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RESPONSE OF SOIL APPLIED HERBICIDES AT DIFFERENT APPLICATION TIMINGS ON THE WEED CONTROL EFFICACY AND PHYTOTOXICITY TO RICE IN DRY-SEEDED CONDITION

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Abstract

Dry-seeded rice (DSR) is a labor and water saving emerging production system. The use of pre-emergence herbicides was found to be the most effective weeds control measure under the DSR system. Although several herbicides are now available in market, the selection of right herbicides with a time of application is crucial for effective control of weeds as well as to reduce the phyto toxicity of crops. A field study in a split-plot design with three replications was conducted to evaluate the effect of application time of soil applied herbicides (viz., 3 times - before crop sowing, after crop sowing but before the first irrigation, and after sowing and first irrigation) and four weeding regimes (*viz.,* weed free, partial-weedy, herbicide oxadiargyl 80 g ai ha^{-1}, and pendimethalin 1000 g ai ha^{-1}) on weed control efficacy, crop performance as well as phytotoxicity of applied herbicides under DSR system. Rice plant stand establishment was highly influenced by application time of herbicides and weeding regimes. Application of pendimethalin at 1000 g ai ha^{-1} significantly reduced the density of rice plant, more so as sowing was advanced. Compared with the non-treated (partial-weedy) treatment (190 to 195 rice plants m^{-2}), pendimethalin application before sowing, after sowing but before irrigation, and after sowing and irrigation reduced rice plant density by 48, 25 and 12%, respectively. While no significant difference was observed on plant density due to the application of oxadiargyl 80 g ai ha^{-1}, regardless of application time. In case of weed control efficacy for individual herbicides, pendimethalin effectively controlled weeds even spraying before sowing and irrigation; but comparatively less effective than spraying after irrigation. In controlling weeds, oxadiargyl was only effective when spraying after sowing and irrigation, but not before irrigation. Grain yield was significantly increased as the time of herbicide was delayed from before sowing (2.2-2.4 t ha^{-1}), after sowing but before irrigation (2.5-2.6 t ha^{-1}), and after sowing and irrigation (4.0-4.1 tha^{-1}). The results suggest that pre-emergence herbicides should be applied after sowing and irrigation for controlling weeds effectively and also reduce crop toxicity under the DSR system.

Introduction

Due to the decreasing availability of labor and water, farmers in many Asian countries are shifting their traditional puddled transplanted rice cultivation system to dry seeded rice (DSR) system (Ahmed *et al.,* 2014; Kumar and Ladha, 2011). DSR can be established directly in the field with no prior tillage (zero tillage) or following dry tillage. Dry seeding reduces labor requirement by eliminating seedling rearing in nursery beds, seedling uprooting, repeated tillage under the wet condition to puddle the soil and manual transplanting (Bari and Ahmed, 2018). Dry-seeding readily enables mechanization of rice establishment using a 'power tiller operated seeder' (PTOS) powered by a two-wheel tractor, or using 4-wheel tractor mounted seed drills, with low labor requirement (Riches *et al.,* 2008). Dry seeding also reduces irrigation water requirement through the exclusion of puddling. Although the DSR system has many benefits over puddled transplanted rice, however weeds are major constraints to its success when grown under non-ponded conditions (Ahmed and Chauhan, 2014; Singh *et al.,* 2006). In the DSR system, weeds and rice germinate simultaneously and most often weeds show more vigorous growth than rice; as a result, the rice seedlings are suppressed by weeds at an early growth stage (Chauhan and Johnson, 2011).

