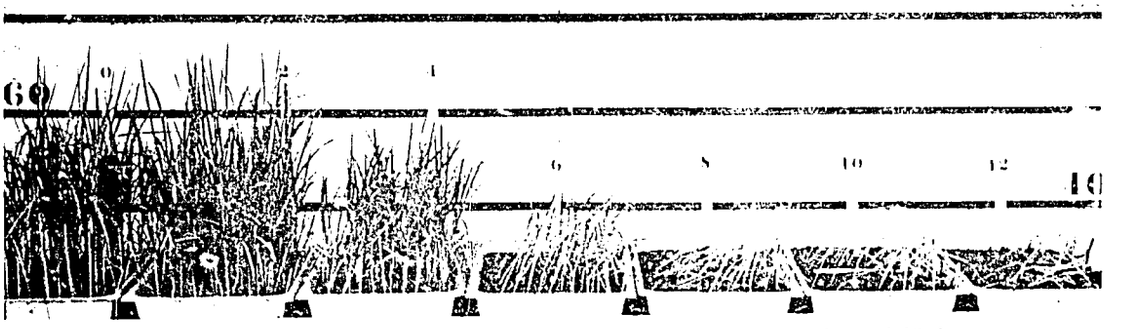

Fig. 1. Survival and recovery of Peta seedlings submerged for 2, 4, 6, 8, 10, and 12 days.

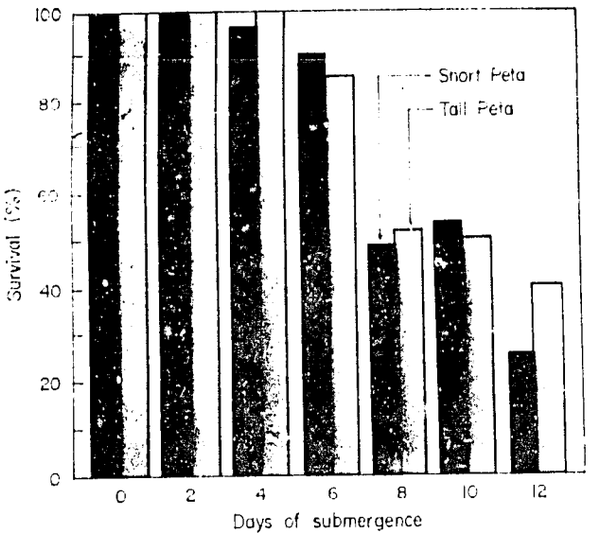

Fig. 2. Percent survival of short and tall Peta submerged for different periods of time.

agrees with the findings of Kondo and Okamura (1), who reported that leaves were greener and survival was higher at lower temperatures.

Turbidity of Water

One set of short Peta seedlings was submerged in clear water and another set in turbid water for 10 days. Plant samples were taken before submergence, after 8 days of submergence, after 10 days of submergence, and 9 days after plants were removed from 10 days of submergence.

In turbid water only 52% of the plants survived (Table 2). Under field conditions, the water turbidity during a flood has 40 to 90% light transmittance. This turbidity is due to soil and other colloidal particles. The decrease in light intensity available to the plants may be the main cause of the low survival in turbid water. Kondo and Okamura (2), however, explained the decreased survival in turbid water differently. They attributed it to mud that adhered to the plants even after submergence. Oka and Kubota (3) also reported less damage to plants submerged in clear water.

Ninety-one percent of the plants survived submergence in clear water. The constant stirring of the water in this experiment may have caused the greater survival compared with that in the other experiments also using clear water. The turbulence may have increased the diffusion of CO_2 in the water, which in turn increased the photosynthesis of the submerged leaves. Yamada (5) reported that photosynthesis occurs even during submergence. The high percentage of survival in clear water was not significantly different from that of the control.

Growth of submerged plants was significantly less than that of nonsubmerged plants (Table 2) and submersion in turbid water caused significantly more inhibition than submersion in clear water. Final dry weights, taken 9 days after treatment ended, were also significantly lowered by submergence. Seedlings that

Table 1. Height, survival, dead leaf tips, and dry weight of short Peta submerged for 10 days at 25- and 30-C water temperatures.

