The effects of flooding and sowing depth on the survival and growth of five rice-weed species

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Summary

Greenhouse experiments were conducted to determine the effects of time and depth of flooding and depth of seeding on the survival and growth of five weed species. The survival of *Rhynchospora corymbosa* (L.) Britt. and *Ludwigia hyssopifolia* (G. Don) Exell was unaffected by the flooding depth, but survival of *Echinochloa colona* (L.) Link and *Cyperus iria* L. decreased with increasing flooding depth. The survival of *E. crus-galli* (L.) Beauv. was the most affected by flooding depth, with no seedling surviving at 15 cm depth. Shoot dry weight and shoot and root length of all five species decreased with increasing flooding depth. When flooding was delayed, there was an increase in the survival of *E. crus-galli, E. colona* and *C. iria*, but survival of *L. hyssopifolia and R. corymbosa* was unaffected. When flooding was delayed, the dry weight and shoot and root lengths of the seedling of all species were greater than when flooding was done immediately. Depth of planting influenced emergence; maximum seedling emergence of all species occurred when seeds were at the soil surface. Emergence of *E. crus-galli* and *E. colona* still occurred when seeds were planted at a depth of 5 cm in saturated soil. However, the emergence of *L. hyssopifolia* and *C. iria* was inhibited at a depth of 4 and 5 cm, respectively. No emergence of *R. corymbosa* seedlings was observed when seeds were sown under flooded conditions.

Introduction

Some weeds of lowland rice-growing areas are adapted to growing in flooded soil while others are not. Water management can be used to control susceptible weeds as well as to regulate the composition of weed populations (Smith and Fox 1973, Smith 1983). For example, the growth of seedlings of *Fimbristylis miliacea* Vahl., an important sedge in lowland rice fields, and of *Ludwigia hyssopifolia* appears to be severely reduced under water (Pons 1982). Deep submergence (15–20 cm) was effective in controlling rice weeds, primarily *Eleocharis geniculata* (L.) Roem & Schult. and *Cyperus difformis* (Moody 1990).

Factors which affect the effectiveness of water management and flooding as weed control measures include standing water depth (IRRI 1977); time of flooding (Civico and Moody 1979, Floresca *et al.* 1979, Navarez *et al.* 1979); weed species (Smith and Fox 1973, Civico and Moody 1979); stage of development of weeds (Civico and Moody 1979); and seeding depth of the weeds (Pons 1982).

Flooding has long been recognized as an effective means of weed control in lowland rice (Cralley and Adair 1943). It prevents many weed seeds from germinating and suppresses weed growth and development when it is applied during the early stages of weed growth. However, flooding induces different germination and growth responses in various weed species. Moist or saturated soil favours the emergence and growth of grasses and sedges which are difficult to control by subsequent flooding once they have established (Mabbayad 1967). Shallow flooding and a shorter period of flooding result in poorer weed control. Continuous shallow flooding (2.5 cm) also results in weed problems, especially with sedges (Chandler 1966). Weed populations decrease as the depth of water increases. Note, however, that Devasundarajah (1971) showed that even as little as 1–2 cm of water will result in a reduction in the number of weeds.

Poor water control contributes to increases in weed populations, reduced weed control efficiency with all methods of weed control, particularly herbicides, and an increase in the time spent weeding. It is essential to keep fields continuously flooded for 30 days after planting, not only to reduce the number of weeds that are present but also to improve the performance of weed control techniques used in association with water management. After establishment, it is more difficult to control weeds, and deeper water is needed to achieve the same degree of control (Civico and Moody 1979). Janiya and Moody (1984) observed that appropriate water management at early growth stages has a major effect on weed growth. A water deficit from 15 days after emergence may reduce growth of rice seedlings due to competition with *Echinochloa colona* (Janiya and Moody 1991).

This study was conducted to examine the effects of time and depth of flooding and sowing depth on the growth and development of five weeds commonly occurring in Malaysian paddy fields. This may provide information on the importance of water management in the control of these weeds or other species occupying similar ecological niches.

Materials and methods

Seeds

Seeds of *E. crus-galli, E. colona, L. hyssopifolia* (G. Don) Exell, *C. iria* and *Rhynchospora corymbosa* (L.) Britt were collected from paddy fields near Tanjung Karang, Selangor. Dry seeds were cleaned by a combination of rubbing, sieving and winnowing. The seeds were dressed with fungicide dust (Thiram) to avoid any fungal growth and stored in air-tight bottles at room temperature. The seeds were kept under laboratory conditions for a maximum of two months.