In Asian countries, manual weeding is very common but because of increasing labor scarcity and labor price, manual weeding alone is not an option. In addition, at the early vegetative growth stage, the morphological characters of rice seedlings and some weeds (particularly grasses) are similar, as a result, manual weeding is difficult at the initial stage of weeds (Ahmed *et al.,* 2015; Rahman *et al.,* 2012). The use of herbicides were found to be the most effective weeds control measures under DSR system (Ahmed and Chauhan, 2014; Ahmed *et al.,* 2015; Rahman *et al.,* 2012; Singh *et al.,* 2006). Herbicides can be applied as a pre-emergence (soil applied to control weeds before emergence) spray and/or a post emergence (control weed after emergence) spray. However, the pre-emergence herbicide is essential to manage weeds effectively in DSR (Khaliq *et al.,* 2011; Singh *et al.,* 2007). The weed control efficiency of pre-emergence herbicide and their phytotoxicity depend on several factors such as soil moisture, soil tilth, environmental conditions, weed species, and herbicide doses (Ahmed and Chauhan, 2015; Awan *et al.,* 2016). Dhareesank *et al.* (2006) and Levene and Owen (1995) noticed that soil moisture is important during the time of herbicide (s) application, which influences both weed control efficacy and crop phytotoxicity by influencing the herbicide absorption, translocation, or metabolism. Moisture may help to increase the efficacy of pre-emergence herbicide by moving the herbicide into the soil which reduces the loss of the herbicide from the soil surface, and absorption of herbicide by the emerging seedlings (Si *et al.,* 2009). Chauhan and Johnson (2011) reported that the pre-emergence herbicide oxadiazon at 1.0 kg ha^{-1} reduced rice shoot biomass by 22 to 36% under dry soil conditions, while by 43 to 56% in saturated conditions.

Herbicides are sprayed by manually using backpack knapsack sprayer. But manually spray is labor consuming and mentioned earlier that labor scarcity is increasing and assumed that in future labor will be more problem. For these reasons, it is important to explore some mechanization options for pre-emergence herbicide spray in the DSR system. Therefore, the aim of the study was to determine the effect of time of application of soil applied herbicide on rice plant establishment, weed growth and crop yield in dry-seeded rice.

Materials and Methods

The field experiment was conducted at the research farm of the Regional Agricultural Research Station (RARS) of Bangladesh Agricultural Research Institute (BARI), Jessore (23°11' N, 89°14' E and 16 m above mean sea level) in the *boro* (dry) season of 2012-13. The area belongs to the AEZ-11, of High Ganges River Floodplain. The climate of the area is subtropical, with an average annual rainfall of 1590 mm (90% of which is received during May to September), minimum temperature of 6–9 ^{0}C in January, and maximum temperature of 36–44^{0} C in April and May. The soil at 0–15-cm depth was a clay loam, with a bulk density of 1.56 Mg m^3, a pH of 7.8, organic carbon of 1%, sand of 32%, silt of 31%, and clay of 37%.

There experiment was arranged in a split-plot design with three replications. Main plots were assigned with time of herbicides application: (i) before sowing (BS) - herbicide was applied after land leveling and one day before sowing; (ii) after sowing but before irrigation (ASBI) (irrigation was applied shortly after sowing, on the same day); (iii) after sowing and irrigation (ASI) - herbicide was applied two days after irrigation; where sub-plots were arranged with weeding regimes (i) weed-free; (ii) partial weedy; (iii) oxadiargyl 80 g active ingredient (ai) ha^{-1} (iv) pendimethalin 1000 g ai ha^{-1}. Size of the sub-plot size was 13.5 m^2 (4.5 m x 3 m). All herbicides were applied using a knapsack-sprayer with a 1.2 m boom with three flat fan nozzles and spray volume was 450 L ha $^{-1}$. To prevent the movement of herbicide after irrigation, the plots were separated by bunds and irrigated one plot at a time. In the weed-free treatment, weeds were removed by manual-hand weeding (at 10, 25, 35, 50 and 65 DAS) in five times. In the partial-weedy treatment, one hand weeding was performed at 40 DAS and weeds were allowed to grow before and after the hand weeding. One weeding was applied as in the absence of any weed control; there may be no or very little yield of DSR (Chauhan and Johnson, 2011). In addition, it is rare that farmers leave their rice fields infested with weeds throughout the season in irrigated areas.

