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Weed control in dry direct-seeded rice using tank mixtures of herbicides in South Asia

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ABSTRACT

Dry direct-seeded rice (DSR) faces with complex weed problems particularly when farmers missed pre-emergence herbicide applications. Thus, an effective and strategic weed control in DSR is often required with available options of post-emergence herbicides. In such situations, tank mixtures of herbicides may provide broad spectrum weed control in DSR. Field experiments were conducted in the wet seasons of 2013 and 2014 to study weed control in response to tank mixtures of herbicides currently applied in DSR in South Asia. Results revealed that the tank mixtures of the currently available herbicides (azimsulfuron plus bispyribac or fenoxaprop, bispyribac plus fenoxaprop, and azimsulfuron plus bispyribac plus fenoxaprop; all applied as post-emergence) rarely resulted in antagonistic effects. Highest weed control efficiency (~98%) was recorded with the tank mixture of azimsulfuron plus bispyribac plus fenoxaprop during both the years. This treatment also produced highest grain yield (7.2 t ha^{-1} in 2013 and 7.9 t ha^{-1}in 2014), which was similar to the grain yield in the plots treated with the tank mix of azimsulfuron plus fenoxaprop, pendimethalin (applied as pre-emergence) followed by (fb) bispyribac, pendimethalin fb fenoxaprop, as well as pendimethalin fb azimsulfuron. Plots treated with the post-emergence application of single herbicide (i.e., azimsulfuron, bispyribac, or fenoxaprop) had lower grain yield (3.0–5.2 t ha^{-1} in 2013 to 3.5–6.1 t ha^{-1}in 2014) than all the sequential herbicide treatments and tank mixtures (azimsulfuron plus fenoxaprop and azimsulfuron plus bispyribac), owing to a broad spectrum weed control. The study suggested that if farmers missed the pre-emergence application of herbicides (e.g., pendimethalin) due to erratic rains or due to other reasons, good weed control and high yield can still be obtained with tank mix applications of azimsulfuron plus fenoxaprop or azimsulfuron plus bispyribac plus fenoxaprop in DSR.

1. Introduction

Rice (*Oryza sativa* L.), being a staple food of more than half of the population of South Asia, is an important crop of India. In most parts of South Asia, rice is grown by transplanting of 25–30 days old seedlings into the puddled fields. Rice consumes a lot of water (~150 cm); out of which about 20–25 cm of water is used only for puddling purpose in transplanted rice (Mahajan et al., 2011). Water is a valuable and scarce natural resource in many regions of the world. Rice farmers in many areas in Asia are likely to have water scarcity for cultivating flooded rice in the future (Tuong and Bouman, 2003). Population projections for India revealed that per capita availability of water is expected to decrease from 1600 to 1000 m^3 $capita^{-1}$ $year^{-1}$ by 2050 (Narula and Lall, 2010). It is also expected that agriculture's share of freshwater use will be reduced by 8–10% by 2025 because of increasing competition from the urban and industrial sectors (Gleick, 2000; Chauhan et al., 2012). Thus, water for cultivating rice will become increasingly difficult to obtain. This situation is worst in the north-west India, which is known as the food basket of India. A recent satellite survey revealed that the ground water table in north-west India is declining on an average at the rate of 0.33 m $year^{-1}$, and there is a net loss of 109 km^3 of groundwater in northern India, double the capacity of India's largest surface reservoir (Rodell et al., 2009). Cultivation of rice in this region is blamed to be the major culprit for water scarcity because rice in this region is mainly cultivated through tubewell irrigation (i.e., underground mining of water).

Puddled transplanted rice is cumbersome as well as energy and

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labour intensive. In the north-west India, due to ordinances (not to transplant paddy before 1st June) passed by some states, the window period (10–30th June) for rice planting has become narrow and there is a scarcity of labour because of huge demand, particularly at the time of transplanting. Delayed transplanting of rice in July not only causes reductions in rice yield (Mahajan et al., 2009) but also become an obstacle for the timely sowing of the subsequent wheat (*Triticum aestivum* L.) crop. This led to high wage rates at the time of rice transplanting because of limited labour availability. It has been observed that labour wages for rice transplanting during the past five years increased five times. Therefore, farmers in north-west India now have shown more interest in drydirect-seeded rice (DSR) as it helps in the timely planting of both rice and wheat. DSR increases profitability, requires less labour, water, and energy, and is more conducive to mechanisation.

Despite several advantages of DSR, it is subjected to much higher weed pressure than the conventional puddled transplanted rice systems (Chauhan, 2012), in which weeds are suppressed by standing water and transplanted rice seedlings, which have a "headstart" over germinating weed seedlings (Moody, 1983). Aerobic soil conditions and alternate wetting and drying in DSR are conducive to the germination and growth of weeds, causing grain yield losses of up to 80% (Mahajan et al., 2009). Thus, an efficient and timely weed control is crucial for the success of DSR. In order to control weeds, farmers use both pre- and post-emergence herbicides (Mahajan et al., 2013; Mahajan and Timsina, 2011).

