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Effect of pre-emergence herbicides and timing of soil saturation on the control of six major rice weeds and their phytotoxic effects on rice seedlings

Tahir Hussain Awan [a, b, *, 1], Pompe C. Sta Cruz [b], Bhagirath Singh Chauhan [c]

[a] Weed Science, Crop and Environmental Sciences Division, International Rice Research Institute (IRRI), Los Baños, Philippines
[b] Crop Science Cluster, College of Agriculture, University of the Philippines, Los Baños, Philippines
[c] The Centre for Plant Science, Queensland Alliance for Agriculture and Food Innovation (QAAFI), The University of Queensland, Toowoomba 4350, Queensland, Australia

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ABSTRACT

The study evaluated the effects of pre-emergence herbicides and their rates [oxadiazon (0.5 and 1 kg ai ha^{-1}), pendimethalin (1 and 2 kg ai ha^{-1}), and pretilachlor with safener (0.6 kg ai ha^{-1})], and time of soil saturation establishment after herbicide application [1, 3, 5, and 7 days after spray (DAS)] in controlling the six major rice weeds, and their phytotoxic effects on rice seedling growth. All herbicides provided 100% control of *Echinochloa colona*, *Echinochloa crus-galli*, *Leptochloa chinensis*, *Cyperus iria*, and *Amaranthus spinosus*. *Murdannia nudiflora* was 100% controlled by oxadiazon and pretilachlor with safener, but poorly controlled (22–75%) by pendimethalin. Pendimethalin at 2 kg ai ha^{-1} was more effective than at 1 kg ai ha^{-1} in reducing the biomass of the stem, leaf, and root of *M. nudiflora* irrespective of timing of soil saturation. Rice plant height was reduced to a maximum (77–96%) by pendimethalin at 2.0 kg ai ha^{-1} followed by oxadiazon at 1.0 kg ai ha^{-1} (38–70%) compared to the non-treated control. In contrast, the tallest rice plants were observed in the non-treated control and those treated with pretilachlor with safener which had 80–100% rice plant survival. The lowest rice plant survival of 0, 6, 7, and 16% was found in the soil applied with pendimethalin at 2 kg ai ha^{-1} and saturated at 1, 3, 5, and 7 DAS, respectively, which was followed by oxadiazon at 1 kg ai ha^{-1}. All herbicides except pretilachlor with safener reduced SPAD values with early soil saturation, which improved with delay in soil saturation timing. Pendimethalin at 2 kg ai ha^{-1} reduced the SPAD values of rice plants by 100–164% relative to the non-treated control and produced the highest phytotoxicity symptoms. Pendimethalin also reduced rice shoot biomass more than oxadiazon, which was compounded by early soil saturation after herbicide application. Pretilachlor with safener was the only herbicide that exhibited low phytotoxic symptoms on rice plants and did not reduce leaf, stem, root, and shoot biomass of rice. Percent reduction in rice leaf, stem, root, and shoot biomass by the different herbicides was in the order of pendimethalin 2 > oxadiazon 1 > pendimethalin 1 > oxadiazon 0.5 > pretilachlor with safener 0.6 kg ai ha^{-1}. Each herbicide treatment reduced rice growth parameters as soil saturation was delayed in the order of 1 DAS > 3 DAS > 5 DAS > 7 DAS. The study suggests that soil water content and herbicide rates are important factors in influencing herbicide phytotoxicity in rice. The application of herbicides should be avoided when the soil is too wet, and irrigation should be delayed at least one week after herbicide application.

1. Introduction

Weed infestation has been considered the most important biological constraint to rice production and is most crucial to be addressed (Baloch et al., 2005; Singh et al., 2005; Mahajan et al., 2009). In dry-seeded rice (DSR) production systems in particular,

* Corresponding author. Weed Science, Crop and Environmental Sciences Division, International Rice Research Institute (IRRI), Los Baños, Philippines.
E-mail addresses: t.awanuplb@mail.com, tahirawanrri@gmail.com (T.H. Awan).
[1] Current: Weed Science, Agronomy Department, Rice Research Institute, Kala Shah Kaku, Punjab, Pakistan.

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high weed pressure lowers the economic return and, in extreme cases, causes complete crop failure (Jabran et al., 2012; Awan et al., 2015a). To avoid such circumstances in DSR systems, proper weed management is one of the most essential prerequisites to ensure higher yield and profit (Singh et al., 2006; Rahman et al., 2012; Mahajan and Chauhan, 2013). Previous studies have shown that if weeds are managed properly, the yield obtained under DSR systems could be similar to the transplanted rice (Singh et al., 2005; Chauhan et al., 2015).

Manual weeding has traditionally been a common practice of controlling weeds in Asia; however, due to the long critical infestation timing of some weeds (5–8 weeks), several manual weedings should be conducted in DSR to avoid the economic yield loss because of weed thus, making this practice non-economical (Anwar et al., 2013; Ahmed and Chauhan, 2014). Moreover, labour has become scarce in the agricultural sector, thus, prompting farmers to apply herbicides as a weed control practice (Suria et al., 2011; Chauhan et al., 2013). The use of herbicides has expanded to become the most effective weed management tool, as it is cheaper, more reliable, and more labor- and time-saving than other weed control measures (Khaliq et al., 2012; Rahman et al., 2012; Awan et al., 2015b).

