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Ecological studies on *Echinochloa crus-galli* and the implications for weed management in direct-seeded rice

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ABSTRACT

Echinochloa crus-galli, a C_4 grass, is one of the world's most serious weeds. Weed management decisions for this species can be derived from knowledge of its seed biology. Studies were conducted to determine the effects of light on germination; seed burial depth and rice residue on emergence and growth; and flooding time and depth on emergence, survival and growth of this species. Light stimulated seed germination but it was not an absolute requirement for germination. The proportion of seeds germinating was greatest for seeds placed on the soil surface (92%), and emergence declined with increasing burial depth in soil; no seedlings emerged from the depth of 8 cm. A burial depth of only 0.4 cm reduced seedling emergence by 50%. Seedling emergence and seedling biomass were reduced by the addition of high level (6 ton ha^{-1}) of rice residue to the soil surface. Early and deep flooding significantly suppressed growth of *E. crus-galli* seedlings. In flooded conditions, with increased water depth the weed allocated more biomass to shoots at the expense of roots. The information gained from this study could contribute to improve weed control approaches. Soil inversion by tillage to bury weed seeds below their maximum depth of emergence, use of crop residue as mulch and early flooding of the crop could serve as important tools for managing *E. crus-galli* and other weed species with similar germination requirements. These management options, however, would need to be compatible with other crop management requirements.

1. Introduction

Echinochloa crus-galli uses the C_4 photosynthetic pathway and is among the world's most serious grass weeds (Holm et al., 1991; Rao et al., 2007). It is a major weed in many crops, including rice (*Oryza sativa* L.), cotton (*Gossypium hirsutum* L.), corn (*Zea mays* L.), sorghum (*Sorghum bicolour* L.), peanut (*Arachis hypogaea* L.), sugarcane (*Saccharum officinarum* L.), cassava (*Manihot esculenta* Crantz), and vegetables (Holm et al., 1991). In direct seeding, *E. crus-galli* has been documented to occur in 22 countries in dry-seeded rice and in 15 countries in wet-seeded rice (Rao et al., 2007). This species resemble the rice crop at the seedling stage and by the time the weed is easily recognized by farmers, crop yield loss may already be unavoidable (Holm et al., 1991). *E. crus-galli* at a density of 9 plants m^{-2} can reduce yield of rice by 57% (Maun and Barrett, 1986). High infestation of *E. crus-galli* can remove up to 80% of the nitrogen from the soil (Holm et al., 1977). In some countries, intensive herbicide use to control this species has led to the evolution of resistance to several herbicides (Rao et al., 2007). Further, this species is also a secondary host to pathogens and viruses of several crops (Holm et al., 1991).

Weed management decisions for a particular species can be derived from knowledge of its seed biology (Bhowmik, 1997). Weed seed germination is influenced by various factors, including light, seed burial depth, and soil moisture (Chauhan and Johnson, 2010b). Light, for example, is an important ecological aspect for germination; the requirement for light means that seeds will only germinate at or near the soil surface. Similarly, knowledge on seedling emergence in relation to soil burial depth could contribute to the use of tillage systems to reduce emerging weed seedlings. Crop residues, as a mulch on the soil surface, in some systems might provide weed suppression (Buhler et al., 1996; Teasdale et al., 1991), which could be integrated into weed management components in rice. The type and quantity of plant material used, however, may stimulate or inhibit weed emergence (Purvis et al., 1985). Little is known of the influence of seed burial depth and crop residue on the emergence of *E. crus-galli* in the tropics.

Flooding is an important component of cultural weed management in rice (Chauhan and Johnson, 2010b). It is, however, the timing and depth of flooding that governs the extent of weed suppression by water (Chauhan and Johnson, 2008, 2009b,c; Hill

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et al., 2001). In direct-seeded rice, due to limited options for flooding immediately after seeding, flooding is usually given after crop emergence. By the time fields are flooded, weeds may have already emerged. Therefore, better understanding the impact of timing on weed growth could enable flooding to be used more effectively as a component of integrated weed management in direct-seeded rice. The information on the influence of flooding on growth and survival strategy of *E. crus-galli* is limited in the literature.

Studies were conducted to determine the effects of light on germination; seed burial depth and rice residue on emergence and growth; and flooding time and depth on emergence and growth of *E. crus-galli* seedlings. The results on seed biology of *E. crus-galli* may provide information on the importance of tillage, crop residue and water management in the control of *E. crus-galli* and other weeds with similar germination requirements.

2. Materials and methods

Experiments were conducted at the International Rice Research Institute, Los Baños, Philippines. Seeds of *E. crus-galli* were collected from several rice fields around Los Baños. Seeds were bulked, cleaned and stored in a laboratory until they were used in the experiments.

