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Management of *Rottboellia cochinchinensis* and other weeds through sequential application of herbicides in dry direct-seeded rice in the Philippines

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ABSTRACT

Dry direct-seeded rice (DSR) systems are becoming popular due to resource conservation and economic returns but high weed pressure limits rice productivity. *Rottboellia cochinchinensis* (Lour.) W. D. Clayton is an emerging noxious weed of DSR and requires a suitable herbicide package for effective control. A field study was conducted to evaluate the efficacy of two pre-emergence (oxadiazon and pendimethalin) and two post-emergence (cyhalofop and bentazon) herbicides used in various combinations and sequences during two consecutive seasons (dry season, 2013–14 and wet season, 2014) at the International Rice Research Institute (IRRI), Los Baños, Philippines. Experiments were laid out in a randomised complete block design with three replications. Weedy plots were kept as control. All the herbicide treatments significantly reduced density and biomass of *R. cochinchinensis* and other dominating weeds at the flowering stage of rice during both seasons. The best treatment was pendimethalin followed by bentazon + cyhalofop, which caused 88–91% reductions in *R. cochinchinensis* density over the weedy control (9.4–13.0 plants m^{-2}) during both seasons. It also reduced *R. cochinchinensis* biomass by 98–99% over the weedy control (331–344 g m^{-2}). Different herbicide sequential treatments also controlled density and biomass of *Cyperus rotundus* L., *Eclipta prostrata* L., *Echinochloa colona* (L.) Link, and *Murdannia nudiflora* (L.) Brenan over the weedy control. Highest reductions in total weed density (82–84%) and total weed biomass (95–97%) over the weedy control were observed from pendimethalin followed by bentazon + cyhalofop applications during both seasons. All the herbicide treatments increased rice grain yield significantly over the control. The maximum grain yield was obtained from pendimethalin followed by bentazon + cyhalofop applications, which was 4.7 and 3.0 t ha^{-1} during the dry season, 2013–14 and the wet season, 2014, respectively. The results suggest that the pre-emergence application of pendimethalin followed by the combination of post-emergence herbicides (bentazon and cyhalofop) may control *R. cochinchinensis* and other noxious weeds in DSR effectively with subsequent increment in rice grain yield.

1. Introduction

Dry direct-seeded rice (DSR) has gained remarkable popularity in Asia given a reduction in water resources due to increasing populations (Rao et al., 2007; Farooq et al., 2011; Kumar and Ladha, 2011; Chauhan, 2013a; Matloob et al., 2014). An increasing demand for rice production and labour shortage have necessitated the adoption of DSR (Mahajan and Chauhan, 2015). This system is practical, economically viable, and socially acceptable and, therefore a profitable system to produce rice (Chauhan, 2013a; Matloob et al., 2014; Ahmed and Chauhan, 2015). Higher weed infestations in DSR, compared against puddled-transplanted rice, is a challenge with this system trade-off. Suitable weed management strategies that are optimised according to different agro-ecological conditions have not been recommended (Chauhan et al., 2013; Awan et al.,

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2015a). Increased weed pressure in DSR causes substantial losses in rice grain yield through competition for nutrients, water, space, and light (Chauhan, 2013a). Yield losses due to weeds in DSR has been reported in the range of 20–80% in different countries (Awan et al., 2015a). A pragmatic weed management package is necessary for increased production under DSR (Mahajan and Chauhan, 2015). This pragmatic approach would involve a judicious use of weed control measures according to resources availability and climatic conditions.

Chemical weed control is the most efficient and economical option in DSR (Khaliq et al., 2012). Lower availability of labour, high fuel and maintenance costs for mechanical implements, reduced effectiveness, and non-uniform weed control are major problems associated with manual, cultural, mechanical, and ecological weed control options (Awan et al., 2015a). The judicious selection of herbicide type, dose, combination, time of application, and method may improve weed control (Chauhan et al., 2012). The use of herbicides across multiple modes of action in combinations may provide better weed control and may avoid the threat of herbicide resistance evolution in weeds (Yu and Powles, 2014). Both pre- and post-emergence herbicides are used to control weeds in DSR (Chauhan et al., 2013; Ahmed and Chauhan, 2015). Research on the sequential use of different combinations involving pre- and post-emergence herbicides is limited, especially in Asian conditions.

Due to a complex weed flora in DSR, a single pre- or post-emergence herbicide application may not provide effective weed control (Mahajan et al., 2013). Due to this reason, the sequential application of pre- and post-emergence is necessary. Pre-emergence herbicides, such as pendimethalin and oxadiazon, have provided varying degrees of control against different weeds in DSR (Chauhan et al., 2013). Pendimethalin is effective on grasses (Rao et al., 2007) whereas, oxadiazon is effective against several grasses, broadleaves, and sedges (Dickmann et al., 1997). Pre-emergence herbicides are usually applied within the first 3 days after sowing and their efficacy depends on soil moisture (Mahajan et al., 2013). Pre-emergence herbicides alone cannot control weeds and requires a post-emergence herbicide application for weed control at subsequent stages (Chauhan et al., 2013; Mahajan et al., 2013).

Post-emergence herbicides, like cyhalofop-butyl and bispyribac-sodium plus metamifop, provided 82–99% weed control in DSR (Chauhan et al., 2013). In this study, MCPA following pretilachlor plus pyribenzoxim offered excellent (up to 99%) weed control. Mahajan et al. (2013) reported that the sequential application of pre- and post-emergence herbicides provided excellent weed control when compared with their single applications. Chauhan and Abugho (2013) observed that oxadiazon followed by the combination of cyhalofop and penoxsulam followed by a hand weeding provided effective weed control in DSR and improved rice grain yield by 23–35% over the weedy control. The improved weed control through combined (tank-mixed) herbicide applications may be due to the synergistic effects (Matloob et al., 2014; Mahajan and Chauhan, 2015).

Rottboellia cochinchinensis is a noxious grass weed, infesting several crops in many countries (Bolfrey-Arku et al., 2011). It has been among the major problematic weeds of maize (*Zea mays* L.) and sugarcane (*Saccharum officinarum* L.) (Bridgemohan and Brathwaite, 1989; Millhollon, 1993). Incidence of *R. cochinchinensis* in DSR is becoming more frequent. Recently, Awan et al. (2015b) suggested *R. cochinchinensis* is a noxious and challenging weed of DSR and suggested that it may reduce yield significantly. This fast growing C_4 grass is a significant competitor of DSR given its ability to fix CO_2 with increased efficiency, efficient nutrients and water uptake and ability to grow under diverse conditions (Oyewole and Ibikunle, 2010; Bolfrey-Arku et al., 2011; Chauhan, 2013b). It has an allelopathic potential, which may also negatively interfere with rice and maize growth (Meksawat and Pornprom, 2010). Ampong-Nyarko and De Datta (1993) revealed that it may cause 30–100% reductions in rice grain yield. Manual control of this weed is tough because of fiberglass-like hairs on its stem, which may penetrate skin severely (Chauhan, 2013b). Suitable herbicides for its control are thus necessary. Bridgemohan and Brathwaite (1989) found pendimethalin (1.5 kg a.i. ha^{-1}) effective against *R. cochinchinensis* in maize. Pendimethalin and prodiamine controlled *R. cochinchinensis* up to 86% when applied pre-emergence in sugarcane (Millhollon, 1993). Research on its chemical potential in DSR is lacking.

Given the emerging threat of *R. cochinchinensis* and other weed infestations in DSR, the present study was conducted to optimize herbicide efficacy under field conditions. To the best of our knowledge, no such study has been conducted to evaluate the suppressive potential of sequential applications of different pre- and post-emergence herbicides with a focus on *R. cochinchinensis* in Philippines. It was hypothesized that potential pre-emergence herbicides may provide better control of *R. cochinchinensis* and other weeds when followed by combinations of post-emergence herbicides. The prime objective was to increase rice grain yield through effective control of *R. cochinchinensis* and other weeds by using suitable sequences of pre- and post-emergence herbicides in DSR.

2. Materials and methods

2.1. Experimental details

A field study was conducted at the International Rice Research Institute (IRRI) farm, Los Baños (14°13 N, 121°13 E), Philippines, to evaluate the efficacy of different herbicides alone and in sequential combinations on weed growth and rice grain yield during two seasons (the dry season, 2013–14 and the wet season, 2014). Two pre-emergence (oxadiazon and pendimethalin) and two post-emergence (cyhalofop and bentazon) herbicides were used in various combinations. The schedule, herbicide combinations, and rates are indicated in Table 1. The experiment was laid out in a randomized complete block design with three replications in both seasons. The size of each experimental plot was 21.6 m^2 (3.6 m × 6.0 m). Herbicides were applied using a knapsack sprayer fitted with flat-fan nozzles at a spray volume of 320 L ha^{-1}. Season-long weed-free and season-long weedy plots were included as controls. In the non-treated (weedy) plots, no weed control measures were undertaken whereas, in the weed-free plots, weeds were removed by pendimethalin application followed by three hand weedings. Mechanical weeding was done at 28 days after sowing (DAS) in respective treatments during both seasons.

2.2. Crop husbandry

The field was prepared by two diskings (ploughing), two rotovator operations, and one laser-aided levelling. The crop was sown on 19 December, 2013 and harvested on 16 April, 2014 during the dry season, 2013–14. The experiment was repeated during the wet season, 2014, when the crop was sown on 13 June, 2014 and harvested on 07 October, 2014. Rice was sown using a seed-drill at the seed rate of 50 kg ha^{-1}, maintaining a row spacing of 20 cm and a seeding depth of 2–3 cm. Nitrogen (N) was applied at 180 kg ha^{-1} in four splits: 25% at emergence completion, 25% at tillering, 25% at panicle initiation, and 25% at flowering. Phosphorus (P) and potassium (K) fertilizers were basally applied in the form of solophos (0-20-0) and muriate of potash (0-0-60), respectively, at the rate of 40 kg ha^{-1} and broadcast prior to the last cultivation. The soil