Water temperature	Height cm	Survival	Dead leaf tips	Dry weight, mg/plant After submergence	Dry weight, mg/plant Final†	Total sugar + starch‡ mg/plant
Not submerged	35 a	100 a	0 a	71 a	410 a	5.03
25 C	31 b	93 a	5 a	36 b	197 b	2.99
30 C	35 a	53 b	33 b	37 b	92 b	2.95

After submergence. † 15 days after treatment. ‡ 14 days after treatment.
Any two means followed by the same letter are not significantly different at the 5% level according to Duncan's multiple range test.

Table 2. Survival and dry weight of short Peta after 10 days of submergence in clear and in turbid water.

Treatment	Survival (%)*	Dry weight, mg/plant Initial	Dry weight, mg/plant After submergence	Dry weight, mg/plant Final*
Not submerged	100 a	21	113 a	444 a
Submerged in clear water	91 a	21	40 b	60 b
Submerged in turbid water	52 b	21	27 c	26 b

* Percent survival and final dry weight were taken 19 days from start of treatment.
Any two means having the same letter are not significantly different.

Table 3. Survival of plants submerged for 10 days under low and under high light intensity.

Light intensity	Survival (%) Short "Peta"	Survival (%) Tall "Peta"	Survival (%) Short "Peta"	Survival (%) Tall "Peta"
	Control		Submerged	
High	100 a	100 a	75 b	93 c
Low	100 a	100 a	40 d	33 e

Any two means having the same letter are not significantly different according to Duncan's multiple range test.

had been submerged in turbid water essentially did not grow after submergence, while seedlings that had been submerged in clear water gained 50% in dry weight compared with 296% for seedlings in the nonsubmerged controls. The total sugars and starch decreased more in plants placed in turbid water (Fig. 3). The lower amounts of N, starch, and total sugars in plants submerged in turbid water may have caused the lower percentage of survival and recovery. This experiment showed that turbidity decreased the tolerance of the rice seedlings to submergence.

Light Intensity

The lower light transmission in turbid water may be the main reason for the lower percentage of survival among submerged plants in turbid water. To test the effect of light intensity, short and tall Peta seedlings were submerged for 10 days under low and under high light intensity. To obtain a low light intensity the plants were shaded with abaca cloth so that they received only 20% of the sunlight. Water temperature was kept at 30 C.

The percentage of survival was significantly higher at high light intensity in both short and tall Peta (Table 3). Tall Peta was significantly more resistant than short Peta under both high and low light intensities. An earlier test showed that at high light intensity, there were no differences between the survival of tall Peta and that of short Peta at 10 days of submergence, although more tall Peta plants than short Peta plants survived at 12 days of submergence. The temperature used in the earlier test was not kept constant at 30 C, and this may explain why the responses of short and tall Peta did not differ.

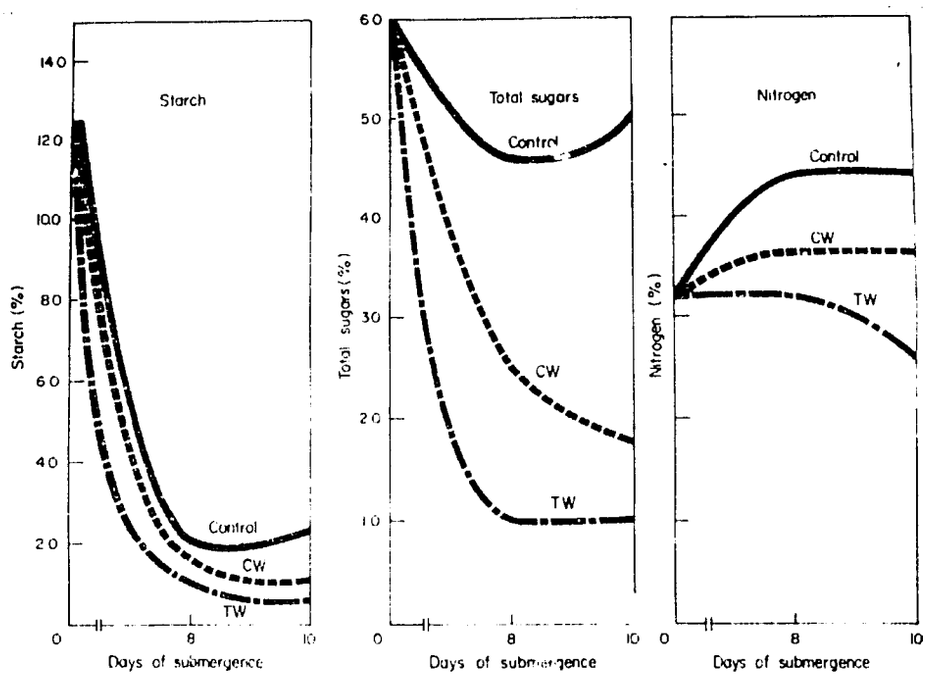

Fig. 3. Changes in starch, total sugars, and N of short Peta submerged for 8 and 10 days in clear (CW) and in turbid (TW) water. Control plants were unsubmerged.