Dry seed of the rice var. BRRI dhan28 (life span 140 days) was sown on 1 February 2013 at 40 kg seed ha^{-1} and a row spacing of 20 cm. The crop was sown into dry tilled soil using a seed-drill with a fluted roller seed-metering device and a power tiller linked to a 2-wheel tractor. Fertilizer was applied at 160-20-60-12-2.2 kg ha^{-1} of N-P.K-S-Zn, respectively (BRRI, 2011), in the forms of urea, triple superphosphate (TSP), MoP, gypsum, and zinc sulphate, respectively. Except for urea, other fertilizers were broadcast during final land preparation (prior to sowing). The urea was applied in four equal splits: at 14 DAS, tillering initiation stage (35DAS), maximum tillering (55 DAS), and panicle initiation stage (65 DAS). A light irrigation was done just after sowing and the field was kept saturated up to 20 DAS and then irrigations were given based on soil water tension using a threshold value of 15 kPa at 15 cm soil depth (Sudhir-Yadav *et al.,* 2011). At each irrigation, water was added until the depth of water on the soil surface reached 5cm.

Data on the density of rice plant (no. m^{-2}) was determined at 14 DAS by counting the number of plants in 1 m of row length in five randomly selected locations in each plot. Weed density was determined at 20 DAS, and weed density and weed biomass were determined at 40 DAS and at anthesis; separated into grasses, broad leaf,and sedges. Total weeds biomass was also determined at the time of rice harvest. At each sampling time, all weeds were collected from two randomly located quadrats of 40 cm Чx 40 cm. The biomass was measured after oven drying the samples at 70 ^{0}C for 72 h. At harvest, panicle density (no. m^{-2}) was determined by counting the number of panicles in 1 m row lengths at 4 randomly selected spots in each plot. Rice grain yield was determined from an area of 6.6 m^2. Grain yield was converted to tha^{-1} at 14% moisture content. Regression analysis between weed biomass and rice grain yield was done using software Sigma Plot11.0 (Systat Software, Inc., Point Richmond, CA). All crop and weed data were analyzed ANOVA to evaluate differences between treatments and the means were separated using the least significant differences (LSD) at the 5% level of significance using statistical software Crop Stat 7.2.

Results and Discussion

Plant density of rice was ranged from 101 to 195 plant m^{-2} and varied significantly ($p \leq 0.01$) by both application time of herbicides and weeding regimes (Figure 1). Plant density ranged from 101 to 195 plant m^{-2}. The lower plant density was recorded in pendimethalin treated plots and considered with the application time; while plant density decreased significantly when application time was advanced. For example, compared with the non-treated plots (190 to 195 rice plants m^{-2}), plant density decreased by 48, 25 and 12% when pendimethalin application time was before sowing, after sowing but before irrigation, and after sowing and irrigation, respectively. In contrast, oxadiargyl did not affect plant density; irrespective of application time. Adequate and uniform plant density is pre-requisites to achieving optimum yield in dry-seeded rice (Ahmed *et al.,* 2014; Chauhan and Opeca, 2012). In the study, the application of pendimethalin to dry soil before irrigation had more phytotoxicity than applied after irrigation.

