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Effects of winter flooding on weedy rice (*Oryza sativa* L.)

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ABSTRACT

Weedy rice (*Oryza sativa* L.), characterised by competitiveness, seed longevity, and dormancy is a troublesome weed to rice fields. Furthermore, its close botanical affinity to cultivated rice makes its control particularly difficult. However, winter flooding of rice fields can be an efficient technique to control weedy rice infestation by promoting weed seed decay, animal predation, or germination.

The effects of winter flooding on weedy rice plant and seed densities were assessed via two methods: field study of plant densities and laboratory study of germination behaviour.

In the field experiment, weedy rice plant density decreased following application of winter flooding. In fact, winter flooding resulted in more than a 95% reduction in the number of viable weedy rice seeds on the soil surface as compared to reductions in the range of 26–77% on fields left dry between rice crops.

The laboratory study showed that weedy rice germinability was affected by storage duration, moisture condition, and thermal regimen. In general, seed germinability increased with storage duration. Both awnless and awned populations displayed poor germinability under low temperature seed storage, but displayed differences when moisture content varied. At −20 °C, we observed, on average, 58% of seeds to be non-viable when stored for 248 days in water. At +5 °C the awnless population showed higher germination percentages following shorter storage durations, particularly water stored seeds. At +25 °C, the highest germination values were recorded in both populations after dry storage, whereas in water, total germination of the awnless population was inversely related to storage duration. Under typical field temperatures, in dry conditions germination behaviour was intermediate between that displayed at +5 °C and +25 °C, while storage in water resulted in a faster dormancy breaking in both populations.

The results suggest that winter flooding can be a useful practice to mitigate weedy rice infestations as it promotes germination already in the autumn, before rigorous winter conditions, and favours the decay of non-germinated seeds under low temperature conditions.

1. Introduction

Weedy rice (*Oryza sativa* L.) is a troublesome weed belonging to the same genus and species as cultivated rice. Weedy rice infestations have been reported to have spread to 40–75% of the total area of rice cultivation in Europe (Ferrero, 2003), 40% in Brazil (De Souza, 1989), 55% in Senegal (Diallo, 1999), 80% in Cuba (Garcia de la Osa and Rivero, 1999), and 60% in Costa Rica (Fletes, 1999). In Italy, where rice accounts for more than 50% of the total European area, weedy rice infestation became significant mainly after the shift in technique from rice transplanting to direct sowing. Over the last 25 years it has become more severe particularly after the cultivation of weak, semi-dwarf indica type rice varieties (Tarditi and Vercesi, 1993). Infestations are also caused by commercial rice seed, which can contain weed grains.

Weedy rice shows a wide variability of anatomical, biological, and physiological features (Craigmiles, 1978; Kwon et al., 1992; Tang and Morishima, 1997; Vaughan et al., 2001). Some plants are blackhulled with a purple apex and long awns, showing evidence of wild traits while others are strawhulled and awnless, mimicking cultivated varieties (Federici et al., 2001). The seed pericarp of most weedy biotypes is pigmented from varying levels of antocyanins, cathekins, and catheolic tannins (Baldi, 1971), causing international literature to identify weedy plants as "red rice."

Weedy rice infestations are responsible for significant yield losses, which are particularly severe in short varieties and late plantings (Diarra et al., 1985; Kwon et al., 1991; Shivrain et al., 2009). A density of 40 weedy rice plants m^{-2} has been shown to result in a crop yield reduction of 46% in Ariette and 58% in Thaibonnet varieties (Eleftherohorinos et al., 2002). The management of weedy rice infestations is much more difficult than that of other

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rice weeds because of the high biological similarity with cultivated rice and the extended germination over a long period of rice growth.

Chemical control with rice selective herbicides is usually ineffective against weedy forms, except in herbicide tolerant varieties obtained through genetic engineering or induced mutation. The most effective control strategies are those that combine preventive, cultural, mechanical, and chemical means, including crop rotations, rice field flooding to more than 5 cm depth of water, and herbicide applications (Diarra et al., 1985; Chin, 2001; Ferrero et al., 1999). The characteristics of this plant that make it so problematic are its competitive advantages over cultivated rice: fast growth, efficient use of nutrients, resistance to dry conditions, high tillering ability, early grain shattering, and high seed dormancy (Labrada, 2006; Noldin et al., 2006). Gu et al. (2003, 2005) have found that red rice dormancy is associated with the presence of awns and the red colour of the pericarp and testa, in addition to that imposed by the covering lemma and palea tissues.