In DSR, early weed control is important to avoid the early competition between the rice and weed seedlings as they emerge simultaneously in this system. Generally, several weed species have better growth potential relative to rice (Chauhan, 2012; Awan et al., 2014a,b). One of the best methods to give a head-start to the rice plant and increase its growth and productivity is to apply pre-emergence (PRE) herbicides (Awan et al., 2015a). PRE or soil-applied herbicides have the advantage over foliage-applied herbicides of killing weeds at their early growth stages. Several studies have highlighted the importance of PRE herbicides in DSR as weed control becomes more expensive and more difficult if PRE herbicide is not applied (Singh et al., 2006; Mahajan and Chauhan, 2013; Awan et al., 2015b).

Among the PRE herbicides now readily available, the three most commonly used and the most effective are oxadiazon, pendimethalin, and pretilachlor with safener (Chauhan et al., 2012; Juraimi et al., 2013; Awan et al., 2015a). The efficiency of PRE herbicides in controlling weeds is, however, dependent on several factors such as soil moisture, soil tilth, composition of the weed flora, herbicide doses, and environmental conditions (Baltazar and De Datta, 1992). Of these, soil moisture is the most important factor as it can influence both herbicide efficacy and crop phytotoxicity by altering herbicide absorption, translocation, or metabolism (Levene and Owen, 1995; Chauhan and Johnson, 2011). Soil-applied herbicides may either be adsorbed or absorbed or both by the seeds present in the soil; this may occur prior to or during seed germination. Adsorbed herbicides remain on the outer surface of the seed coat and may be absorbed later by the seedling as they emerge through the seed coat following germination. Absorbed herbicides, meanwhile, enter the seed by mass flow (dispersed in imbibed water) or diffusion. Seeds continue to absorb herbicides even after maximum water imbibition, hence, herbicides accumulate within the seeds at a greater concentration than in the surrounding soil solution (Anserson, 1983).

In DSR systems, PRE herbicides are recommended to be applied within 1–3 days (no standing water, just saturation) after first flush irrigation. Flushing, a common practice in DSR, is the application of irrigation water after seeding of rice in a dry field to facilitate germination and seedling emergence (Singh et al., 2006; Rao et al., 2007). PRE herbicides when applied in dry soil are adsorbed by soil colloids, thus, reducing their availability for absorption as the chemical barrier becomes thin and not deep enough to prevent weeds from germinating. Under this circumstance, it is possible for weeds to germinate under the thin chemical barrier. Therefore, soil should be adequately saturated before application of PRE herbicides. Moisture in the soil is crucial in increasing the efficacy of PRE herbicides as it facilitates the movement of the herbicide into the soil, thereby reducing herbicide losses from the soil surface and increasing the absorption of the herbicide by the emerging seedlings (Stickler et al., 1969). It may be detrimental to the crop when moisture is more than adequate.

Generally, farmers apply flush irrigation 3–7 days after PRE herbicide application which can potentially cause phytotoxicity to rice with the excess moisture. A recent study in Bangladesh showed that the application of pendimethalin as a PRE herbicide during the Aman (June–November) season decreased rice plant density by 14–22% as heavy rains occur immediately after spraying. During the boro (December–May) season, on the other hand, in which no precipitation occurs immediately after herbicide application, the crop plant density is not affected (Ahmed and Chauhan, 2014). Chauhan and Opeña (2013) also found that rice plant stand was lower when heavy rains occurred immediately after the application of oxadiazon compared with the non-treated plots. The results of these studies indicate the importance of soil moisture status after PRE herbicide application. However, there is limited information on how many days after PRE herbicide application excess moisture/flush irrigation can be safely applied. Generating information on this aspect will help in minimizing the adverse effects of PRE herbicides on the rice crop.

Aside from adequate soil moisture, an appropriate herbicide rate is very important in controlling weeds effectively and reducing crop phytotoxicity (Harding et al., 2012). Application rates of many soil-applied herbicides vary with soil properties in order to provide a constant quantity of biologically active herbicides that will interact with the weed. Previous studies on several crops under different environmental conditions found substantial variations in weed control efficiency using different herbicide rates (Zhang et al., 2000). One study reported that a high rate of oxadiargyl (150 g ha^{-1}) caused rice seedling mortality in anaerobic conditions but not in aerobic conditions (Gitsopoulos and Froud-Williams, 2004).

There are lack of informations on when irrigation can be safely started after the application of PRE herbicide. What will be the effects of varying rates of PRE herbicides applied at different times of soil saturation on weed control efficacy and phytotoxicity to crop? These effects have not yet been extensively studied as well. The present study aimed to address these and hypothesized that herbicide efficacy and phytotoxicity to crop can be influenced by (1) the timing of soil saturation establishment after PRE herbicide application and (2) varying rates of PRE herbicides. Specifically, this study was conducted to evaluate the effect of PRE herbicides, their rates, and different times of soil saturation after their application in controlling six major rice weeds viz., *Echinochloa colona* (L.) Link, *Echinochloa crus-galli* (L.) Beauv., *Leptochloa chinensis* (L.) Nees, *Cyperus iria* L., *Murdannia nudiflora* (L.) Brenan, and *Amaranthus spinosus* L., as well as the herbicides' phytotoxic effects on rice germination and seedling growth.

2. Materials and methods

2.1. Experimental site

The study was conducted at the laboratory and screenhouse facilities of the International Rice Research Institute (IRRI), Los Baños, Laguna, Philippines in June 2013 and was repeated in June 2014. The screenhouse was made up of a large iron steel frame with all the sides covered with steel mesh of 2-mm size to maintain an environmental condition similar to field conditions. A transparent