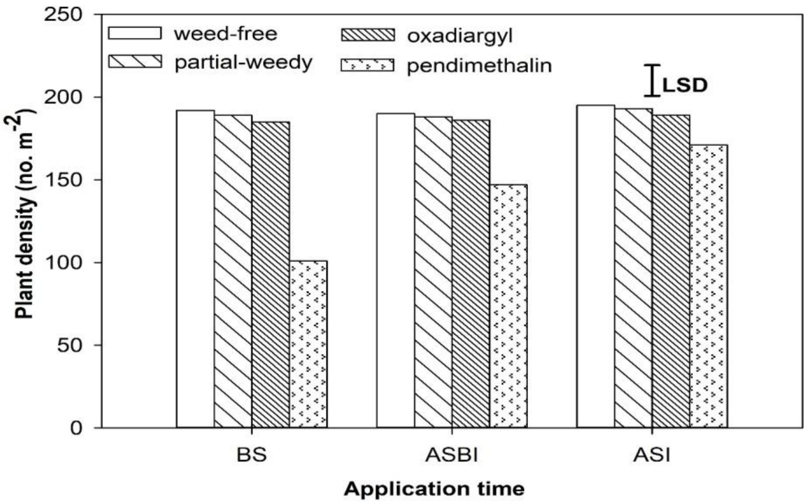

Fig. 1. Effect of application time of soil applied herbicides and weeding regimes on rice plant stand establishment density at 14 DAS in dry seeded *boro* rice. BS represents herbicide application before sowing; ASBI represents herbicide application after sowing but before irrigation; ASI represents herbicide application after sowing and irrigation. The vertical bar indicates interaction LSD at 5% level of significance.

These results are consistent with the findings of Jordan *et al.* (1998) who suggested that pendimethalin should be applied once the rice seed has imbibed water but prior to the emergence of both rice and weeds. The results also supported by the previous study in where they found, compared with the non-treated treatment, plant density decreased by 14 to 22% when rain was occurred immediate after application of pendimethalin; however, in the same study plant density was similar between pendimethalin treated and non-treated plots when there was no rain immediate after sowing (Ahmed and Chauhan, 2014). Similar results were reported by Chauhan and Opeca (2012), who found that rice plant stand was lower compared with the non-treated plots when heavy rains occurred immediately after the oxadiazon application. Thus, soil moisture at the time of application has an important influence on herbicide phytotoxicity in rice.The dominant weed species in the experiment were: *Celosia argentea* L.*, Cyperus rotundus* L., *Dactyloctenium aegyptium* (L.) Willd., *Digitaria ciliaris* (Retz.) Koel., *Echinochloa colona* (L.) Link., *Eleusine indica* (L.) Gaertn, *Leptochloa chinensis*

L., *Phyllanthus niruri* L., and *Spilanthes paniculata* Wall. Ex Dc. At 20 DAS, there was a significant interaction between herbicide timing and weeding regimes on the density of grass and broad leaf weeds, but not for sedges (Figure 2). Pendimethalin was found very effective against grasses regardless of application time and reducing the density of grass species to zero when applied before sowing or after sowing but before irrigation, and reducing it to 8% in the weedy plots when applied after sowing. Oxadiargyl was also found effective against grasses when applied at after sowing, but before and after irrigation (grass density was reduced 80 and 88%, respectively, in comparison with the weedy treatment). But the performance of oxadiargyl was very poor when applied before sowing and reduced the grass density by only 38%. The increase of broadleaf weed, oxadiargyl was not effective when applied before sowing; however, it effective and reduced density by 32 and 77% when applied after sowing but before irrigation, and after sowing and irrigation, compared with the non-treated plots (330-360 plant m^{-2}). Regarding the application time, pendimethalin controlled broadleaf more effectively than oxadiargyl when applied before sowing, and after sowing but before irrigation; however, applied after sowing and irrigation, oxadiargyl was more effective than the pendimethalin.

