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Reducing seed-densities in rice seedbeds improves the cultural control of apple snail damage

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ABSTRACT

Several cultural methods are known to reduce the densities of exotic apple snails (*Pomacea* spp.) and the damage they cause to rice in Asia. However, one aspect of seedling production – seedbed seed-density – has been largely overlooked and could compromise popular cultural control methods such as delayed transplanting. We conducted experiments to examine the effects of seedbed seed-density on hill survival in snail-infested paddy fields in the Philippines and to examine the interactions between seedbed seed-density and other cultural methods (delayed transplanting, 3 seedlings per hill and hand-picking). Seedbed seed-density determined seedling weight and stem thickness at the time of transplanting. Hill survival was highest where cultural methods (delayed transplanting and 3 seedlings per hill) were combined with low seed-density seedbeds (60–120 g m^{-2}). Furthermore, reduced seedbed seed-density was directly related to increased hill biomass in field plots 32 days after transplanting. Hand-picking of snails together with delayed transplanting and 3 seedlings per hill eliminated hill mortality due to snail herbivory. Farmers adopting cultural snail control methods, but without adhering to low seedbed seed-densities risk increased losses due to snails because of poor quality seedlings. We suggest that seedbed seed-densities should not exceed 120 g m^{-2} with better results at even lower densities.

1. Introduction

In recent decades, two species of apple snail [*Pomacea canaliculata* (Lamarck) and *Pomacea maculata* (D'Orbigny): Ampullariidae], originally from Brazil and Argentina, have been deliberately or accidentally introduced to East Asia, North America, Southern Europe (Spain), and Western South America (Ecuador and Chile) (Horgan et al., 2014). Furthermore, recent reports indicate that, since 2012, these species have now spread to Pakistan (Baloch et al., 2012) and to central Myanmar (pers. comm. Plant Protection Division, Myanmar Agriculture Ministry). Many of these regions are important rice-growing areas where apple snails can cause serious financial losses to farmers by consuming delicate rice seedlings during rice crop establishment. In invaded regions, the snails often reach high densities that can result in 100% loss of rice seedlings (Joshi and Sebastian, 2006).

Apple snail damage to rice is limited to the crop establishment phase (Halwart, 1994; Naylor, 1996). The snails may actually become beneficial to farmers at later crop stages by consuming nuisance weeds (Joshi et al., 2006). Therefore, the best management options may be those that control snail damage during crop establishment without eliminating the snails from the rice paddies. Following the establishment of apple snails in rice-growing regions of the Philippines in the 1980s, several national and international programs developed simple cultural methods to reduce snail damage (FAO, 1989; Rice IPM Network, 1991; Wada et al., 2002; Joshi and Sebastian, 2006). These were communicated to rice farmers through campaign and extension programs (Escalada, 1991; Rice IPM Network, 1991). Several cultural methods have been promoted. Most have aimed at reducing snail mobility – by reducing water levels in rice paddies and placing barriers (usually meshes) over the entry points of water to the fields – or increasing seedling resistance through delayed transplanting of rice seedlings (usually by 10–15 days) (Litsinger and Estano, 1993; Sanico et al., 2002; Teo, 2003). This latter method is based on knowledge that, as the dry matter content of plants increases, the plants become tougher and more difficult for snails to feed on (Qiu and Kwong, 2009; Wong et al., 2010); however, older rice plants may also become more fibrous because of higher lignin and cellulose content during development (Scheller and Ulvskov, 2010). Other cultural methods have included hand collecting (henceforth hand-picking) and disposal of snails or their eggs from the rice fields (Naylor,

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1996), baited snail traps (FAO, 1989), rotating rice with a dry crop (e.g., soybean) (Wada et al., 2004; Wada, 2004), or adjusting farm machinery and tillage methods to increase snail mortality (Wada, 2004). Furthermore, Sanico et al. (2002) indicated that hill mortality can be avoided by transplanting at more than one seedling per hill. Several studies have also examined possibilities for the biological control of apple snails in rice, and other crops using fish (Teo, 2006; Wong et al., 2009), ducks (Teo, 2001), or turtles (Yoshie and Yusa, 2008; Dong et al., 2012).

Despite the investment in public extension programs devoted to cultural controls, there have been rapid and massive increases in molluscicide sales and use in many snail-affected regions (i.e., Philippines: Adalla and Magsino, 2006; Japan: Wada, 2006; Ecuador: Felix et al., 2011). Furthermore, focus group discussions with farmers in the Philippines (Horgan, unpublished) and farmer surveys in Vietnam (Huan and Joshi, 2002; Türke et al., unpublished) and Ecuador (Felix et al., 2011) indicate that, although farmers are aware of cultural snail control methods, they mainly opt to use molluscicides. Molluscicides have several associated problems: they are a health hazard for humans (Anderson, 1993); they are unselective, killing or causing behavioral changes in beneficial snails and aquatic organisms (Calumpang et al., 1995; Zidan et al., 2000; Gyotoku et al., 2002); and they could lead to selection of behavioral changes in snails to avoid poisoning (Jelnes, 1987). Furthermore, molluscicides often fail to reduce damage to seedlings, and in some cases are less effective than cultural methods (Litsinger and Estano, 1993; Naylor, 1996; Joshi et al., 2001). Molluscicides are also sometimes toxic to the developing rice plants (Joshi et al., 2004).

