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Performance of sequential herbicides in dry-seeded rice in the Philippines

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ABSTRACT

Economical and sustainable weed management in dry-seeded rice (DSR) depends on appropriate combinations of potential pre-emergence and post-emergence herbicides. A field study was conducted during the dry seasons of 2013 and 2014 at the International Rice Research Institute, Philippines, to evaluate the weed control efficiency of some pre- and post-emergence herbicide combinations in a DSR system. The herbicide treatments were: (i) oxadiazon 750 g ai ha^{-1} was sprayed at 1 DAS fb 2,4-D 500 g ai ha^{-1} at 28 DAS; (ii) oxadiazon 750 g ai ha^{-1} was sprayed at 1 DAS fb bispyribac-sodium 30 g ai ha^{-1} at 14 DAS fb 2,4-D 500 g ai ha^{-1} at 28 DAS; (iii) oxadiazon 750 g ai ha^{-1} was sprayed at 1 DAS fb bispyribac-sodium 45 g ai ha^{-1} at 14 DAS fb 2,4-D 500 g ai ha^{-1} at 28 DAS; (iv) bispyribac-sodium 30 g ai ha^{-1} was sprayed at 14 DAS fb 2,4-D 500 g ai ha^{-1} at 28 DAS; and (v) bispyribac-sodium 45 g ai ha^{-1} was sprayed at 14 DAS fb 2,4-D 500 g ai ha^{-1} at 28 DAS. The lowest weed density (22–28 plants m^{-2}) and biomass (7–16 g m^{-2}) were found in the plots treated with oxadiazon fb bispyribac-sodium 45 g ha^{-1} fb 2,4-D. However, weed density and biomass in this treatment were similar to that in the treatment oxadiazon fb bispyribac-sodium 30 g ha^{-1} fb 2,4-D. The highest weed density (123–239 plants m^{-2}) and biomass (108–149 g m^{-2}) were recorded in the plots treated with bispyribac-sodium 30 g ha^{-1} fb 2,4-D. The plots treated with oxadiazon fb bispyribac-sodium 30 g ha^{-1} fb 2,4-D had 12–14% higher rice grain yield than the plots that did not receive bispyribac-sodium (i.e., oxadiazon fb 2,4-D), and 20–25% higher grain yield than the plots that did not receive oxadiazon (i.e., bispyribac-sodium 45 g ha^{-1} fb 2,4-D). The results suggest that pre-emergence herbicides must be used in DSR to achieve effective weed control and high grain yield.

1. Introduction

Worldwide, rice is grown on 165 million hectares, with an annual production of about 740 million tons of paddy (FAO, 2013). Total rice production area in Asia is 146 million ha with a production of 671 million tons of paddy which is around 90% of the world's rice (FAO, 2013). The common method of rice cultivation in Asia is transplanted rice. However, farmers are shifting towards dry seeding, which is considered more profitable and sustainable than flooded rice because it requires 35–57% less water and 67% less labour than the traditional method of transplanted rice (Mazid et al., 2003; Bhushan et al., 2007; Farooq et al., 2011; Chauhan et al., 2012; Singh et al., 2006; Suria et al., 2011).

Mechanised dry-seeded rice (DSR) is becoming an attractive option to farmers in many Asian countries because of the increasing scarcity of fresh water and the shifting of labour from agriculture to industries (Ahmed et al., 2014; Chauhan and Abugho, 2013). However, weeds are the major constraints in DSR production systems. Yields losses from weed competition are greater in DSR systems than in transplanted rice (Baloch et al., 2005; Mahajan et al., 2009; Chauhan et al., 2015). The dominant weed species in DSR are *Cyperus iria* L., *Cyperus rotundus* L., *Echinochloa colona* (L.) Link, *Echinochloa crus-galli* (L.) P. Beauv., *Eclipta prostrata* (L.) L., *Fimbristylis miliacea* (L.) Vahl, *Ischaemum rugosum* Salisb, *Leptochloa chinensis* (L.) Nees, *Ludwigia hyssopifolia* (G. Don) Exell, and *Rottboellia cochinchinensis* (Lour.) W.D. Clayton (Awan et al., 2014a,b; Awan et al., 2015; Chauhan et al., 2015). Potential yield losses in DSR due to weeds were reported to be 33–80% in Pakistan (Awan

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et al., 2006; Khaliq et al., 2012) and 71–96% in the Philippines (Phoung et al., 2005; Chauhan and Johnson, 2011a: Awan et al., 2015). Weed management is, therefore, the major challenge in the success and future large-scale adoption of DSR systems by farmers in irrigated and rainfed rice growing areas (Mahajan et al., 2009; Chauhan, 2012).

Previous studies have shown that if weeds are managed properly, the yield obtained from DSR systems could be similar to the yield from transplanted rice (Singh et al., 2005; Chauhan et al., 2015). A number of weed management options are available in rice production in different countries. However, the choice of weed management options is dependent on climatic conditions, soil type, technology available, farmers' economic situations, and yield targets (Buhler, 2002; Juraimi et al., 2013).

In Asian countries, manual weeding is the traditional and widely used weed control method. However, the shortage of labour and higher wage rates are making this method less common. In addition, because of high weed pressure in DSR systems, several manual weedings are needed to keep the field weed-free (Ahmed and Chauhan, 2014; Chauhan and Opeña, 2012; Suria et al., 2011). These factors make chemical methods the most effective and economical for weed control in DSR systems. Several herbicides are available in the Asian rice market, including pre-emergence (e.g., oxadiazon, oxadiargyl, pendimethalin, pyrazosulfuron, pretilachlor, butachlor, clomazone, etc.) and post-emergence (e.g., bispyribac-sodium, bentazon, fenoxaprop, ethoxysulfuron, penoxsulam, 2,4-D, etc.) (Chauhan et al., 2012; Pellerin and Webster, 2004; Suria et al., 2011). Several studies reported that, to prevent the simultaneous emergence of weeds with the rice crop, pre-emergence herbicides should be applied, which allow the crop to grow in a relatively weed-free environment in its early growth stages (Chauhan and Abugho, 2013; Khaliq et al., 2011; Rahman et al., 2012). However, the application of pre-emergence herbicides alone is not enough to provide season-long weed control in DSR systems (Khaliq et al., 2011). The sequential application of pre-emergence followed by post-emergence herbicides can produce 58–504% higher rice grain yield than the weedy plots (Chauhan et al., 2015). The overall efficacy of pre-emergence herbicides can vary from product to product and environmental conditions can also affect the efficacy (Chauhan and Abugho, 2013; Ahmed and Chauhan, 2014; Mahajan and Chauhan, 2013). Among the pre-emergence herbicides used in DSR systems, oxadiazon was superior as it effectively controlled annual grasses and broadleaf weeds (Awan et al., 2015; Chauhan and Johnson, 2011b; Chauhan and Opeña, 2013; Ishaya et al., 2007). Although pre-emergence herbicides are essential in DSR systems, they have some limitations such as a narrow application timing, requirement for a critical soil moisture level, and possible phytotoxicity to rice (Baloch et al., 2005; Pellerin and Webster, 2004). For these reasons, some studies gave more importance to the use of post-emergence herbicides and their effectiveness in controlling weeds (Chauhan and Abugho 2013; Khaliq et al., 2012).

Post-emergence herbicides are used in DSR systems for the selective control of weeds. The application of a single post-emergence herbicide in DSR systems often provides suboptimal weed control because of complex weed flora and long critical weed control periods (up to the first 5–7 weeks after crop establishment) (Awan et al., 2015; Khaliq et al., 2011). For example, bispyribac-sodium was effective against most of the grass and broadleaf weed species, bentazon and ethoxysulfuron were effective against broadleaf and sedge weed species, fenoxaprop was effective against only a few grass weed species, and 2,4-D against broadleaf weed species (Ahmed and Chauhan, 2014; Gopal et al., 2010; Jabran et al., 2012; Mahajan and Chauhan, 2013).

Some studies suggested that a single pre-emergence herbicide or a single post-emergence herbicide hardly provides satisfactory yield in DSR systems mainly because of the narrow spectrum of herbicide activity (Chauhan and Opeña, 2012; Suria et al., 2011). Therefore, the best weed control option in DSR systems was the applications of pre-emergence herbicide followed by (fb) a post-emergence herbicide or a mixture of post-emergence herbicides fb one hand weeding (Chauhan and Opeña, 2012; Mahajan and Timsina, 2011). However, agricultural labour is decreasing day by day, and it will be difficult in the future to find labour for hand weeding. Therefore, an effective weed management in DSR systems has to eliminate the need for hand weeding. In this study, we hypothesized that eliminating hand weeding can be possible by developing effective herbicide programs.

A previous study found that grass and broadleaf weeds were more problematic in DSR systems than in transplanted rice systems (Singh et al., 2006). Emergence of some broadleaf weeds, such as *Murdannia nudiflora* L. and *Phyllanthus niruri* L. was delayed in DSR systems (Ahmed and Chauhan, 2014; Chauhan and Opeña, 2012). The objective of this study was to evaluate the combinations of herbicide programs that will effectively control grass and broadleaf weeds so that the need for hand weeding can be eliminated. Different combinations of oxadiazon as the pre-emergence herbicide, fb bispyribac-sodium and 2,4-D as the post-emergence herbicides were selected for this study. Bispyribac-sodium, which controls a range of grass and broadleaf weeds, is the most widely used post-emergence herbicide in DSR systems in many countries, including India, Pakistan, Philippines, and Malaysia (Chauhan, 2012). However, some studies reported that this herbicide was poor in controlling *Leptochloa chinensis* (L.) Nees and *Digeria* spp. (Awan et al., 2015; Khaliq et al., 2011; Chauhan and Abugho, 2013). These two weed species were reported as the major weeds in DSR systems (Ahmed and Chauhan, 2014; Rao and Ratnam, 2010). Therefore, it was hypothesized that bispyribac-sodium at an increased rate may be more effective in controlling grass weeds.

2. Materials and methods

2.1. Experimental location and soil type

Field experiments were conducted during the dry seasons of 2013 and 2014 at the research farm of the International Rice Research Institute (IRRI), Los Baños, Laguna, Philippines. The soil was composed of 27% sand, 44% silt, 29% clay, and had a pH of 6.8, organic carbon of 1%, available P_2O_5 of 37 mg kg^{-1}, and available K of 1.13 meq 100^{-1}.

2.2. Crop management

The field was laser leveled before the start of the experiment and was dry cultivated with two passes of discing followed by two passes of rotavator. Seeds of the rice variety Rc222 at a seed rate of 50 kg ha^{-1} were sown with a seed-drill at a distance of 20 cm row spacing and at depths of 1–2 cm. The crop was planted on December 12, 2012 and December 19, 2013. Phosphorus and potassium, each at a rate of 40 kg ha^{-1}, were applied before the last cultivation. Nitrogen (N) in the form of urea was applied after crop emergence at a rate of 180 kg N ha^{-1} in four equal splits, that is, at 14 days after sowing (DAS), 30 DAS (during active tillering), 60 DAS (during panicle initiation), and 80 DAS (at flowering). The field was flood irrigated immediately after sowing and then as required by the crop. No water stress was allowed during the whole growing season.