Control of weeds through the application of pre-emergence herbicides (for instance, pendimethalin) is quite tricky. The time window for the application of pre-emergence herbicides is very narrow (usually 0–3 days of seeding) and it requires adequate moisture during the application time (Mahajan et al, 2013). Sometimes, farmers missed the optimum application time of pre-emergence herbicides due to onset of erratic rains at that time or due to other reasons. Weed flora in DSR is very complex and a single use of a pre- or post-emergence herbicide does not provide effective weed control in DSR (Mahajan et al., 2009). The use of herbicide combinations, whether the herbicides are applied simultaneously (tank-mixed) or sequentially, generally improves weed control compared with a single herbicide application (Mahajan and Timsina, 2011). Earlier, Mahajan and Chauhan (2013) revealed that sequential applications of pre- and post-emergence herbicides provided better weed control than the sole application of pre- or post-emergence herbicides in DSR.

Among the post-emergence herbicides, bispyribac-sodium (bispyribac hereafter), azimsulfuron, and fenoxaprop-p-ethyl (fenoxaprop, hereafter) are widely used by the farmers in DSR. However, each herbicide provides selective weed control, for instance, bispyribac is effective mainly against *Cyperus iria* L. and azimsulfuron is effective mainly against *Cyperus rotundus* L. (Mahajan and Chauhan, 2013). Earlier, fenoxaprop without safener was used in DSR for the control of *Leptochloa chinensis* (L.) Nees and *Dactyloctenium aegyptium* (L.) Willd., but it also caused toxicity to the rice crop (Gopal et al., 2010). A new formulation of fenoxaprop (with isoxadifen, a safener), a relatively new herbicide in India, inhibits the synthesis of a majority of fatty acids in the meristem tissues of weeds by acting on ACCase within 1–2 weeks of application without any toxicity to the rice crop, depending on the environmental conditions. Isoxadifen reduces the foliar uptake of fenoxaprop in rice and accelerates its transformation into non-phytotoxic metabolites. According to Blouin et al. (2010), fenoxaprop provides excellent control of major grasses such as *L. chinensis*, *D. aegyptium*, *Digitaria sanguinalis* (L.) Scop., and *Echinochloa colona* (L.) Link. that are predominant in DSR fields. Because fenoxaprop does not have an activity on broadleaf weeds or sedges, it is likely that other herbicide(s) with an activity on broadleaf or sedge weeds will be needed in a weed control program containing fenoxaprop in DSR. It would be beneficial in DSR to apply fenoxaprop plus another herbicide with broadleaf or sedge activity in a mixture, saving both time and cost. However, often broadleaf or sedge herbicides in a mixture with herbicides with grass activity, such as fenoxaprop, may antagonise or reduce the activity of the herbicide on grass weeds. Thus, the identification of compatibility of potential tank-mix herbicides with fenoxaprop is important in DSR. Such information will help DSR farmers to achieve broad spectrum of weed control.

Research surveys at the farmers' fields revealed that control of complex weed flora with a single post-emergence herbicide application is really a difficult task for the DSR farmers (Mahajan et al., 2013, 2009). Undoubtedly, the development and availability of effective post-emergence herbicides have encouraged farmers to try this new method of crop establishment (DSR) in Asia. As a result, the area under DSR in the north-western part of the Indo-Gangetic Plains is increasing (Mahajan et al., 2013). However, the emergence of new and complex weed flora in DSR restricts the area expansion and sustainability of this crop establishment method. Literature suggests that the repeated use of the same herbicides encourages the problem of herbicide resistance in weeds (Kim, 1996). For a broad spectrum of weed control in DSR, applications of herbicides with different modes of action (chemistry) is needed. Applications of different herbicides as a tank mixture may prove helpful in delaying the problem of herbicide resistance as well as a shift in weed flora, which is invariably associated with the use of a single herbicide (Wrubel and Gressel, 1994). Diggle et al. (2003) in a specific modelling study revealed that; where the assumption of independent resistance are met, resistance to the mixture can only arise via the spontaneous evolution of resistance mechanisms to both (or all) mixture components. The likelihood of this mechanism decreases with each additional herbicide in the mixture (Wrubel and Gressel, 1994).

Therefore, the combined application of different herbicides with different modes of action is required for broad spectrum weed control in DSR and for delaying the development of herbicide resistance. To the best of our knowledge, a very few studies in this line have been conducted in DSR grown in this region. Thus, it is essential to identify economic and effective herbicide combinations for managing complex weed flora in DSR. This study was conducted for generating detailed information for managing a mixed population of grass, sedge, and broadleaf weeds in DSR effectively and economically with tank mix applications of newly available post-emergence herbicides.

2. Materials and methods

2.1. Experimental site

A field study was conducted for two years (wet seasons of 2013 and 2014) at the research farm of Punjab Agricultural University, Ludhiana (30.93°N, 75.86°E), India. The climate is semiarid, with an average annual rainfall of 400–700 mm (75–80% of which is received from July to September), a minimum temperature of 0–4 °C in January, and a maximum temperature of 41–45 °C in June. The soil type at the experimental site was Fatehpur Series sandy loam (Entisol, Typic Ustipsament) with 0.3% organic matter with a pH of 7.2. Groundwater depth at the site was below 25 m, and the water was non-saline.

2.2. Experimental design and treatments

The treatments in each year were arranged in a randomised complete block design with three replications. Twelve weed control