The amount of dormant seeds that are present in the soil constitutes the soil seed bank; it can be transient or persistent relative to the dormancy and longevity characteristics of a species (Baldoni and Benvenuti, 2001). Low winter temperatures cause breaking of transient dormancy in summer annuals while high summer temperatures may induce an increase in dormancy level (Battla and Benech-Arnold, 2007). In fact, temperature is the main factor that controls seed dormancy levels, thus regulating the cycle between dormancy and germination (Baskin and Baskin, 1998). Previous studies on weedy rice biology have demonstrated that in temperate areas there are essentially two periods during the year when this species can germinate, autumn until the beginning of winter and then in early spring (Teekachunhatean, 1985).

The weedy rice seed bank is depleted as a consequence of seed germination, pathogen attacks, deep seed burial, and animal predation by arthropods and rodents, and water birds who play a role in fields flooded over winter (Delouche et al., 2007).

In some rice cultivation areas, particularly in the United States, winter flooding is a widespread practice consisting of flooding rice fields from the start of autumn following rice harvest until the spring before tillage operations. Winter flooding is mainly aimed at managing rice straw as an alternative strategy to the burning of rice residue (van Groenigen et al., 2003). Flooding improves rice straw decomposition primarily because water birds tear the residue into smaller pieces, which facilitates its soil contact. The consequent decrease in crop residue and the increase in decomposition makes nitrogen more available the following spring, which reduces the number of tillage passes needed to make a seed bed (Bird et al., 2002; van Diepen et al., 2004; van Groenigen et al., 2003).

Winter rice field flooding provides a substitute habitat for many wetland species, in particular, waterfowl that can feed and nest under these conditions (Czech and Parsons, 2002; Fasola and Ruiz, 1996). Previous studies conducted in the United States have shown that rice field shallow flooding, at a water depth of 15–20 cm, can enhance the density of many species of water birds (Elphick and Oring, 1998). This increased waterfowl foraging activity in winter flooded fields may reduce weed biomass at harvest time (van Groenigen et al., 2003; Bird et al., 2002). It has been established that, grass weeds are the predominant infestation at harvest time in rice fields, and that winter flooding can cause a consistent reduction in grass weed pressure in the subsequent growing season due to seed foraging waterfowl (van Groenigen et al., , 2003). However, few studies exist on weed behaviour after winter flooding in rice fields, and there is a dearth of knowledge on rice weed germination patterns.

This study undertook evaluation of the effects of rice field winter flooding on weedy rice seeds under both field and laboratory conditions. The field study aimed to determine the influence of winter flooding on weedy rice seeds on the soil's surface while the laboratory study undertook assessment of different storage conditions on weedy rice seed germination, including those occurring in winter flooded fields.

2. Materials and methods

2.1. Field study

The study was conducted during 2005–2008 on two sites (Montonero and Sali Vercellese), located in Vercelli province in northwest Italy. In each site, the study was undertaken on a farm which was chosen because either it was highly representative of a rice cultivation system and weedy rice infestation, or for its water availability during winter. At both farms, rice has been cultivated as a mono-crop for at least 50 years.

At Montonero the experimental design included three paddy fields of approximately 2.5 ha each that were managed differentially as described below:

(1) winter flooded where the field had never been winter flooded in the years preceding the experiment (OW1);
(2) winter flooded where the field had been winter flooded starting in the year preceding the experiment (OW2);
(3) maintained dry during the winter period (DRY).

The three differing management techniques were applied consistently to their respective fields during the over winter periods considered in the experimental three-year period.

The experimental design used at Sali Vercellese included OW1 and OW2 treatments only due to farm policy to winter flood all fields. Likewise, each field at this site was managed consistently over the three experimental years. As treatment management DRY was excluded from our work, this study can be regarded as a complementary trial to corroborate results obtained in equivalent treatments (OW1 and OW2) of the Montonero experiment.

At both sites before each rice harvest, the total number of weedy rice plants was counted in three zones (6×2 m^2) randomly chosen within each field.

Ten soil core samples were taken from each zone at two different times after harvest (autumn) and at the end of winter flooding (spring). Each core had a diameter of 12 cm and a depth of between 2 and 4 cm. Each soil core was maintained in its own tightly closed plastic bag and stored in a freezer at -20 °C to protect against disaggregation. After defrosting, their integrity had been well maintained. Weedy rice and rice seeds were initially removed from the surface of the cores and put in paper bags for drying. After drying, the hulls of all seeds were removed using forceps to distinguish weedy rice from rice on the basis of pericarp pigmentation. As most of the Italian weedy rice biotypes are pigmented, all white pericarp seeds were considered rice varieties and not counted in this assessment. The count of weedy rice seeds present on the soil surface was carried out separately for each core.

2.2. Laboratory study

This study started in October 2006 by hand collecting about 3 kg of weedy rice seeds of both awnless and awned populations infesting rice fields on the Montonero farm. The two populations were considered separately throughout the study. Seeds were dried in open trays for approximately one week at room temperature and then tested for their germinability after storage under several conditions for different periods resulting from combining the following factors: