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Agronomic indices, growth, yield-contributing traits, and yield of dry-seeded rice under varying herbicides

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ABSTRACT

Dry-seeded rice (DSR) is an emerging resource-conserving technology in many Asian countries, but weeds remain the major threat to the production of DSR systems. A field study was conducted in 2012 and 2013 at the International Rice Research Institute (IRRI), Los Baños, Philippines, to evaluate the performance of sole and sequential applications of preemergence (oxadiazon and pendimethalin), early postemergence (butachlor + propanil and thiobencarb + 2,4-D), and late postemergence herbicides (bispyribac-sodium and fenoxaprop + ethoxysulfuron) with different modes of action in comparison to manual weeding in DSR. The sequential applications of all preemergence and postemergence herbicides reduced weed density and biomass by 80–100% compared to the nontreated plots. The sole application of postemergence herbicides reduced weed density by only 44–54% and weed biomass by 51–61%, whereas oxadiazon alone reduced weed density and biomass by 96–100%. All herbicide treatments and manual weeding significantly affected tiller number, biomass, crop growth rate, agronomic indices, yield-contributing parameters (panicle density and filled grains), and yield (biological and grain) of rice. The highest grain yield was obtained in the manually weeded plots (5.9–6.1 t ha^{-1}) and the plots treated with oxadiazon alone (5.4–5.6 t ha^{-1}) and oxadiazon followed by postemergence herbicides (5.2–5.8 t ha^{-1}). The lowest paddy yield (0.22 t ha^{-1}) was achieved in the nontreated plots followed by the plots treated with the sole application of bispyribac-sodium and fenoxaprop + ethoxysulfuron. The results suggest that oxadiazon is the best broad-spectrum and economically effective herbicide when applied alone or in combination with other effective postemergence herbicides with different modes of action, depending on the weed species present in the field.

1. Introduction

Lower water availability coupled with labor shortages has resulted in an increasing inability to cultivate rice using the manual transplanting method. In light of these problems, rice growers in many Asian countries are shifting from transplanting to dry seeding. This is because dry-seeded rice (DSR) systems require 35–57% less water and 67% less labor than the traditional method of transplanted rice (Mazid et al., 2003; Farooq et al., 2011). Direct seeding may be a strategic solution to these problems, but sowing rice seeds into dry soil exposes the crop to many abiotic and biotic stresses, including competition from weeds, and new host–pathogen interactions, all contributing to a low yield. Heavy weed infestation is the major disadvantage of DSR because of cultivation in aerobic soil conditions (Balasubramanian and Hill, 2002) as compared to puddled-transplanted rice (PTR) systems.

DSR systems can produce yield levels similar to those of PTR if weeds are controlled effectively (Mahajan et al., 2009). Therefore, proper weed management is considered to be one of the most important prerequisites for profitable rice cultivation using DSR systems. The high weed pressure in DSR reduces economic returns and, in extreme cases, a complete failure of the crop occurs (Jabran et al., 2012). Potential yield losses in DSR due to weeds were reported to be up to 80% in Pakistan (Khaliq et al., 2012), 20–80% in Sri Lanka (Amarsinghe et al., 1998), 71% in the Philippines (Phoung et al., 2005), and 40–100% in South Korea (Kim and Ha, 2005). Hence, judicious weed management is a crucial factor in the

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attainment and sustenance of food security in developing countries in Asia (Chauhan et al., 2012).

Various cultural, mechanical, manual, and chemical weed management strategies are practiced to control weeds in DSR systems. Manual weeding can also be used in areas where labor is easily available at low wages. However, some weeds such as *Ischaemum rugosum* Salisb., *Echinochloa colona* (L.) Link, *Echinochloa crus-galli* (L.) P. Beauv., and *Leptochloa chinensis* (L.) Nees resemble rice seedlings at their early growth stages, making hand weeding difficult to carry out under DSR conditions. Sometimes, laborers uproot the rice seedlings instead of weeds, thereby reducing the rice plant population to below-optimum level.

Among the weed control strategies, chemical weed control is the most efficient and economical (Suria et al., 2011; Khaliq et al., 2012). Most rice farmers who practice DSR adopt herbicides because their use reduces weed control time in DSR crops by 100 h per hectare as compared with hand weeding (Mazid et al., 2003). In Asian countries where direct seeding is replacing PTR as the method of rice establishment (e.g., Philippines, Korea, Malaysia, Vietnam, Sri Lanka, and India), there is an increased use of herbicides (Azmi et al., 2005; Rao et al., 2007).