Soil

The soil used in this experiment was collected from ricefields near Tanjung Karang, Selangor. The soil was Sabrang Series (45% sand, 19% silt and 36% clay) with 37% organic matter and pH 4.7.

Effect of flooding depth on survival and growth

Effects of flooding depth on the survival and establishment of five weed species were studied in a greenhouse experiment. Two litre plastic pots were filled with alluvial soil (Sabrang Series) collected from paddy fields near Tanjung Karang. Each pot was planted with 50 seeds of a species. There were three pots for each species. One week after germination, ten seedlings of each species were transplanted into fibreglass basins (360 × 120 × 30 cm) filled with Sabrang Series soil up to 15 cm deep. The experiment was laid out in a split plot design with five flooding depths as the main plot and weed species as sub-plot. The flooding depths were 0 (saturated soil), 2.5, 5.0, 10 and 15 cm. The water levels were checked and maintained daily. The soils in the basin were divided into five sub-plots before transplanting to accommodate 10 seedlings of each species. The plants surviving at 14 weeks after transplanting (WAT) were counted, and five surviving plants of each species from each basin were washed thoroughly with water and dried to constant weight in an oven at 55°C. The treatments were duplicated and the means were used for presentation. Data were subjected to an analysis of variance and means were compared by Duncan multiple range test at 5% probability level.

Effect of time of flooding on survival and growth

Ten one-week-old seedlings of each species were transplanted separately into 16 litre buckets which were two-thirds filled with saturated soil taken from the same location as above. Four different flooding times were applied: 0 (immediately after transplanting), 1 WAT, 2 WAT and 3 WAT. The water depth was 10 cm for all species. Three buckets were used for each flooding treatment of each species. The water levels were checked and maintained daily. There were ten plants for each flooding treatment. At 14 WAT, the surviving plants in each bucket were counted; the plants were then removed, freed of soil and oven-dried at 55°C for dry weight determination. Data were subjected to an analysis of variance, and means were compared by Duncan multiple range test at 5% probability level.

Effect of sowing depth and flooding on emergence and growth

One litre plastic pots were filled with the same soil taken from a paddy field near Tanjung Karang. The pots were grouped into two sets of 300 pots each. The first set of pots were placed in fibreglass basins filled with water to 4 cm above the soil surface. In the other set of pots, the soil was kept saturated. The experiment was laid out in a split plot design with flooding treatments as the main plot and sowing depths as sub-plots. Each pot was sown with 50 seeds of each species. Depth of sowing treatments was 0 (soil surface), 1, 2, 3, 4 or 5 cm. There were 10 replicate pots for each treatment and each species. Water levels in the fibreglass basins were checked and maintained daily. The numbers emerged and shoot lengths were determined 14 days after planting. The plants were then washed thoroughly and oven-dried at 55°C to constant weight. Data were subjected to an analysis of variance, and means were compared by Duncan multiple range test at 5% probability level.

Results and discussion

Effect of flooding depth on survival and growth

Results on the effect of flooding depth are summarized in Table 1. *E. crus-galli* seedlings were killed by flooding at 15 cm depth (Table 1) while significant decreases in their survival between 0 and 2.5 and between 5 and 10 cm depths were observed. Dry weight, shoot length and root length of *E. crus-galli* showed a significant reduction between 0 and 2.5 cm depth of flooding, suggesting that this species is increasingly damaged by deeper submergence. This species is known to be one of the noxious weeds in direct-seeded paddy fields (Ho and Zuki 1988). Smith and Fox (1973) reported that submergence of the soil effectively controlled *E. crus-galli*, *Brachiaria platyphylla* and *Aechynomene vinginica*.

Table 1. Effects of flooding depth on the survival and growth of five weed species 14 WAT when flooding occurred immediately after transplanting.

