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Integrated weed management in dry-seeded rice using stale seedbeds and post sowing herbicides

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ABSTRACT

Dry-seeded rice (DSR) grown with alternate wetting and drying water management (AWD) has recently been introduced in northwest India as an alternative to conventional puddled hand-transplanted rice which is labour, water and energy intensive. The aerobic seedbed of DSR can be extremely susceptible to invasion by diverse weed flora, and if weeds are not controlled effectively, yield losses can be very high. This study was undertaken to investigate the impacts of stale seedbed techniques on the soil weed seedbank and weed infestation in DSR, and to determine the influence of integration of the stale seedbed methods with post sowing herbicides on weed control and rice grain yield. The study, conducted in 2014 and 2015, comprised three seedbed treatments in main plots: without stale seedbed-conventional method, stale seedbed with glyphosate 1 kg ha^{-1}andstale seedbed with shallow (5 cm) tillage, and four post sowing herbicide treatments in sub plots: unsprayed check, pendimethalin 0.75 kg ha^{-1} (pre-emergence), bispyribac-sodium 0.025 kg ha^{-1}(post-emergence) and pendimethalin followed by bispyribac-sodium. The two stale seedbed treatments included one additional irrigation prior to sowing which increased weed seedling emergence prior to sowing by 1.9–2.2-fold; weeds in the stale seedbed treatments were then killed with the application of glyphosate or shallow tillage. At sowing, both stale seedbed treatments significantly decreased the viable seedbank of *Echinochloa colona* and *Dactyloctenium aegyptium* to 25–30% of that without a stale seedbed. After rice harvest, both stale seedbed treatments had a significantly lower seedbank than without a stale seedbed, by 13–33%; the stale seedbed with tillage had significantly lower seedbank at harvest than the stale seedbed with glyphosate in the second year. The sequential application of pendimethalin and bispyribac resulted in a significantly lower seedbank of both these grass weed species at harvest. At 20 DAS, both stale seedbed methods had 22–51% lower density of *Cyperus rotundus* and 42–67% less grass weeds than rice sown without a stale seedbed. There was more than a 2-fold increase in *C. rotundus* density from 2014 to 2015 without a stale seedbed and with the stale seedbed with glyphosate, and a 1.6-fold increase in the stale seedbed with tillage. In the absence of post sowing herbicides, the stale seedbed with tillage increased grain yield from 0.7–1.0 t ha^{-1} to 2.1–2.5 t ha^{-1}, while the stale seedbed with glyphosate only increased grain yield in 2015. The combination of the stale seedbed with tillage, pendimethalin and bispyribac had the highest rice grain yield (7.3 t ha^{-1}) and the highest economic returns ($ 1310 ha^{-1}); the returns in this treatment were $ 260 ha^{-1} higher than using the same herbicides used without a stale seedbed. The results indicate that integrated use of a stale seedbed with shallow tillage followed by the sequential application of post sowing herbicides has potential to control the complex weed flora in dry-seeded rice. The reasons for greater consistency in weed control with the stale seedbed with tillage than glyphosate are unclear and need further investigation in dry seeded rice, as do the long term effects of use of stale seedbeds.

1. Introduction

Rice, a staple food of India grown on 43.4 million ha (Anon., 2016), has been traditionally established in puddled soil by hand-transplanting, and this remains the most common practice in northwest India including Punjab and Haryana. Puddling (wet tillage) benefits rice by reducing water percolation losses, killing weeds, facilitating transplanting of rice seedlings, and creating anaerobic conditions which enhance nutrient availability (Sanchez, 1973). Repeated puddling, however, destroys the soil aggregates resulting in a massively structured topsoil and a shallow (typically within 15–25 cm soil depth) hardpan of low permeability (Kukal and Aggarwal, 2003a,b). The

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deterioration in soil physical properties can negatively affect the growth of upland crops grown in a rotation with rice (Aggarwal et al., 1995; Gajri et al., 1999; Gathala et al., 2011). In a recent survey in Punjab (Bhullar et al., 2018), farmer respondents (n = 211) reported 4.8% (0.3 t ha^{-1}) higher grain yield of wheat after non-puddled drill-sown dry-seeded rice (DSR) than after puddled hand-transplanted rice (PTR) ($p < 0.1$).

In PTR, wet tillage and continuous flooding for the first 15d after transplanting requires a large amount of irrigation water (*e.g.* 425–810 mm) (Sudhir-Yadav et al., 2011) and the puddling process requires large input of energy (2016–2390 MJ ha^{-1}) (Verma and Dewangan, 2006). Furthermore, hand-transplanting into the puddled soil requires large labour input (300–350 man-h ha^{-1}) (Bhatt et al., 2016). This was not a major impediment until about 10 years ago when labour scarcity and the associated rise in labour costs decreased rice profitability and became a major challenge for rice growers in Punjab and Haryana. Kamboj et al. (2013) identified labour scarcity as the biggest hurdle for sustainable agriculture in this region. The declining water table, increasing costs of labour, diesel and electricity and increased rainfall variability due to climate change have emerged as serious issues for the traditional hand-transplanted rice production system (Gill et al., 2013). Therefore, many researchers and policy makers have highlighted the need to develop alternative rice production systems for this region.

