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Relative time of weed and crop emergence is crucial for managing weed seed production: A study under an aerobic rice system

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ABSTRACT

Managing weed seed production may help in reducing weed emergence and biomass in successive seasons in dry-seeded rice. Field experiments were conducted in 2012 and 2013 to ascertain the effect of delayed weed emergence, i.e., 0, 14, 28, 42, 56, and 70 days after sowing (DAS) on seed production ability of *Digitaria ciliaris* and *Echinochloa crus-galli* in two rice cultivars (PR115 with 125 days duration and PR114 with 145 days duration). Emergence of *E. crus-galli* was similar in both the cultivars, except at 42 DAS, where the emergence was higher in PR114 than PR115 during 2012. In PR114, *D. ciliaris* continued to emerge up to 56 DAS, although the increase was significant up to 28 DAS; the increased emergence of this weed was noticed up to 14 DAS in PR115. Weed biomass was also higher in PR114, although the rate of the decrease with respect to emergence time was similar in both the rice cultivars. *D. ciliaris*, when emerged with the crop, produced 11,820 seeds per plant in PR114, but seed production reduced by 25% in PR115. However, differences in seed production of *E. crus-galli* were noticed when this weed emerged between 14 and 42 DAS. An exponential model predicted that, for a 99% reduction in seed production of *D. ciliaris*, 42–45 days of crop advancement, while, for *E. crus-galli*, 21–33 days of crop advancement was required. Our study suggests that delaying the weed emergence in the crop and/or adopting better competitive rice cultivars can reduce the weed seed production substantially.

1. Introduction

Dry-seeded rice (DSR) was introduced in Asia as an alternative establishment method for making rice production more sustainable and profitable than conventional puddled transplanted rice (Chauhan, 2012; Ahmed et al., 2014). Weeds have been cited as one of the major production constraints in dry-seeded rice systems (Singh et al., 2006; Rao et al., 2007; Sanusan et al., 2010), as the yield losses may go up to 100% under uncontrolled conditions (Singh et al., 2014). Three main reasons for this extent of yield loss are: 1) crop and weeds emerge simultaneously, causing a high degree of competition from the start (Chauhan, 2012); 2) high populations of diverse weed flora (Sharma et al., 1977; Chin, 2001; Tomita et al., 2003; Singh et al., 2008; Kamoshita et al., 2010); and 3) weeds grow faster in DSR than in flooded transplanted rice (Karim et al., 2004; Begum et al., 2006; Chauhan and Johnson, 2009; Kamoshita et al., 2010). A specific weed may also have more competitive ability in DSR than in transplanted rice. For example, Hill et al. (1990) found that 3 and 66 plants m^{-2} of *Echinochloa* spp. were required to reduce crop yield by 20% at the same rice plant density in DSR and transplanted rice, respectively.

There have been genetic variations in rice cultivars with respect to competitive ability against weeds (Fischer et al., 2001; Haefele et al., 2004), which can be used as one of the weed management tools in DSR. Traditional rice cultivars which are tall and quick growing have been more competitive with weeds than short cultivars (Kawano et al.,1974; Mahajan and Chauhan, 2013). In a recent study, the critical period of crop-weed competition was found to be influenced by rice cultivars (because of differences in competitiveness) and weed infestation (Singh et al., 2014). Presently, weeds in DSR are controlled by sequential applications of pre- and post-emergence herbicides. This practice helps in avoiding crop-weed competition during the critical period of crop growth. Weeds that emerge later or escape the late herbicide applications may not

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reduce yield, but can enrich the weed seed bank through seed production (Gallandt, 2006), thereby increasing weed infestation every year.

The main source of weed infestation in any crop is the weed seed bank, which gets depleted by germination, physiological ageing, decay, and predation (Buhler et al., 1997; Forcella, 2003; Chauhan and Johnson, 2010). Changes in weed seed bank regulate many of the most important weed species communities; however, weed seed germination and emergence is complex under natural conditions and poorly understood, especially under DSR systems. The one way to manage weed seed banks is to reduce the input to the soil through reducing weed seed production, which would help in lesser weed population in succeeding years. Emergence of weed seedlings at different times after crop emergence may result in differences in growth and productivity, depending on the conditions during early development of the crop plants (Lindstrom and Kokko, 2000). For example, weeds which emerge late, are usually less competitive with lesser biomass and seed production than early-emerging ones (Hartzler et al., 2004; Chauhan and Johnson, 2010). Competitive rice cultivars that favour early crop establishment under aerobic rice systems and depress weed growth, can reduce weed infestation and their seed production; thus, may manage weeds in such systems efficiently.

