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Herbicide options for effective weed management in dry direct-seeded rice under scented rice-wheat rotation of western Indo-Gangetic Plains

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ABSTRACT

Farmers' participatory field trials were conducted at Madhuban, and Taraori, the two participatory experimental sites/locations of the Cereal Systems Initiative for South Asia (CSISA), a collaborative project of IRRI and CIMMYT in Karnal district of Haryana, India, during *Kharif* (wet season) 2010 and 2011. This research aimed to evaluate preemergence (PRE) and postemergence (POST) herbicides for providing feasible and economically viable weed management options to farmers for predominant scented rice varieties. Treatments with pendimethalin PRE fb bispyribac-sodium + azimsulfuron POST had lower weed biomass at 45 days after sowing (DAS). At Madhuban, highest grain yield of scented basmati rice (3.43 t ha^{-1}) was recorded with the sequential application of pendimethalin PRE fb bispyribac-sodium + azimsulfuron POST. However, at Taraori, yields were similar with pendimethalin or oxadiargyl PRE fb bispyribac-sodium and/or azimsulfuron POST. Applying oxadiargyl by mixing with sand onto flooded field was less effective than spray applications in non-flooded field. The benefit-cost ratio of rice crop was higher with herbicide treatments at both sites as compared with the non-treated weed-free check except single PRE and POST applications and sequential application of oxadiargyl PRE fb oxadiargyl PRE. In a separate experiment conducted at Nagla and Taraori sites, scented rice cultivars' ('CSR 30′ and 'Pusa 1121′) tolerance to three rates of azimsulfuron (15, 25, and 35 g ai ha^{-1}) was evaluated over two years (2010 and 2011). CSR 30 (superfine, scented) was more sensitive to higher rates (35 g ai ha^{-1}) of azimsulfuron as compared to Pusa 1121 (fine, scented). Crop injuries were 8 and 28% in case of CSR 30; 5 and 15% in Pusa 1121 when applied with azimsulfuron 25 and 35 g ai ha^{-1}, respectively. Azimsulfuron applied at 35 g ai ha^{-1} reduced yield in both cultivars but in CSR 30 yield reduction was twofold (11.5%) as that of Pusa 1121 (5.2%).
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1. Introduction

Rice (*Oryza sativa*) is a major cereal crop and staple food for more than half of the world's population. About 90% of the world's rice is produced and consumed in Asia (FAO, 2014). Rice is predominantly grown by transplanting seedlings into puddled (conventional wet-tillage) soil and kept flooded for most part of the growing season. The puddled soil ensures good crop establishment, weed control with standing water, and reduces deep-percolation losses (Sharma et al., 2003). However, the conventional method of rice crop establishment requires a large amount of water, labour, and energy, which are gradually becoming scarce and more expensive. Thus, reducing the profitability and sustainability of puddled transplanted rice (PTR). Because of high rate of withdrawal of ground water in conventional tillage based puddled transplanted rice, water tables in some areas of North-West Indo-Gangetic Plains (IGP) has been declining by 0.1–1.0 m per year, resulting in increased cost of water pumping (Humphreys et al., 2010; Rodell et al., 2009; Hira, 2009). There is evidence that water scarcity prevails in IGP (Tuong et al., 2005) and labour costs have increased dramatically due to migration of rural labour to cities (Chauhan, 2012) as well as other non-agricultural sectors of rural economy.

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One of the factors behind migration of labour to cities is the implementation of the Mahatma Gandhi National Rural Employment Guarantee Act-2005 which guarantees 100 days of work to all unemployed people in rural India (Anonymous, 2014). Dry direct-seeded rice (DSR) has shown promise under several ecologies and production systems to overcome these challenges, and is considered as potential alternative to PTR.

In DSR systems, dry rice seeds are sown with or without tillage and irrigation is applied periodically to maintain soil at field capacity. DSR has water saving of 11–18% in irrigations (Tabbal et al., 2002) and reduces total labour requirement (11–66%) compared to PTR, depending on season, location, and type of DSR (Kumar et al., 2009; Rashid et al., 2009). Other benefits of DSR include faster and easier planting, improved soil health, higher tolerance to water deficit, less methane emission, and often higher profit in areas with an assured water supply (Datta, 1986; Kumar and Ladha, 2011; Pathak et al., 2009). In addition, DSR matures 7–10 days earlier than the PTR rice allowing timely planting of the succeeding wheat crop (Giri, 1998; Singh et al., 2006).

However, weed management is the major challenge in DSR (Rao et al., 2007; Singh et al., 2007). DSR systems are subject to much higher weed pressure than PTR system (Rao et al., 2007), in which weeds are suppressed by standing water and transplanted rice seedlings, that provide 'head start' over germinating weed seedlings (Moody, 1983). In DSR, weeds emerge simultaneously with crop seedlings and grow more quickly in moist soil than in PTR (Khaliq and Matloob, 2011), resulting in severe competition for resources to the crop. Therefore, weeds present the main biological constraint to the success of DSR (Chauhan, 2012), and failure to control weeds result in yield losses ranging from 50 to 90% (Chauhan and Johnson, 2011; Chauhan and Opeña, 2012).