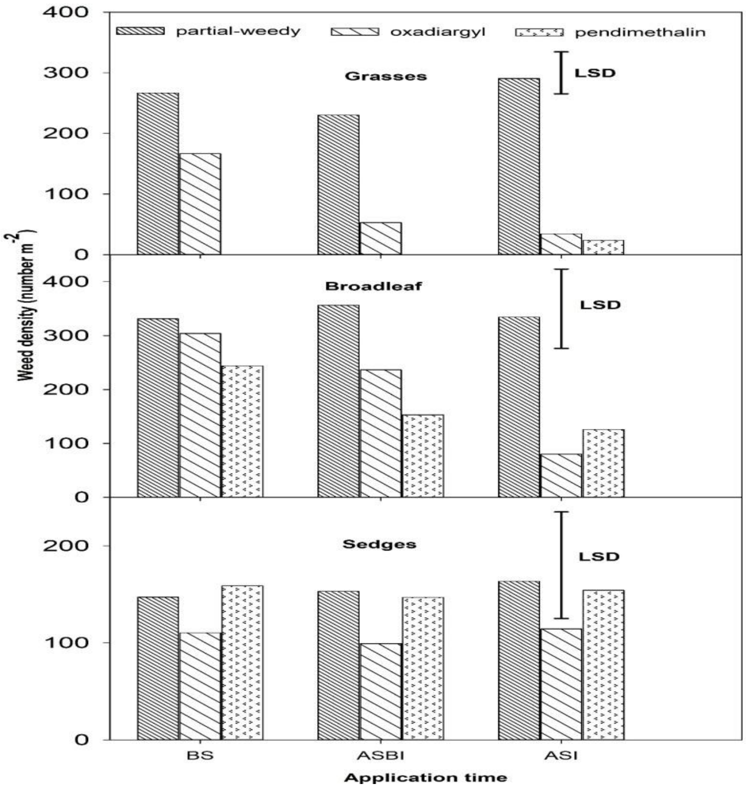

Fig. 2. Effect of application time of soil applied herbicides and weeding regimes on grasses, broadleaf and sedge weed density at 20 DAS in dry seeded *boro* rice. BS represents herbicide application before sowing; ASBI represents herbicide application after sowing but before irrigation; ASI represents herbicide application after sowing and irrigation. The vertical bar indicates interaction LSD at 5% level of significance.

Compared with the non-treated plots, pendimethalin reduced broadleaf density by 29, 56, and 63% when applied before sowing, after sowing but before irrigation, and after sowing and irrigation, respectively. The effectiveness was greatest for both herbicides when applied after sowing and irrigation. Neither herbicide was able to control sedge. Pendimethalin effectively controlled grass weeds, but the poor control of sedge weeds was consistent with previous studies (Ahmed and Chauhan, 2014; Khaliq *et al.,* 2011; Singh *et al.,* 2006). On the other hand, oxadiargyl is a very effective pre-emergence herbicide, used to control a range of grass, broadleaved, and sedge weeds in different crops (Dickmann *et al.,* 1997; Gitsopoulos and Froud-Williams, 2004). The interactions between application time and weeding regimes on total weed density and weed biomass recorded at 40 DAS (before hand weeding in partial-weedy plots) were found significant ($p \leq 0.01$) (Figure 3). Considered with the weeding regimes, partial-weedy plots had always higher weed density (498 to 557 plants m^{-2}) and biomass (44 to 48 g m^{-2}) than the herbicides treated plots. Between the herbicides, oxadiargyl performed better than the pendimethalin when applied after sowing and irrigation and compared with the non-treated plots oxadiargyl reduced weed density and biomass by 57 and 41%, respectively, in where pendimethalin did 46 and 37%. Although pendimethalin application before sowing, and after sowing but before irrigation had similarly reduced weed density and biomass, compared with the non-treated plots; however, oxdiargyl was not effective in at that application. Compared with the non-treated plots, oxdiargyl reduced weed density and biomass by 6 and 40%, and 11 and 20% when applied before sowing, and after sowing, but before irrigation, respectively. At anthesis, weed density and biomass had similar trends to the density and biomass at 40 DAS (Figure 4). At this stage, both of the herbicides had more effective weed control when applied after sowing and irrigation, and compared with the partial-weedy plots; where oxadiargyl reduced weed density and biomass by 43 and 44% and pendimethalin reduced 38 and 40%, respectively.

Fig. 3. Effect of application time of soil applied herbicides and weeding regimes on weed density and biomass at 40 DAS in dry seeded *boro* rice. BS represents herbicide application before sowing; ASBI represents herbicide application after sowing but before irrigation; ASI represents herbicide application after sowing and irrigation. The vertical bar indicates interaction LSD at 5% level of significance.