Table 4. Survival and changes in sugar and starch of short Peta plants grown at two levels of N and submerged for 10 days.

Nitrogen level in soil	Initial	Control	Submerged	Difference
		[illegible]		
High	[illegible]	[illegible]	[illegible]	[illegible]
Low	[illegible]	[illegible]	[illegible]	[illegible]
		[illegible]		
High	[illegible]	[illegible]	[illegible]	[illegible]
Low	[illegible]	[illegible]	[illegible]	[illegible]*
		[illegible]		
High		[illegible]	[illegible]	[illegible]
Low		[illegible]	[illegible]	[illegible]

*Significant at the 5% level.

Depth of Submergence

Seedlings of short Peta were grown in porcelain pots. Twenty days after sowing, the plants were submerged for 6 days at submergence depths of 0, 20, 50, and 70 cm, measured from the tip of the longest leaf to the water surface. The temperature of the water varied from 26 to 30 C. The percentage of survival in plants was determined 2 weeks after the plants were taken out of the water. The percentage of survival decreased with depth of water (Fig. 4). The lower survival of plants submerged deeper in water may be attributed to lower light transmittance. Westlake (4) reported that even in clear water light intensity decreases with depth.

Nitrogen Status

The experiment on turbidity indicated the possible influence of accumulated carbohydrates on the resistance of plants to submergence. To vary the carbohydrate content of the plant, two N levels were used for growing the short Peta seedlings. Each tray of soil in the high N treatment was fertilized with 5 g ammonium sulfate applied before sowing; another tray

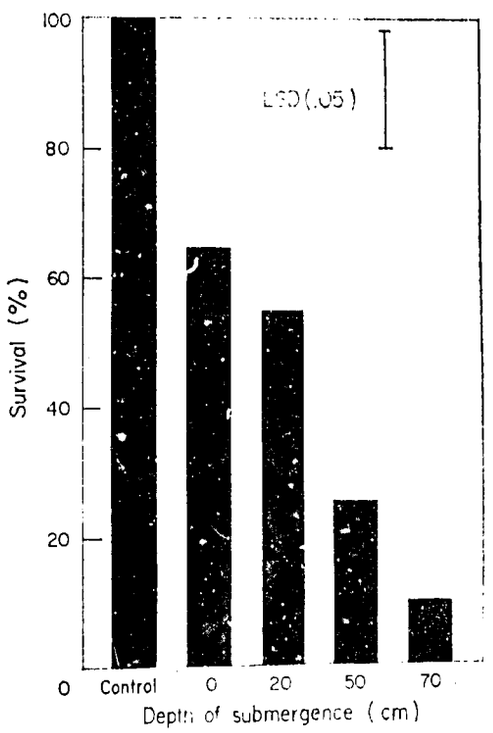

Fig. 4. Percentage of survival of short Peta submerged for 6 days at different depths of water.

did not receive added N. All plants were submerged for 10 days at a water temperature of 30 C. The percentage of survival was significantly higher in plants grown at the low N level (Table 4). The amount of starch in plants grown at both the low and the high level of N decreased with submergence, but the reduction was greater at the low N level. The initial high

carbohydrate content of the plants, particularly the starch content, is probably an important factor that affects the resistance of the plant to submergence. Yamada (5) reported that N topdressing before flooding causes a large decrease in resistance against submergence because it decreases the starch content of the plants. During submergence the available carbohydrates are exhausted rapidly because photosynthesis is low. Yamada found a negative correlation between respiratory rate and resistance to flooding. Our data show that plants with more initial carbohydrates survive better.

Longer duration of submergence, higher water temperature, greater turbidity, lower light intensity, higher soil N, and deeper submergence, can decrease the plant's carbohydrate content and thus decrease the percentage of survival under submerged conditions.

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