Recent research conducted in north and eastern India underpinned the successful development of a drill-sown rice production system (Gill et al., 2013). Mechanised seeding of rice into dry or moist non-puddled soil is the fastest growing reduced till technology in the Indian Punjab; the area under dry-seeded rice (DSR) increased to 115,000 ha in 2014 from < 1000 ha in 2010 (Anon., 2014). The major drivers of adoption are the lower cost of rice establishment, ability to plant on time, lower amount of irrigation water needed to establish DSR, and the rising interest in conservation agriculture (Mahajan et al., 2013; Kumar and Ladha, 2011; Bhullar et al., 2018). When all components of the DSR system are implemented effectively, grain yield can be similar to that of PTR (Gill et al., 2013; Sudhir-Yadav et al., 2011; Bhullar et al., 2018). Furthermore, the combination of dry-seeding and alternate wetting and drying water management (AWD) reduces irrigation input and increases irrigation water productivity in comparison with PTR. As labour costs for crop establishment are much lower in DSR, net profitability can be greater than in PTR provided that weeds are adequately controlled (Bhullar et al., 2016b, 2018).

In PTR, rice seedlings are transplanted in the main field and therefore have a size advantage over weeds germinating *in situ*. Furthermore, continuous ponding of water in PTR suppresses the establishment of many weed species which are not adapted to flooded conditions. In contrast, DSR germinates and establishes at the same time as the weed seeds. The aerobic seedbed of DSR is also conducive to the germination and establishment of a more diverse weed flora than in PTR (Gill et al., 2013). Therefore, DSR can be extremely susceptible to invasion by weeds, and if weeds are not controlled effectively, yield losses can be as high as 100% (Singh et al., 2014). Bhullar et al. (2016a) reported a strong negative correlation ($r^2 = 0.95$, $p < 0.001$) between weed biomass and DSR grain yield, which clearly highlights the poor competitive ability of DSR with weeds and the need to control weeds effectively during the whole growing season.

Since DSR fields are characterized by floristically diverse weed communities (Rao et al., 2007), a single herbicide cannot provide effective weed control. Mahajan et al. (2013) reported *Echinochloa colona* L., *Leptochloa chinensis* L., *Digitaria sanguinalis* L., *Dactyloctenium aegyptium* L., *Eleusine indica* L., *Cyperus rotundus* L. and *Cyperus iria* L. as major weeds of DSR in Punjab. A farmers' survey conducted in 2014 indicated that during the early years of DSR adoption, the weed flora in DSR was very similar to that in PTR, but after 2 years the weed flora had shifted markedly towards grasses (Bhullar et al., 2018).

The stale seedbed technology has been used to manage weed infestations in many crops, including rice (Singh and Singh, 2012; Riemens et al., 2007; Dogan et al., 2009). This method of weed control involves wetting the soil to stimulate weeds to establish well before sowing of the crop. Weeds that establish prior to sowing can be killed with the use of non-selective herbicides or with tillage. If a stale seedbed can be used effectively, weed establishment in the forthcoming crop can be dramatically decreased. The reduced population of weeds that emerges after sowing can be controlled more effectively with herbicides. Weed seedlings emerging earlier are likely to be more competitive with the crop than seedlings emerging later in the crop (Cousens et al., 1987), and crop yield losses can be sensitive to small differences in the time of weed and crop emergence (Chikoye et al., 1995). The delay of weed emergence relative to the crop should be a basic principle guiding the development of weed management strategies (Liebmann and Gallandt, 1997; Chauhan and Johnson, 2010). Weed emergence may be delayed relative to the crop by management practices such as herbicide application or mechanical cultivation that kill a cohort of weeds or reduce their growth (Liebmann and Gallandt, 1997).When *Echinochloa* germination was delayed relative to that of rice, weed survival and rice yield loss were greatly decreased (Gibson et al., 2002). The integration of pre-and post-emergence herbicide application decreased rice yield loss by 23–27% compared with pre-emergence herbicide only (Bhullar et al., 2016a). Hence, the use of a single method of weed control is unlikely to provide effective weed control in DSR. While the potential for using herbicides to improve weed control when weed emergence is delayed under a stale seedbed appears to be substantial, this practice has not been investigated in DSR in northwest India. The effects of stale seedbeds using herbicides or tillage on the soil weed seedbank and weed dynamics is a knowledge gap for DSR in the region. Further, how weed flora and the rice crop respond to the interaction effects of stale seedbed methods and post sowing herbicides has not been studied in DSR.

Therefore, the present study was conducted to test the following hypotheses: (1) the use of a stale seedbed and/or post sowing herbicide will deplete the soil weed seedbank, (2) the use of a stale seedbed with glyphosate or shallow tillage is equally effective in controlling weeds in DSR, and (3) the combination of a stale seedbed and post sowing herbicides will be more effective in controlling weeds and increasing yield in comparison with the use of post sowing herbicides alone

2. Materials and methods

2.1. Experimental site

A field study was conducted under irrigated conditions in the *kharif* (summer) seasons of 2014 and 2015 at the research farm of the Punjab Agricultural University, Ludhiana, India. The soil (0–15 cm) was a sandy loam, pH (8.0), EC (0.13 dS m^{-1}), low in organic carbon (0.39%), extractable N (243 kg ha^{-1}), extractable P (8.8 kg ha^{-1}) and extractable K (337 kg ha^{-1}). The average bulk density of the soil was 1.55 g cm^{-3}. The experimental field was under a pigeonpea-wheat system in 2011 and under a DSR-wheat system in 2012 and 2013.

The climate of the region is semi-arid sub-tropical, with a mean annual rainfall of 733 mm, most of which falls during the monsoon season (late June to September) (Fig. 1). The region has extremely hot and dry conditions with high evaporative demand at the optimum time for dry seeding (73 mm in second week of June). Once the rains start, temperature and pan evaporation decrease (Figs. 1 and 2), and humidity increases.

2.2. Experimental design

The experiment was conducted in a split-plot design with four replicates. Three seedbed treatments were compared in the main plots: (1) without a stale seedbed-conventional method (control), (2) stale seedbed with glyphosate @ 1 kg ha^{-1}, and (3) stale seedbed with