2.1. Effect of light on seed germination

Seed germination was determined by placing 25 seeds evenly in a 9-cm diameter Petri dish containing two pieces of Whatman No. 1 filter paper and 5 ml of distilled water. The dishes were then incubated at 30/20 °C alternating day/night temperature in two light regimes [light/dark (12 h/12 h) and continuous dark (24 h)]. The photoperiod was set to coincide with the high-temperature interval. Dishes were wrapped in double layers of aluminium foil to maintain complete darkness. Germination was determined after 14 days, at which time seeds with emerged radicals were considered to have germinated.

2.2. Effect of seed burial depth on seedling emergence

The effect of seed burial depth on seedling emergence was determined in a screenhouse (frame building with 2-mm steel mesh sides and overhead transparent plastic cover to prevent rain damage). Fifty seeds of *E. crus-galli* were placed on the soil surface, or covered with the same soil to achieve burial depths of 0, 0.5, 1, 2, 4, 6, and 8 cm in 15-cm-diameter plastic pots. Soil (clay 26%, silt 34%, and sand 40%; pH 6.6; and organic carbon 2.1%) used for this experiment was collected from rice fields, autoclaved, and passed through a 3-mm sieve. Pots were watered initially with an overhead sprinkler and later sub-irrigated. Seedling emergence was defined as the appearance of the coleoptile, and emergence was counted until 21 days after sowing (DAS).

2.3. Effect of rice straw on seedling emergence and biomass

Fifty seeds of *E. crus-galli* were sown on the soil surface in plastic pots and finely chopped rice (IR64, a variety widely grown in Asia) straw (leaves and stems) was spread on the surface at rates equivalent to 0, 1, 2, 4, and 6 ton (t) ha^{-1}. The amounts of rice straw used in this study represent the range of quantities found in low-yield systems in rain-fed environments and high-yield systems in irrigated environments. The soil used in this experiment was as described above. Emerged seedlings were counted until 21 DAS as described above. At the end of the experiment, emerged seedlings were harvested, placed in paper bags and oven-dried at 70 °C for 72 h for dry biomass measurements.

2.4. Effect of depth and seedling age at time of flooding on seedling growth

Twenty seeds of *E. crus-galli* were spread on the soil surface in plastic trays and the soil maintained at saturation level until the flooding was applied. The seedlings were thinned at 4 DAS and 10 seedlings per tray were maintained. The weed sowing dates were staggered so that all the plants were flooded at the same time. The flooding times of the plants were 5, 10, 15, and 20 DAS, and the flooding depths were 0 (saturated soil), 2, and 10 cm. The soil used in this experiment was as described above. The trays with the seedlings were transferred to large containers to retain water and maintain the required water levels. To ensure uniformity of water quality and maintain the water levels, a continuous water flow was installed for all containers. There was minimal soil disturbance in the trays and no water turbidity throughout the experiment. Survival, height, and shoot and root dry biomass of seedlings were recorded 14 d after flooding (Chauhan and Johnson, 2009c).

2.5. Effect of flooding on seedling emergence and biomass

In the previous experiment, it was observed that once *E. crus-galli* seedlings have emerged, flooding would not give efficient control of this species. An additional experiment was, therefore, conducted to evaluate the effect of early flooding on seedling emergence and seedling biomass. Forty seeds of *E. crus-galli* were sown on the soil surface in plastic trays. The treatments were five flooding times (0, 1, 2, 3, and 4 DAS) and four flooding depths (0, 2, 4, and 6 cm). The experiment was carried out as described above. After 14 d of flooding, emerged seedlings were counted, harvested, and oven-dried at 70 °C for 72 h for biomass.

2.6. Statistical analysis

All experiments, except the light experiment, were conducted in a randomized complete-block design. The light experiment was analysed using one-way analysis of variance (ANOVA) as there was no true replication at the treatment level. The flooding experiments were established with four replications, while other experiments had three replications. All experiments were conducted twice in two independent "trials". As there were no significant interactions between treatments and trials, the data were combined over the experimental trials and subjected to ANOVA (GenStat 8.0, 2005). Regression analysis was used where appropriate; otherwise, means were separated using least significance difference (LSD) at the 5% level of significance. A three-parameter sigmoid model was best fitted to the seedling emergence (%) obtained at different seed burial depths or residue amounts. The model was

$$E = E_{max}/\{1 + \exp[-(x - T_{50})/E_{rate}]\}$$

where E is the total seedling emergence (%) at time x, E_{max} is the maximum seedling emergence (%), T_{50} is the time to reach 50% of maximum seedling emergence, and E_{rate} indicates the slope. An exponential decay curve of the form

$$E = E_{max} \times \exp(-E_{rate} \times x)$$

was fitted to the seedling emergence (%) obtained at different seed burial depths, where E represents emergence (%) at burial depth x, E_{max} is the maximum emergence and E_{rate} indicates the slope.