Flooding depth (cm)	Survival (%)	Dry weight (g)	Shoot length (cm)	Root length (cm)
Echinochloa crus-galli				
0	100 a	55.79 a	119.0 a	22.0 a
2.5	74 b	4.55 b	19.8 b	7.6 b
5.0	70 b	2.40 b	20.8 b	5.6 b
10.0	74 b	2.43 b	18.7 b	5.9 b
15.0	0	0	0	0
Echinochloa colona				
0	100 a	42.10 a	87.0 a	12.2 a
2.5	76 b	29.11 b	74.4 b	13.2 a
5.0	74 b	1.24 c	17.6 c	6.4 b
10.0	74 b	1.38 c	13.6 c	6.4 b
15.0	50 c	1.56 c	15.2 c	7.0 b
Ludwigia hyssopifolia				
0	100 a	9.48 a	53.0 a	7.0 a
2.5	100 a	6.35 b	45.0 b	6.0 b
5.0	98 a	0.09 c	7.6 c	2.8 c
10.0	96 a	0.07 c	5.6 c	2.4 c
15.0	92 a	0.06 c	6.7 c	2.5 c
*Cyperus iri*a				
0	100 a	16.79 a	41.0 a	8.0 a
2.5	100 a	15.83 b	31.8 b	6.4 b
5.0	96 ab	0.49 c	4.8 c	2.2 c
10.0	94 ab	0.18 c	4.6 c	2.0 c
15.0	86 b	0.01 c	4.8 c	2.1 c
*Rhyncospora corymbos*a				
0	100 a	24.34 a	65.0 a	9.2 a
2.5	94 a	20.00 b	61.2 b	9.4 a
5.0	94 a	0.16 c	10.2 c	5.2 b
10.0	96 a	0.20 c	8.4 c	4.0 c
15.0	94 a	0.11 c	9.0 c	2.6 d

Means within a column followed by the same letter are not significantly different at the 5% level according to Duncan's multiple range test.

Saturated soil favoured the survival and growth of *E. colona*. Flooding to a depth of 15 cm reduced its stand by 50%. Once established, *E. colona* survived flooding. Dry weight and shoot length decreased significantly between 0, 2.5, and 5 cm of flooding depth. However, dry weight and shoot length of *E. colona* were not significantly different between the flooding depth of 5, 10 and 15 cm. Root length decreased significantly at flooding depths greater than 5 cm. Civico and Moody (1979) reported that the survival of *E. colona* was generally unaffected by depth of flooding. This indicates its ability to grow equally well in a well-drained, saturated or flooded soil, provided that it had emerged at the time of flooding.

Depth of flooding did not affect the survival of *L. hyssopifolia*, but its growth was significantly reduced by flooding. Flooding depths of up to 15 cm did not significantly affect the survival of *L. hyssopifolia*, which was more than 90% in all flooding depths. However, dry weight, shoot length and root length all showed a significant decrease between the 0, 2.5 and 5 cm flooding depths. No significant differences were observed at depths greater than 5 cm.

About 86% of *C. iria* seedlings were able to survive in deep water (15 cm). This was significantly lower than the 100% survival rate under saturated conditions. Dry weight at 5 cm flooding depth was reduced by 2% of that of plants in saturated (0 cm depth) soil, while the shoot and root lengths were reduced by 88 and 72% respectively. Flooding at depths greater than 5 cm had showed effects not significantly different from those obtained at 5 cm.

None of the flooding levels affected the survival of *R. corymbosa* (Table 1). However, flooding depth had a marked effect on its dry weight and shoot length which were reduced by 99 and 84%, respectively, at 5 cm flooding depth. Root length was also reduced at flooding depths of 5 cm and deeper.

Effect of time of flooding on survival and growth

Data on the effects of flooding time on the survival and growth of *E. crus-galli* six weeks after transplanting (WAT) are shown in Table 2. Its survival rate increased as the time of flooding was delayed: 97% when flooded at 3 WAT compared with 74% when flooded immediately after transplanting (0 WAT). Survival of *E. colona* was significantly reduced when seedlings were flooded immediately after transplanting as compared with survival rates of plants flooded at 1, 2 or 3

WAT. The survival of *L. hyssopifolia* was not affected by time of flooding. With *C. iria*, delaying flooding to 3 WAT increased its survival to 99%, but the survival rate significantly decreased when plants were flooded immediately after transplanting. No significant differences in survival of *R. corymbosa* were observed between the flooding times, suggesting that this species is tolerant to flooding even soon after transplanting.