The traditional methods of weed control in rice include hand-weeding by hoe or hand pulling, but this is becoming less common because of labour scarcity at critical time of weeding and increasing labour costs (Chauhan, 2012; Kumar and Ladha, 2011). Moreover, seedlings of some grassy weeds such as *Echinochloa crus-galli* (L.) look similar to rice seedlings (Rao and Moody, 1987, 1988), making hand weeding more tedious, difficult, and less effective. However, adoption of DSR technology usually leads to shift in weed flora composition towards difficult-to-control weeds (Singh et al., 2013). In this situation, use of herbicides is becoming more popular in DSR because they are more effective, easy to apply, provide selective control, saves on labour and costs less.

Farmers generally apply herbicides by mixing them in sand for easy operation and prefer to use either single application of PRE or POST herbicides which fails to control diverse weed flora observed in DSR (Chauhan, 2012; Chauhan and Opeña, 2012). However, it is important to use a broad-spectrum herbicide program including PRE and POST herbicides for season-long effective weed control and to avoid shifts toward problematic weed species (Chauhan, 2012; Singh et al., 2008) or evolution of herbicide-resistant weed biotypes. Traditional methods of weed control with manual labour increases the cost of cultivation. Moreover, labour shortage makes it difficult to manage weeds in a timely manner. Return over variable cost with manual weeding is one of the major concerns of farmers in process to adopt DSR in South Asia. Crop safety to new herbicides is another concern particularly in scented rice. Therefore, two studies were conducted to (1) evaluate herbicide options available for effective weed control in DSR, and (2) evaluate tolerance of potential scented rice cultivars (fine and superfine basmati) to azimsulfuron.

2. Materials and methods

2.1. Experiment 1. Herbicide options for weed management in DSR

2.1.1. Study location

Field studies were conducted at two farmers' participatory research platforms (Madhuban, and Taraori; Karnal, India) of the Cereal Systems Initiative for South Asia (CSISA), a collaborative project of IRRI and CIMMYT, during the *Kharif* (wet) season of 2010. The soil type at both Taraori and Madhuban village was sandy clay loam in texture. Both sites were low in organic matter (0.34–0.37%) with alkaline reaction (pH range of 8.0–8.1). Rice-wheat is the major cropping system of the region and popularly known for basmati/scented rice cultivation.

2.1.2. Experimental design and treatments

Eleven treatments including PRE and POST herbicide combinations (Table 1) were evaluated in a randomized complete block design (RCBD) with three replications at each location. Herbicides included in the study were butachlor (Butaveer®, Chambal Fertilizers & Chemicals Ltd.), oxadiargyl (Topstar®, Bayer Crop Science), pendimethalin (Stomp®, BASF India Ltd.), bispyribac-sodium (Nominee gold®, PI Industries), and azimsulfuron (Segment®, Dupont India Ltd.).

2.1.3. Experimental details

At each location, a burndown application of glyphosate (1.0 kg ai ha^{-1}) was made on the experimental area in mid-May 2010 and was followed by a light tillage with one pass of disc harrow and one pass of spring loaded tyne cultivator followed by planking before seeding. Fungicide-treated (carbendazim@ 0.5 g ai kg^{-1} rice seed) seeds of 'CSR 30' cultivar (superfine, scented; basmati cultivar) were planted in the second week of June, 2010, at both the locations. Seeds were drill-seeded at a rate of 20 kg ha^{-1} with a multi-crop seed-cum-fertilizer planter (Dasmesh®) at 2–3 cm soil depth. Light irrigation was provided immediately after seeding. All PRE herbicides except oxadiargyl (sand mix application), were sprayed on the third day of irrigation. Oxadiargyl was mixed with sand (8 kg ha^{-1}) and broadcast in standing water (2–3 cm) after irrigation on the day of seeding (general farmer practice). All POST herbicides, except sequential PRE application of oxadiargyl, were applied at three-to four-leaf stage of rice [20–22 days after seeding (DAS)]. The sequential oxadiargyl was applied at the two-to three-leaf stage of rice (15 DAS). The herbicides were applied using a battery operated back-pack knapsack sprayer fitted with a flat-fan nozzle and calibrated to deliver 500 L ha^{-1} for PRE spray and 375 L ha^{-1} for POST spray. The area of each plot was 24 m^2 (6×4 m). The crop was managed following the standard recommended practices for the region. Fertilizers, 25 kg N, 30 kg P_2O_5, and 25 kg $ZnSO_4$ ha^{-1}, were applied as a basal dose. N and $ZnSO_4$ were broadcasted uniformly and P_2O_5 was applied using a multi-crop seed-cum-fertilizer planter while planting. Remaining amount of N (50 kg ha^{-1}) was applied in two splits at 40 and 60 DAS. Two sequential foliar sprays of 1% $FeSO_4$ were applied at 40 and 47 DAS, though only the Madhuban location showed iron deficiency at this stage. After the first irrigation at the time of seeding, the second light irrigation was applied 5 DAS. Subsequent irrigations were provided at a weekly interval except tillering and panicle emergence stage. Irrigations were applied at 3–4 days interval at tillering stage and during panicle emergence.

Weed biomass and weed density was determined at 20 and 45 DAS from a randomly selected 1 m^2 quadrat in each plot. Weed samples were oven dried before weighing at 70 °C till the constant weight was achieved. Visual injury (20 and 45 DAS) evaluation for crop was based on chlorosis, and stunting whereas visual weed

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