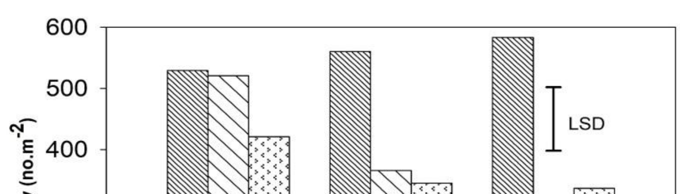

Fig. 4. Effect of application time of soil applied herbicides and weeding regimes on weed density and biomass at rice anthesis in dry seeded *boro* rice. BS represents herbicide application before sowing; ASBI represents herbicide application after sowing but before irrigation; ASI represents herbicide application after sowing and irrigation. The vertical bar indicates interaction LSD at 5% level of significance.

The results of weed density and biomass indicate that the application of pendimethalin before sowing had a significant effect on weed density and weed biomass, while oxadiargyl did not response. There was a consistent trend for better herbicide performance with the application after sowing and irrigation than before irrigation. The result was that weed density and biomass of oxadiargyl and pendimethalin applied after sowing and irrigation were similar. These results were consistent with the findings of Ahmed and Chauhan (2015), who reported that both of the herbicides (oxadiargyl and pendimethalin) were similarly performed in terms of controlling weeds when they applied after sowing and irrigation. Panicle density was strongly affected by both application time and weeding regimes (Figure 5). The highest numbers of panicles (320 to 335 m^{-2}) were recorded in the weed-free plots, while plots treated with herbicides had always lower numbers of panicle as compared with the weed-free plots. Regarding the application time, all herbicides significantly ($p \leq 0.01$) reduced panicle density when application time was advanced. The effect of oxidargyl and pendimethalin on panicle density was similar within each application time. The mean reduction in panicle density was 50, 40 and 12% with the application before sowing, after sowing but before irrigation, and after sowing and irrigation, respectively, compared with the weed-free plots. The lowest panicles (160 to171 m^{-2}) were recorded in the partial-weedy plots.

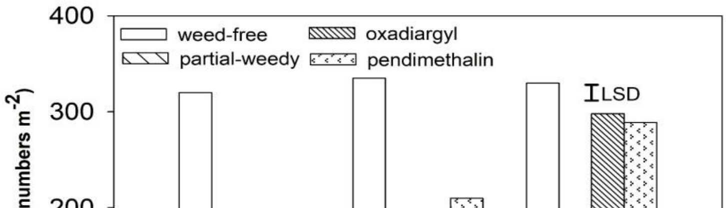

Fig. 5. Effect of application time of soil applied herbicides and weeding regimes on rice panicle density m^{-2} at physiological maturity in dry seeded *boro* rice. BS represents herbicide application before sowing; ASBI represents herbicide application after sowing but before irrigation; ASI represents herbicide application after sowing and irrigation. The vertical bar indicates interaction (LSD at 5% level of significance.

Trends in the effects of the treatments on grain yield were similar to the effects on panicle density, with higher yield as the time of herbicide application was delayed (Figure 6). Regarding the application time, grain yield of rice in oxidiargyl and pendimethalin treated plots were found significantly similar and the highest (oxadiargyl 4.10 t ha^{-1} and pendimethalin 3.97 t ha^{-1}) when applied at after sowing and after irrigation.

