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Herbicide and winter flood treatments for controlling volunteer rice off-season

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ABSTRACT

Field experiments were conducted to study the efficacy of 12 herbicide treatments for volunteer rice control with, or without, winter-flooding in Stuttgart and Rohwer, Arkansas, USA over two years (2012–13 and 2013–14). Herbicides were applied either in the fall or at 35 d prior to planting rice in the spring. Commercially harvested Clearfield™ long-grain inbred rice 'CL152' was used as volunteer rice seed, broadcasted and lightly incorporated in October, 2012 and 2013. 'Jupiter' (medium-grain inbred, conventional rice) was planted in May as the rice crop. Winter-flood was initiated soon after the fall herbicide treatments were applied and terminated in February. Winter-flood reduced volunteer rice germination by 34% in 2013 and by 40% in 2014. Some fall herbicide treatments, without winter flood, generally caused more injury to the rice crop planted in the spring than the winter-flooded treatments. Fall application of pyroxasulfone (0.12 kg ha^{-1}), flumioxazin (0.14 kg ha^{-1}), and sulfentrazone (0.34 kg ha^{-1}) as well as pre-plant application of pyroxasulfone (0.12 kg ha^{-1}) and 2,4-D (2.24 kg ha^{-1}), resulted in lower volunteer rice infestation, averaged over flood treatments. Pre-plant application of 2,4-D (2.24 kg ha^{-1}), sulfentrazone in the fall (0.34 kg ha^{-1}) and pyroxasulfone pre-plant (0.12 kg ha^{-1}) injured the rice crop by 20%, 23%, and 47%, respectively. Fall application of pyroxasulfone (0.12 kg ha^{-1}) followed by a lower rate of 2,4-D (1.12 kg ha^{-1}) 35 d pre-plant caused minimal (6%) crop injury and did not reduce yield. This treatment provided better volunteer rice control (73%) than pyroxasulfone alone at 0.12 kg ha^{-1} applied in the fall (64%). To evaluate the overwintering potential of hybrid and non-hybrid volunteer seeds, these seed types were planted at three depths (0, 7.5, 15 cm) in flooded and non-flooded conditions in a buried-pot experiment at Stuttgart and Rohwer over 2 years. Winter-flood reduced rice germination by 50% in 2013–14 and 40% in 2014–15 (averaged over seed type and burial depth), after 160 d and 130 d of burial, respectively. After the winter, the viability of hybrid seed (germinable + dormant) was higher (13 and 53%) than that of non-hybrid seed (8 and 27%) in both years.
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1. Introduction

Volunteer rice (*Oryza sativa* L.) is a common problem in the rice paddy, which emerges from shattered seeds of the previous crop (Gealy, 2005; Warwick and Stewart, 2005; Sudianto et al., 2013). This is a global problem in rice production; the severity of which, differs depending mainly on the region, varieties planted, and crop rotation practices. In temperate regions volunteer rice germinates either before the winter (October–November) or in the spring (April–May) (Kumar et al., 2008; Sudianto et al., 2013). In the tropics, volunteer rice germinates continuously after harvest; thus, necessitating mechanical or chemical control measures to prevent interference with the succeeding crop or ratooned rice. Volunteer rice is a weed when it is morphologically and phenologically different from, and has lower grain yield and quality compared with, the planted cultivar. Volunteers from hybrid rice are

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segregating plants, which compete with the crop, but could also have low yields and low grain quality *per se*, thereby reducing the overall productivity of a given field and the overall quality of harvested grain. Therefore, it is expected that the impact of volunteer rice from conventional cultivars would be less than those from hybrid rice or weedy rice. In addition, volunteers from a herbicide-resistant (HR) rice crop (e.g. Clearfield rice™) could serve as agents for resistance gene flow from rice cultivars to the natural weedy rice populations through outcrossing (Gealy et al., 2003; Gealy, 2005; Gressel and Valverde, 2009; Shivrain et al., 2007; Sudianto et al., 2013). Typically, <1% cross pollination occurs between rice cultivars and weedy populations (Gealy et al., 2003; Cao et al., 2006; Shivrain et al., 2007), but the introgressed crop genes can persist in the weedy populations indefinitely (Ellstrand et al., 1999; Gealy et al., 2003). These outcrosses give rise to populations of weedy type plants which compete with rice, contaminate the harvested grain and increase economic losses.

The amount of crop seed left in the field depends primarily on the harvesting efficiency. Furthermore, rice cultivars differ in seed shattering trait, which also impacts the amount of grain lost before or during harvest. Early and high level of seed shattering is a common trait among the diverse types of weedy rices (Delouche et al., 2007). The proportion of shattered seed that will become volunteers in the following cropping season is impacted by many factors. Shattered rice seeds can be consumed by predators, killed by adverse climatic conditions, germinate, or remain dormant to enrich the seed bank (Vidotto et al., 2001). The environmental conditions experienced by seed after dispersal or shattering and storage (Cohn and Hughes, 1981; Ferrero, 2003) affects seed dormancy or germination (Fogliatto et al., 2011). The longevity of weedy rice seed increases with depth of burial (Goss and Brown, 1939, 1940; Delouche et al., 2007) and buried seeds in flooded soil last longer than those buried in non-flooded soil (Noldin et al., 2006). Cultivated rice seed has a short life span in soil (less than 2 years) (Goss and Brown, 1939, 1940) compared with weedy rice (Noldin et al., 2006; Fogliatto et al., 2011), but crop seeds stay viable long enough to be a problem in the succeeding season.