Among herbicides, sulfonylurea and phenoxy compounds are the widely used chemicals for controlling sedges and broadleaved weeds in DSR (Azmi et al., 2005; Ashraf et al., 2006; Awan et al., 2006; Mahajan and Chauhan, 2013). Propanil, pendimethalin, fenoxaprop, molinate, thiobencarb, quinclorac, butachlor, and acetochlor have been extensively used for controlling grass weeds (Rao et al., 2007). Oxadiazon herbicide has been found to be effective in controlling annual grasses, annual sedges, and broadleaved weeds in rice (Dickmann et al., 1997). Likewise, the application of bispyribac-sodium as postemergence has been found to be very effective against grasses and broadleaved weeds (Khaliq et al., 2012).

Preemergence herbicides (oxadiazon, pendimethalin, etc.) are applied within 3 days after sowing (DAS) of rice, preferably immediately after planting and before the emergence of weeds and crops. These herbicides are usually cell division inhibitors and are no longer effective beyond the first-leaf stage. Early postemergence herbicides (e.g., butachlor, propanil, thiobencarb, etc.) are applied at the 2–4-leaf stages. Late postemergence herbicides (e.g., bispyribac-sodium, azimsulfuron, fenoxaprop, ethoxysulfuron, 2,4-D, etc.) are usually applied on leaves and the application time ranges from 14 to 28 DAS.

Since DSR is infested with complex and diverse weed species, no one single herbicide is competent to control all weed species. Therefore, a combination of herbicide (sequential applications or tank mixtures) or a broad-spectrum herbicide along with other cultural practices is essential for the effective control of all groups of weeds such as sedges, broadleaves, and grasses. There are, however, a few specific problems related to the use of preemergence herbicides such as the limited window for application (within 2–3 DAS) and the need for adequate soil moisture during application. If optimum conditions are not present, then the application of early postemergence herbicides may be a better option (Mahajan and Chauhan, 2013).

Currently, very limited information is available in the Philippines on different preemergence, early postemergence, and late postemergence herbicides with different modes of action when applied alone or in sequential applications in DSR systems. To provide wider options for growers for economic weed control in DSR, it is necessary to evaluate the efficacy and economics of different preemergence, early postemergence, and late postemergence herbicides applied alone or in sequential applications. In addition, there is a need to evaluate early and late postemergence options, in case growers missed the application of preemergence herbicides.

We hypothesized that (a) preemergence and early-postemergence herbicides are equally effective and comparable with manual weeding in controlling weeds, and (b) if preemergence and early-postemergence herbicides are applied in good conditions, we may not need the application of late-postemergence herbicides. To test this hypothesis, this study was designed to investigate the performance of different preemergence, early postemergence, and late postemergence herbicides with different modes of action when applied solely or in sequences and to find out the most appropriate weed control herbicide treatment that is comparable with manual weeding and will provide maximum profit to rice growers.

2. Materials and methods

2.1. Experimental site

Experiments were conducted at a farm of the International Rice Research Institute (IRRI), Los Baños (14°13 N, 121°13 E), Philippines, to evaluate the efficacy of nine herbicides and 11 combinations on weed growth and crop growth rate, yield, and yield components of rice under mechanized dry-seeded conditions. The field study was conducted in the wet season (WS) of 2012 and dry season (DS) of 2013. Soil physical and hydraulic properties at different depths of the experimental site are shown in Table 1. The experimental soil had a pH (H_2O) of 5.8; exchangeable K^+ 1.57, Mg^+ 9.54, Na^+ 1.0, Ca^+ 15.6, and total cation exchange capacity of 29.6 meq 100 g^{-1} of soil. It had 0.16% N (Kjeldahl), 46.0 mg kg^{-1} soil-available P_2O_5, 1.53 meq 100 g^{-1} soil-available K_2O, 1.4% organic carbon, and 2.3% organic matter.

2.2. Treatment and experimental design

NSIC RC82 (IR154), a short-duration (110 days) rice cultivar, was used in the experiment. Nine herbicides were evaluated in this study: two preemergence (oxadiazon and pendimethalin), three early postemergence (butachlor, propanil, and thiobencarb), and four late postemergence (bispyribac-sodium, fenoxaprop, ethoxysulfuron, and 2,4-D). Six of these herbicides are available as three commercial products, butachlor + propanil, thiobencarb + 2,4-D IBE, and fenoxaprop + ethoxysulfuron.

The experiment, consisting of 13 treatments, was laid out in a randomized complete block design with three replications. Eleven herbicide combinations and manual weeding (weed-free)

Table 1
Soil physical and hydraulic properties at different depths at the experimental site.

Soil depth (cm)	Texture (%)			Bulk Density (g cm^{-3})	Volumetric water content (%)		HC (cm d^{-1})
	Clay	Sand	Silt		FC	PWP	
0–10	40	20	40	1.4	45	13	9
10–20	37	29	34	1.1	50	26	10
20–30	37	26	37	1.1	39	20	14

FC = field capacity, PWP = permanent wilting point, HC = hydraulic conductivity.