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Shade reduces growth and seed production of *Echinochloa colona*, *Echinochloa crus-galli*, and *Echinochloa glabrescens*

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ABSTRACT

Echinochloa species are problematic weed species in direct-seeded rice systems in Asia. Because of concern about the continuous use of single herbicides, cultural weed management strategies need to be developed to maintain the sustainability of direct-seeded rice systems. However, the design of such strategies requires an understanding of the differential responses of weeds to shade caused by crop interference. The effects of shade on growth and seed production of *Echinochloa colona*, *Echinochloa crus-galli*, and *Echinochloa glabrescens* were determined. Weeds of three *Echinochloa* species were grown continuously in full sunlight or in 50% or 25% of full sunlight, or started in full sunlight and transferred to 50% or 25% of full sunlight at 21 days after sowing. The results suggested that changes in shade regime did not affect the plant height of *E. colona* and *E. glabrescens*; however, shade reduced the height of *E. crus-galli*. Compared with the plants grown in full sunlight, 75% of continuous shade reduced *E. crus-galli* height by 22%. Shade reduced leaf, total shoot, and root biomass and seed production in all the weed species, if occurred during the early growth of the weeds. The weeds responded with increased leaf biomass ratio when grown in shade. Compared with full sunlight, continuous shade of 75% increased leaf biomass ratio by 90% in *E. colona* and this value was 25% in the other two species. The results of this study show that shade can reduce weed growth and seed production of *Echinochloa* species but it should not be considered as a stand-alone strategy to manage these weeds in rice. This highlights the need for the integration of other weed management strategies to achieve complete control of these species.

1. Introduction

Rice is an important crop in Asia, where more than 90% of rice is grown and consumed. In Asia, it is commonly grown by manual transplanting of seedlings after intensive cultivation in wet soil, the cultivation called puddling. In many areas, however, it is difficult to find labour at the critical stage of transplanting and, when available, labour is very expensive. In addition, a significant irrigated rice area in Asia may experience water scarcity in the future (Tuong and Bouman, 2003). Therefore, in recent years, there has been an inclination towards direct seeding of rice as farmers respond to increased costs or decreased availability of labour and water (Pandey and Velasco, 2005). Weeds, however, are the major biotic constraints to the production of a direct-seeded rice crop as there is no standing water and seedling size advantage to suppress weeds at the time of crop establishment (Chauhan, 2012; Chauhan and Johnson, 2010).

Echinochloa species are the dominant weed species in direct-seeded rice-based cropping systems. They are also an example of crop mimicry as they resemble the rice crop at the seedling stage. By the time weeds are easily distinguished by farmers, crop yield losses have already occurred (Holm et al., 1991). *Echinochloa colona* (L.) Link. was reported to reduce yield of direct-seeded rice by more than 75% when present at a density of 280 plants m^{-2} (Mercado and Talatala, 1977). *Echinochloa crus-galli* (P.) Beauv. reduced rice yield by more than 50% at a density of only 9 plants m^{-2} (Maun and Barrett, 1986). Similarly, *Echinochloa glabrescens* L. has been shown as a highly competitive weed species in the rice ecosystem (Holm et al., 1977).

In Asia, herbicide use is common to control weeds in direct-seeded rice. However, there is concern about the development of herbicide-resistant weeds and shifts in weed flora due to the continuous use of a single herbicide or herbicides with a similar mode of action, less availability of new and effective broad-spectrum herbicides, and concern related to environmental pollution including surface and groundwater contamination (Chauhan, 2012; Chauhan et al., 2012a,b). In the Philippines, for example,

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E. crus-galli was found to be resistant to butachlor + propanil herbicide (Juliano et al., 2010).

Cultural weed management strategies need to be developed to maintain or increase the sustainability of direct-seeded systems. The use of weed-competitive cultivars, narrow row spacing, and high seeding rates are some of the non-chemical strategies that could help in suppressing weeds by closing the canopy quickly and increasing shade on the weeds (Chauhan, 2012; Chauhan and Johnson, 2011a; Chauhan et al., 2011b) as competition for light is an important factor in crop–weed interference. However, the design of such non-chemical strategies requires an understanding of the differential responses of weeds to shade (Gibson and Fischer, 2001). In an earlier study, *Echinochloa phyllopogon* (Stapf) Koss, for example, responded to shade by increasing leaf biomass (Gibson et al., 2004). In Asia, relatively limited information is available on the response of *Echinochloa* species to shade. A study was therefore conducted to determine the effect of shade on the growth and seed production of *E. colona*, *E. crus-galli*, and *E. glabrescens*.