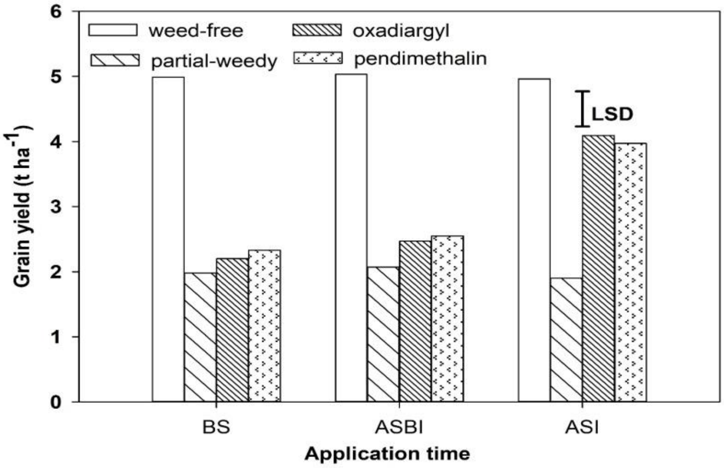

Fig. 6. Effect of application time of soil applied herbicides and weeding regimes on rice grain yield in dry seeded *boro* rice. BS represents herbicide application before sowing; ASBI represents herbicide application after sowing but before irrigation; ASI represents herbicide application after sowing and irrigation. The vertical bar indicates interaction LSD at 5% level of significance.

However, the maximum grain yield obtained in herbicides treatments had 1 t ha^{-1} lower yield than the yield of weed-free treatment (4.90 to 5.05 t ha^{-1}). Partial-weedy treatment had always lower yield (1.90 to 2.07 t ha^{-1}) and herbicide application after sowing and irrigation increased yield by 2.1 t ha^{-1}, compared with the partial-weedy treatment. However, rice grain yield was negatively correlated with weed biomass at harvest and 73% (R^2 = 0.73) of the variation was explained by this relationship (Figure 7). These results were similar to the previous studies in Bangladesh and the Philippines and both of which found that grain yield was negatively correlated with weed biomass (Ahmed and Chauhan, 2014; Chauhan and Opeca, 2012).

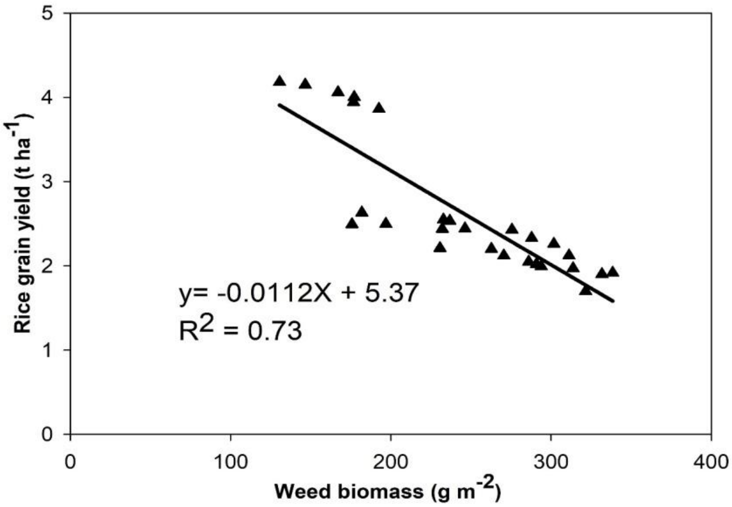

Fig. 7. Relationship between rice grain yield and weed biomass at harvest in dry seeded *boro* rice.

Conclusion

Most of the soil applied herbicides are required sufficient soil moisture which is usually provided by irrigation or rainfall. The moisture turns the herbicide into a solution that helps absorb or adsorb by weed seeds or uptake by emergence weeds. The current study suggested that to increase herbicide efficacy on weeds and reduce phytotoxicity to dry seeded rice, both oxadiargyl and pendimethalin should be applied after sowing and irrigation. In addition, the study also suggested, pre-plant application of pendimethalin might not be feasible, and this might reduce some mechanization options (e.g., spray with a tractor before irrigation/wet conditions). The results also indicated that there is a need to further strengthen weed management strategies as the yield gap was around 1 t ha^{-1} between the weed free treatment and treatment with pre-emergence herbicide followed by one hand weeding.

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