Reasons for the apparent low adoption of cultural snail control methods may relate to poor or inadequate communication of methods to farmers in the face of the efficient marketing of chemical products (Huan and Joshi, 2002). Poor communication may also underlie apparent inconsistencies in the efficiency of cultural control methods. In some cases this could be due to contradictory advice relayed to farmers concerning optimal crop establishment methods. For example, delayed transplanting is aimed at increasing seedling resistance before exposure in the field; however, seedbed seed-densities recommended to farmers vary considerably and are often high (i.e., >200 g m^{-2}, Sarwa et al., 2011; Adhikari et al., 2013; Subedi, 2013), which, because of intraspecific competition between seedlings can result in weak seedlings with low dry matter content.

In the present study, we examine the effects of seedbed management and transplanting methods on rice crop establishment in snail-infested paddies in the Philippines. We predicted that low seedbed seed-densities would promote higher seedling survival after transplanting by producing larger, tougher seedlings compared to those from seedbeds with high seed densities. We further predicted that low seedbed seed-densities could improve the success of simple cultural control methods (hand-picking, delayed transplanting, increased seedling numbers per hill) in reducing snail damage. To our knowledge, this is the first study to highlight the role of seedbed seed-density as a means of directly reducing snail damage to rice or as a factor in determining the success of other cultural methods for apple snail control.

2. Materials and methods

2.1. Seedbed preparation and management

Seedlings of rice variety IR64 were produced on replicated seedbeds in a screen house at the International Rice Research Institute (IRRI) in Los Baños, The Philippines (14°11′N, 121°15′E). IR64 was selected as a consistently popular rice variety grown in many South-East Asian countries and from which several modern varieties have been derived (Khush and Virk, 2005). The variety is also susceptible to snail damage (Cagauan and Joshi, 2002) and therefore allowed a rigorous testing of management options. Dry seedbeds were prepared using paddy soil in concrete bays inside the screen house. The bays had a soil base, topped with paddy soil to a depth of about 30 cm and were permanently flooded (5–10 cm) with circulating water (1 day flow). To insure independence of treatments, the seedbeds were divided into portions to accommodate seedling production aimed at 24 treatment-combinations in the field and greenhouse experiments (see below). The treatments were randomly assigned to the portions. Treatments were combinations of seedling age [18 days after sowing (DAS) and 28 DAS] and sowing density (henceforth seedbed seed-density) (240, 120 and 60 g m^{-2}). Separate portions of the seedbeds were also set up to accommodate transplanting at 1 seedling hill^{-1} and 3 seedlings hill^{-1} and for hand-picked and non hand-picked (control) plots in the field experiment. The area required for each seedbed portion was calculated based on the number of seedlings required for each experimental block, the average weight of individual seeds, the noted germination success of the seed, and a 20 cm edge for each portion (only seedlings from the centers of the portions were used in experiments). Seeds were sown on two occasions with a period of 10 days between the first and second sowing to attain seedlings of 18 and 28 DAS at the same time. Seedbeds received no fertilizer or pesticide treatments and were rain-fed. When the seedlings were ready for transplanting, they were harvested by experienced rice farm-workers into bundles, placed in separate plastic trays (according to assigned treatments), and transported to the field site. A set of seedlings was also collected for choice experiments to be conducted in a greenhouse facility (see below). At the time of transplanting in the field, a sample of seedlings was collected to determine seedling dry weight and specific weight (3 seedlings each per replicated seedbed portion). The specific weight is an indicator of stem-toughness and was estimated as the dry weight per centimeter of stem (i.e., Steinbauer, 2001) using 2 cm stem portions cut at 3 cm from the seedling base. Seedlings and stem portions were dried in a forced draught oven at 50 °C for 3 days.

2.2. Experiment 1: effects of seedbed seed-density, hill density and seedling age on snail herbivory (greenhouse choice experiment)

Twenty-four plastic trays with dimensions 40 × 50 × 12 cm (W × L × D) were prepared by filling with paddy soil to a depth of ca. 3 cm, and adding tap-water to a total depth of 5 cm. The trays were set out as 5 blocks of 4 trays each with seedlings from a single and corresponding seedbed block. Seedlings were transplanted to the trays as 12 hills (randomly assigned to treatments) as in the field plots (seedling age [2] × hill density [2] × seedbed seed-density [3]). Apple snails were collected from rice paddies at IRRI for the experiment. Using published primers (Cooke et al., 2012), *P. canaliculata* has been verified as the predominant (possibly only) apple snail species occurring at IRRI (Stuart and Horgan, unpublished). Snails were added to the trays two days after transplanting the seedlings. The snails were added to the trays as follows: 1 tray per block with 3 large snails (ca. 35 mm shell height), 1 tray with 4 medium snails (ca 25 mm shell height), 1 tray with 6 small snails (ca 15 mm shell height), and 1 tray without snails (control). These numbers of snails were used to maintain a constant mass of body weight at about 11.5 g dry weight (excluding the shell) in the experimental arenas using the formula body weight = 0.038(shell height) × 2.78. This formula was derived by collecting 52 apple snails of a range of sizes (10–38 cm shell height) from the rice paddies. The snail shell height of each snail was measured and the