When the flooding time was delayed for 2 or 3 WAT, shoot and root length of all species increased. At 3 WAT, the shoot length of *E. crus-galli* and *E. colona* were 42.4 and 50.1 cm respectively. Delaying flooding until one week after transplanting reduced shoot length of *E. colona* but did not affect that of *E. crus-galli*. The shoot lengths of *L. hyssopifolia*, *C. iria* and *R. corymbosa* at 3 WAT were 34, 37 and 30.8 cm respectively. For *E. crus-galli*, delaying flooding until 1 WAT had essentially the same affect on root length as flooding immediately after transplanting but significant increases in shoot length were observed between 1, 2 and 3 WAT. On the other hand, for *E. colona*, significant increases in root length were observed between 0, 1 and 2 WAT, but no significant difference was observed between flooding at 2 and 3 WAT. Significant differences in root lengths were observed for *L. hyssopifolia* and *C. iria* at 1 WAT. Root lengths of *R. corymbosa* did not significantly increase when plants were flooded at 2 WAT when compared with root lengths of seedlings flooded immediately after transplanting.

Echinochloa crus-galli had a significantly higher total dry weight when flooding occurred at 1 or 2 WAT compared to those flooded immediately after transplanting. Dry weights of *E. colona* showed significant differences among all treatments, with the highest at 3 WAT. *L. hyssopifolia* showed no significant differences in total

Table 2. Effects of time of flooding on the survival and growth of five weed species at 6 WAT.

Flooding time (WAT)	Survival (%)	Dry weight (g)	Shoot length (cm)	Root length (cm)
Echinochloa crus-galli				
0	74 b	2.43 c	18.7 b	5.9 c
1	80 b	6.45 b	23.4 b	5.9 c
2	95 a	12.93 a	40.2 a	8.7 b
3	97 a	13.78 a	42.4 a	11.4 a
Echinochloa colona				
0	74 b	1.38 d	13.6 d	6.4 c
1	82 a	7.03 c	30.9 c	9.0 b
2	89 a	11.94 b	40.1 b	9.8 a
3	93 a	14.12 a	50.1 a	9.7 a
Ludwigia hyssopifolia				
0	96 a	0.07 c	5.6 c	2.4 b
1	98 a	4.83 b	29.1 b	7.7 a
2	97 a	6.54 a	31.0 b	7.1 a
3	98 a	6.94 a	34.0 a	7.8 a
Cyperus iria				
0	94 b	0.18 b	4.6 d	2.0 b
1	97 ab	3.00 b	26.3 c	4.6 a
2	98 ab	4.26 a	33.0 b	4.7 a
3	99 a	4.04 b	37.0 a	4.9 a
Rhyncospora corymbosa				
0	96 a	0.20 d	8.4 d	4.0 b
1	99 a	1.67 c	14.9 c	3.4 c
2	100 a	5.35 b	23.6 b	4.0 b
3	100 a	6.99 a	30.8 a	4.7 a

Means within a column followed by the same letter are not significantly different at the 5% level according to Duncan's multiple range test.

Table 3. Effects of submergence and seeding depth on emergence, dry weight and shoot length of five weed species.

Depths (cm)	*E. crus-galli*		*E. colona*		*C. iria*		*L. hyssopifolia*		*R. corymbosa*
	Saturated	Flooded	Saturated	Flooded	Saturated	Flooded	Saturated	Flooded	Saturated
Emergence (%)									
0	73 a	13 a	44 a	6 a	91 a	9 a	63 a	6 a	14 a
1	39 c	12ab	41 b	2 a	88 a	9 a	58 b	3 b	6 b
2	43 b	7ab	33 c	2 a	50 b	3 b	55 c	2 b	4 c
3	29 c	7ab	28 d	–	25 c	–	10 d	–	4 c
4	30 c	5 b	17e	–	10 d	–	–	–	–
5	33 c	–	2f	–	–	–	–	–	–
Dry weight (mg)									
0	360 a	110 a	140 a	32 a	190 a	40 a	110 b	15 a	100 a
1	260 b	50 b	120 b	30 a	170 b	30 b	110 b	20 a	60 b
2	210 b	40 b	110 b	15 b	160 b	4 c	120 a	–	40 c
3	210 b	80 b	90 c	–	80 c	–	10 c	–	20 d
4	200 b	60 b	40 d	–	20 d	–	–	–	–
5	170 c	–	10 d	–	–	–	–	–	–
Shoot length (cm)									
0	8.1a	5.7a	7.5a	3.8a	5.5a	5.5a	4.2a	4.3a	4.6a
1	8.0a	5.1a	6.5ab	3.5a	5.0a	4.0b	4.0ab	3.5a	4.1ab
2	7.9a	4.3ab	6.5ab	3.4a	4.5b	3.0c	3.8b	–	4.0b
3	7.7ab	4.1bc	6.0b	–	4.5b	–	3.6b	–	3.5b
4	7.0b	3.2c	6.0b	–	4.0b	–	–	–	–
5	6.0c	–	5.5c	–	–	–	–	–	–