In aerobic rice systems including DSR, *Echinochloa crus-galli* (L.) P. Beauv, *E. colona* (L.) Link, *Digitaria ciliaris* (Retz.) Koeler, and *Dactyloctenium aegyptium* (L.) Willd are the predominant and problematic grass weeds. *E. crus-galli*, a C_4 weed, is an example of crop mimicry because it closely resembles rice at the seedling stage (Holm et al., 1977). By the time farmers can recognize these weed seedlings, yield losses already might be unavoidable. In previous studies, *E. crus-galli* at a density of 9 plants m^{-2} reduced rice yield by more than 50% (Maun and Barrett, 1986) and heavy infestation removed up to 80% of the nitrogen from the soil (Holm et al., 1977). In the Philippines, *E. crus-galli* has evolved resistance to butachlor and propanil (Juliano et al., 2010). Another weed, *D. ciliaris*, also a C_4 weed, is serious weed of 11 countries, mostly in Asia (Holm et al., 1977) and in a broad range of crops, including rice, peanut, cotton, maize, sorghum, vegetables, pineapple, cassava, and tea. This weed is considered as aggressive, especially in competition for nitrogen (Okumura et al., 1986). *D. ciliaris* is an annual weed which spreads through the seed and perhaps it is most conspicuous and troublesome in cereal crops, cotton, legumes, and vegetables, as it establishes rapidly before the crop gives adequate shade.

Bispyribac-sodium is a common herbicide applied as post-emergence to control weeds in DSR; however, there are reports that *D. ciliaris* is less affected by this herbicide (Singh et al., 2015). For such weeds, it becomes necessary to limit them in the crop, for a “no seed threshold level” for the weed, rather than a “no yield decline threshold level” for crop, which may require prolonging the weed free period in DSR. Therefore, the present research aimed to determine the effect of delayed weed emergence under different rice cultivars on seed production of *D. ciliaris* and *E. crus-galli*. As in natural field conditions, weed emergence is delayed by keeping the weeds under check, thus, this study was done in context to simulate critical weed free period requirement for reducing the seed production of problematic weeds in DSR. The outcome of this study will help in further research work on planning integrated weed management strategies in DSR with reduced seed production by these and similar weeds.

2. Material and methods

2.1. Description of the experiment

A field experiment was conducted during the summer seasons of 2012 and 2013 at Punjab Agricultural University, Ludhiana, India. The soil at the site had pH 7.3, with available N, P, and K of 182, 13, and 145 kg ha^{-1}, respectively. The field was prepared by giving four ploughings, two with a disc harrow and two with a cultivator, followed by levelling and sowing of rice with a conventional rice seed-drill. Two rice cultivars (PR114, with 145 days duration; and PR115, with 125 days duration) were used in the study. For six weed emergence times [0, 14, 28, 42, 56, and 70 days after sowing (DAS) of rice], weeds were allowed to emerge after the specific periods of weed-free crop as per the treatments. Rice was sown on May 29, 2012 and June 6, 2013 using 25 kg seeds ha^{-1} in 20-cm rows. The field was supplied with 30 kg P_2O_5, 30 kg K_2O, and 13 kg Zn ha^{-1}, broadcasted before the levelling operation. Four equal splits of nitrogen at 150 kg ha^{-1} were applied at 14, 28, 49, and 70 DAS. Irrigation was applied immediately after sowing and the field was kept moist throughout the season by applying irrigation at weekly interval, which was discontinued two weeks before crop harvest.

2.2. Observations

Weed emergence and weed biomass of *D. ciliaris* and *E. crus-galli* were recorded using a quadrat of 40 cm × 40 cm at two representative places in each plot. Weed biomass was recorded after drying plant samples at 70 °C in an oven for 72 h. Weed seed production data was recorded from five tagged plants of *E. crus-galli* and *D. ciliaris* for each emergence time. Weeds emerged within five days after hand weeding were considered to germinate/emerge at that particular time. Other weed species were also allowed to grow in the plot after specific time intervals, but the data of only these two dominant weed species was collected. Total plot size of each of the treatment was 10 m^2.

2.3. Statistical analyses

The experiment was conducted in a split-plot design and each treatment was replicated thrice. The varieties were considered to be the main treatment and the weed emergence times as the sub-plot treatment. The analysis of variance was performed in SAS 9.3 (SAS Institute, 2003). Tukey's test was done as post hoc tests for comparison of means for different treatments. For time-series experiments, regression models best explained the relationship between the variables, thus, seed production per plant was plotted against the weed emergence time in the crop, using JMP pro. The form of the exponential decay curve was used to model the effect of the weed emergence time on seed production of weed species:

$$y = ae^{-bx}$$

where, y is the predicted variable (seeds $plant^{-1}$), a represents the maximum reproductive potential of the weed, when it emerges with the crop, b is the fitted constant, and x is the weed emergence time (days) after sowing of crop. A linear model was fitted for the relation of weed biomass with emergence time under two rice cultivars.

3. Results

3.1. Weed emergence

Although a range of weeds associated with DSR were observed in the experiment, weed emergence data of two dominant grass weeds i.e., *E. crus-galli* and *D. ciliaris*, was recorded and presented in Fig. 1. The effect of rice cultivars on the emergence pattern of *D. ciliaris* was visible during both years, with higher emergence at 42 and 56 DAS in PR114 as compared to PR115. At other timings,