2. Materials and methods

Seeds of *E. colona*, *E. crus-galli*, and *E. glabrescens* were collected in April 2011 from rice fields near to Los Baños, Philippines. The experiments were conducted in 2011 and 2012 in a screenhouse (frame building with 2-mm steel mesh) at the International Rice Research Institute, Los Baños, Philippines. Three seeds of each weed species were sown in the centre in individual pots (25 cm diameter and 25 cm height) filled with 9 kg of soil. The soil was collected from an upland rice field. Seedlings were thinned to one plant per pot at 5 days after sowing (DAS). The soil used in the experiments had a pH of 6.6 and organic carbon of 2.7%. The soil had sand, silt, and clay contents of 24%, 52%, and 24%, respectively. Nitrogen was applied at 100 kg ha^{-1} in three equal splits at 14, 28, and 56 DAS.

Plants were grown continuously in 100% of full sunlight or under black mesh screens (50% or 25% of full sunlight), or started in full sunlight and transferred under the screens at 21 DAS (100–50 and 100–25). Photosynthetically active photon density (PPFD) in the 100% of full sunlight treatment was 1210 mol m^{-2} s^{-1} and the screens reduced PPFD to 50% and 25% of full sunlight. Pots with each weed species were arranged in a completely randomised design with four replications and the pots were rotated to new positions every 14 d to reduce any position effects. The pots were irrigated two times daily such that water was not limiting. The experiments were repeated in two runs (four replications per run).

E. colona, *E. crus-galli*, and *E. glabrescens* plants were harvested at 85, 95, and 100 DAS, respectively, when shaded plants of each weed species produced seeds. The time taken to panicle emergence was recorded for each weed species. The height of the weeds was measured from the base of the plant to the tip of its uppermost leaf. Plants were removed from the pots and roots were washed to remove soil. Plants were divided into the components of leaves, stems, and roots. All different components were oven-dried at 70 °C for 72 h and weighed to determine dry biomass. The seeds produced by each plant were counted.

The data were combined over repeat experiments and subjected to ANOVA as there was no interaction between the treatment and the run (GenStat 8.0, 2005). The data for each weed species were analysed separately. Data variance was visually inspected by plotting residuals to confirm homogeneity of variance before statistical analyses. Means were separated using standard error of difference at a significance level of 5%.

3. Results

3.1. Plant height

Changes in shade regime did not affect plant height of *E. colona* and *E. glabrescens*; however, the height of *E. crus-galli* was influenced ($P < 0.001$) by the shade (Tables 1–3). Under different shade regimes, the height of *E. colona* ranged from 85 to 95 cm and the height of *E. glabrescens* was 135–149 cm. *E. crus-galli* plants were 114 cm tall when grown in full sunlight (Table 3). Shade reduced the height of *E. crus-galli*; however, the height was similar when grown in 50% sunlight or transferred from full sunlight to 50% sunlight or to 25% sunlight. Compared with the plants grown in full sunlight, 75% of continuous shade reduced *E. crus-galli* height by 22%.

3.2. Biomass

Shade regime influenced leaf, total shoot (leaf + stem), and root biomass and leaf biomass ratio in all weed species (Tables 1–3). Compared with the *E. colona* plants grown in full sunlight, continuous shade of 50% and 75% reduced leaf biomass by 28% and 69%, respectively (Table 1). The corresponding values for total shoot biomass were 42% and 84%, respectively. When plants grown in full sunlight were transferred to 50% sunlight, there was a small reduction (29%) in total shoot biomass of *E. colona*, whereas plants grown in full sunlight and then transferred to 25% sunlight showed a 62% reduction in total shoot biomass compared with plants grown continuously in full sunlight. Shade regime also influenced leaf biomass ratio in *E. colona* (Table 1). Plants grown continuously in 25% sunlight resulted in 90% greater leaf biomass ratio than plants grown in full sunlight. Compared with the plants grown in full sunlight, *E. colona* root biomass decreased by 57% and 89% when grown in 50% and 25% sunlight, respectively. The 100–50 treatment showed a relatively small reduction in root biomass but plants grown in the 100–25 treatment showed a 76% reduction in root biomass compared with the *E. colona* plants grown in full sunlight.

E. crus-galli plants grown in 50% and 25% sunlight showed a 44% and 70% reduction, respectively, in leaf biomass compared with the

Table 1
Effect of shade on vegetative and reproductive traits of *Echinochloa colona* at 85 days after sowing.

Shade regime (% of full sunlight)	Height (cm $plant^{-1}$)	Leaf biomass (g $plant^{-1}$)	Total shoot biomass (g $plant^{-1}$)	Leaf biomass ratio (g g^{-1})	Root biomass (g $plant^{-1}$)	Seed production (no. $plant^{-1}$)
100	95.3	4.15	22.00	0.19	1.68	7716
50	94.3	2.99	12.75	0.23	0.73	2809
25	84.6	1.28	3.58	0.36	0.19	603
100–50	93.8	4.04	15.59	0.25	1.09	3217
100–25	92.9	2.06	8.34	0.25	0.40	2425
P-values	0.113	<0.001	<0.001	<0.001	<0.001	<0.001
Standard error of difference	NS[a]	0.587	1.516	0.024	0.261	512.8

[a] Abbreviations: NS, non-significant.