To minimize volunteer rice, Arkansas farmers have been practicing: (1) winter-flood or fallow without flood, (2) stale seedbed technique using glyphosate and tillage, (3) planting the same cultivars over several years to avoid contamination by dissimilar crop seeds, and (4) burning of residue after rice harvest (R.C Scott, Extension Weed Scientist, pers. communication). Except for winter flooding, these techniques are also practiced in tropical regions. Stale seedbed technique is commonly practiced in Asia (Renu et al., 2000; Singh et al., 2007; Kumar et al., 2008; Chauhan and Johnson, 2010). Crop rotation is also practiced (Chauhan, 2013), but not as much as needed.

In regions where herbicide-resistant Clearfield™ rice is planted (the Americas, Italy, Malaysia), volunteer rice from conventional cultivars can be controlled with acetolactate synthase (ALS) inhibitor herbicides in Clearfield™ rice. However, there is no chemical option during the rice growing season for controlling ALS-resistant volunteer rice from Clearfield™ rice. Soil-applied herbicides with good residual activity for grass control, applied prior to planting the rice crop, would be a potential alternative, Pre-plant application of such type of herbicides, coupled with tillage, could be done in temperate or tropical regions, but its efficacy on volunteer rice (or weedy rice) and its residual effect on the succeeding rice crop are not known. This research was conducted to (1) assess the effects of fall- and pre-plant-applied herbicides on volunteer rice population in the succeeding rice crop and how this is impacted by winter-flooding; (2) determine the effect of fall- and pre-plant-applied herbicides on the rice crop; and (3) compare the overwintering potential of hybrid and non-hybrid rice seeds.

2. Materials and methods

2.1. Experiment 1. Off-season control of volunteer rice

To evaluate the effect of off-season herbicide treatments and winter flooding on volunteer rice germination, experiments were conducted at the Rice Research and Extension Center (RREC), Stuttgart (34°27′54.8″N, 91°23′58.4″ W) and the Southeast Research and Extension Center (SEREC), Rohwer, (34°48′07.8″N, 91°17′11.6″ W), Arkansas, USA between 2012 and 2014. The soil at RREC was a DeWitt silt loam (fine smectitic, thermic, Typic Albaqualfs) with 1.2% organic matter and a pH of 5.8. The soil at SEREC was Sharkey clay with <1% organic matter and a pH of 7.2. The experimental units were in a split-plot arrangement within a randomized complete block design with three replications at each location. The main factor was winter-flood (two levels: winter-flood and no flood) and the sub-factor was herbicide treatment (12 levels; fall and spring pre-plant applications). In both years, the field was prepared in mid-October. Clearfield™ rice 'CL152' was broadcast-seeded over the whole field (175 kg ha^{-1}) and lightly incorporated (Fig. 1, Table 1). CL152 is a short-season, semi-dwarf, long-grain Clearfield™ rice cultivar. Levees were formed to separate the flooded and non-flooded treatments, prior to herbicide application. For fall and pre-plant application, the herbicides were applied using a CO_2 backpack sprayer fitted with 4 flat fan nozzles (Tee Jet 11002) spaced 48 cm apart, delivering 187 L ha^{-1} of spray volume at 276 kPa boom pressure. Each bay was covered with a fine mesh netting to prevent seed loss by predation. Winter-flood treatment was initiated two weeks after the fall herbicide application and was continued until February in the following year (Fig. 1). The pre-plant herbicide treatments were applied in March, 35 d prior to planting of rice (Table 1). Rice 'Jupiter' was drill-seeded at 100 kg ha^{-1} in April in zero-till conditions. Jupiter is a mid-season, medium-grain inbred rice cultivar. Permanent flood was established at the four-to five-leaf stage of rice. Phosphorus (P_2O_5) and potassium (K_2O) were applied pre-flood at 110 kg ha^{-1} and 30 kg ha^{-1}, respectively. Nitrogen (N) fertilizer was applied twice to provide 100 and 50 kg ha^{-1} N immediately before permanent flooding and at panicle initiation, respectively. For general weed control in rice, clomazone + quinclorac (0.67 kg ai ha^{-1} + 0.56 kg ai ha^{-1}), preemergence (PRE) and propanil + thiobencarb (4.5 kg ai ha^{-1} +3.4 kg ai ha^{-1}), post-emergence (POST) were applied to the whole field at both locations. Bensulfuron-methyl POST (0.12 kg ha^{-1}) was applied to control aquatic weeds (*Heteranthera limosa* and *Sagittaria montevidensis*) at RREC. Standard agronomic and pest management practices were implemented during the growing season and the crop was harvested with a combine in October in both years. The herbicide treatments which resulted in severe injury on rice in the first year were replaced with sequential application of promising herbicide treatments in the second year (Table 2). The total volunteer rice reduction was estimated with reference to the respective average of non-treated plots in winter-flood and no-flood treatments.

2.2. Data recorded

Volunteer rice germination was recorded from a 1-m^2 quadrat, located at a representative site in each plot at 18 WAS (weeks after sowing), 20 WAS, 28 WAS and 30 WAS (Fig. 1). Neither volunteer rice nor weed emergence occurred before 28 WAS due to unfavorable weather conditions (Fig. 2). Crop injury and rice stand count were recorded 3 weeks after rice 'Jupiter' planting (29 WAS). Volunteer rice plants were removed manually at 33 WAS (after permanent flood in rice crop). Yield and grain moisture (%) were recorded at harvest.

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