Means within a column followed by the same letter are not significantly different at the 5% level according to Duncan's multiple range test.

dry weight between flooding treatments at 2 and 3 WAT, but showed significant reductions between treatments at 0, 1 and 2 WAT. *C. iria* showed significant increases in dry weight when flooded at 1, 2 and 3 WAT. Dry weights of *R. corymbosa* significantly increased with each delay in flooding.

Effect of sowing depth and flooding on emergence and growth

The emergence and growth of the five weed species according to sowing depth and presence or absence of flooding are shown in Table 3. Emergence of *E. crus-galli* sown in saturated soil decreased by 40% when seeds were planted at a depth of 1 cm as compared to sown on the surface, while in flooded soil, *E. crus-galli* seedlings failed to emerge. Emergence in flooded soil was lower than that of seeds sown at all depths in saturated soil. Under saturated conditions, emergence from the 5 cm sowing depth was reduced by 54% of the emergence at soil surface. In flooded soil, no emergence was observed at 5 cm depth. Note that Kataoka and Kim (1978) reported that *E. crus-galli* emerged only from 1 and 2 cm depths in flooded soil. Its dry weight decreased with increasing seeding depths. The greatest reduction in dry weight was observed at 5 cm depth. Shoot length was also reduced by increasing seeding depths under either condition. These observations were similar to that of Kennedy *et al.* (1980) who observed that seeds of *E. crus-galli* can germinate and grow for prolonged periods in a totally oxygen- free environment.

Emergence of *E. colona* reduced significantly with increasing seeding depth, particularly under flooding conditions where no emergence was observed at 3 cm depth and deeper. Dry weight of plants sown at 5 cm depth was reduced by 93% compared to that of seedlings planted at the soil surface.

Seeding depth reduced the rate of emergence of *C. iria*, *L. hyssopifolia* and *R. corymbosa*. Sowing seeds of *C. iria* at 4 cm depth in saturated soil reduced emergence by 89% compared with those sown at the soil surface. No emergence was observed below 3 cm depth under flooding conditions; nor was emergence observed when seeds were sown at 5 cm depth, in either flooded or saturated soil conditions. At 4 cm, its dry weight was reduced by 89% as compared with those placed on soil surface. However, increasing seeding depth caused only a slight decrease in shoot elongation of *C. iria*.

No emergence of *L. hyssopifolia* was observed at 3 and 4 cm depth in flooded and saturated soil respectively. Earlier reports have shown that germination of this species was completely inhibited by submergence (Pons 1982). In saturated soil, its dry weight showed a marked reduction at 3 cm depth when compared to that at the soil surface. Its shoot length increased with increasing seeding depth. The emergence of *R. corymbosa* seedlings was very low in saturated soil and completely inhibited under flooding conditions, suggesting that this species will not establish in flooded soil.

It is already known that the germination rate of weed seeds decreases with decreasing oxygen concentrations (Pons 1982). Erickson (1976) suggested that there is a critical oxygen partial pressure for normal or optimal plant growth and a critical pressure below which no plant growth occurs. Therefore, the reduction of emergence reported here might be due to anaerobic conditions in flooded soil, especially with deeper seeding (Kennedy *et al.* 1980).

The results presented here suggest that the survival and subsequent growth of some weed seedlings in rice fields will be affected by flooding and seeding depth. In general, seedling establishment was greatly affected, especially when seeds were sown deep in the soil. Most of the weed seeds studied was less able to emerge when sown deep in soil. Flooding to a depth of 15 cm inhibited the survival of *E. crus-galli* and reduced the survival of *E. colona* and *C. iria*. Flooding immediately after transplanting reduced the survival of *E. crus-galli* and *E. colona*, suggesting that the establishment of these species could be more readily reduced directly after seeding. The longer flooding is delayed after weed emergence, the deeper the water is needed to achieve even partial weed control. Certain species, such as *E. crus-galli* and *E. colona* in particular can be controlled in direct-seeded rice fields by proper water management such as in addition to using other control practices.

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