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Seedling broadcasting as a potential method to reduce apple snail damage to rice

Finbarr G. Horgan*, Jesús Yanes Figueroa, Maria Liberty P. Almazan

International Rice Research Institute, DAPO Box 7777, Metro Manila, Philippines

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ABSTRACT

Exotic apple snails (*Pomacea* spp.) are a major threat to the productivity and profitability of rice farming globally. Cultural methods that are applicable to traditional rice transplanting are often successful in reducing snail damage to rice. However, high labor and irrigation costs associated with transplanting highlight the need to develop modern rice crop establishment methods to replace traditional, labor-intensive methods. This study examined four broad categories of rice crop establishment for their vulnerability to apple snail damage. Seedlings from dapog nurseries and wet-direct seeding were highly vulnerable to damage and produced no grain in snail-infested ponds in the Philippines. Rice transplanted from dry bed nurseries at 21 days after sowing (DAS) had high mortality (85%) and consequently low yields. In contrast, seedling broadcasting (21 DAS) significantly reduced rice vulnerability (22% seedling mortality) to snail damage compared to all other methods and resulted in the highest grain yields per plot in our experiments. We attribute lower vulnerability to snail damage and successful stand development to reduced transplanting shock at the time of seedling broadcasting and to the generally good condition of seedlings even after 21 days in polyvinyl chloride trays. We suggest that seedling broadcasting be considered as a crop establishment method with potential to sustainably manage apple snails in irrigated rice.

1. Introduction

Crop establishment is a key phase in rice production where costs are often high and success can determine the productivity and profitability of the crop (De Datta, 1981). Crop establishment refers to the period between sowing of the rice seeds and the formation of a good root system in the rice paddy that allows the plants to optimize nutrient, water and light conditions. Because rice is produced globally under a range of different ecological and socio-economic landscapes, several crop establishment methods have been developed (Table 1). These are defined on the basis of whether the seed is directly sown to the field (direct seeded rice) or transplanted (transplanted rice). Direct seeded rice is further defined largely based on the conditions of the field to which the seed is sown – being either puddled (wet direct seeding) or dry (dry direct seeding). Furthermore, for transplanted rice, seedlings can be produced on wet bed nurseries, dry bed nurseries, mat nurseries, or dapog nurseries for manual transplanting or in specialized seed trays for machine transplanting (De Datta, 1981; Litsinger and Estano, 1993; Farooq et al., 2011). A mat nursery usually consists of rice sown to a thin layer of soil (3–4 cm) mixed with manure or urea and laid over a plastic sheet (Pasuquin et al., 2008). A dapog nursery is similar to a mat nursery but uses less or no soil, with seeds densely sown over a plastic sheet or banana leaf and covered with moistened straw to protect the delicate seedlings (Litsinger and Estano, 1993). Each method has a range of associated advantages and disadvantages: For example, direct seeding has considerably lower labor costs than transplanting, but often requires more herbicides to control associated weeds (Farooq et al., 2011). Transplanting gives better control of weeds, but can be expensive, and depending on the seedling production system may be prone to transplanting shock – a physiological condition that slows rice development and can sometimes reduce yields (Dingkuhn et al., 1991; Teo, 2003; Subedi, 2013).

In many rice growing regions, the invasion by herbivorous aquatic snails has further complicated issues around crop establishment. Apple snails, *Pomacea canaliculata* (Lamarck) and *Pomacea maculata* Perry (previously *Pomacea insularum* d'Orbigny), originally from South America, east of the Andes, have, since the 1980s, spread throughout much of the world's lowland tropical and subtropical regions where rice is produced (Horgan et al., 2014a).

* Corresponding author. Tel.: +63 2 5805600 x 2708.
E-mail address: f.horgan@irri.org (F.G. Horgan).

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Table 1
Rice crop establishment methods.[a]

Method	Nutrient addition	Sowing densities[b]	Seeding or transplanting methods	Age (in days) of seedlings at seeding or transplanting	Field conditions at seeding or transplanting
Transplanting					
Wet-bed nursery [1,2]	Optional [1]	$\leq$120 g m^{-2} [3][c]	By hand [1]	20–50 [2,4][d]	Puddled – 0–5 cm water [1]
Dry-bed nursery [1]	Optional [1,5]	$\leq$120 g m^{-2} [3][c]	By hand [1]	20–50 [2,4][d]	Puddled – 0–5 cm water [1]
Dapog [1,2,6]	No [2]	$\leq$3000 g m^{-2} [1]	By hand [2,6]	9–14 [1,2][e]	Puddled – 0–5 cm water [2,6]
Mat nursery [2]	Yes [2,7]	$\leq$50–120 g m^{-2} [2]	By hand [2,7]	14 [2]	Puddled – 0–5 cm water [2]
Seedling trays [2,7]	No [2]	1 seed per tray compartment [2]	By machine [7]	7–14 [2,7]	Puddled – 0 cm standing water [2,7]
Seedling broadcasting					
Wet-bed nursery [8]	Optional [1]	$\leq$120 g m^{-2} [3][c]	By hand [8]	15–35 [8]; 10–15 [9]	Puddled – 0 cm standing water [8]
Dry-bed nursery [8]	Optional [1,5]	$\leq$120 g m^{-2} [3][c]	By hand [8]	15–35 [8]	Puddled – 0 cm standing water [8]
Dry nursery with soft polyvinyl chloride (PVC) trays [8]	No [8]	2 to 4 seeds per tray compartment [8]	By hand or machine [8]	15–25 for hand and 15–25 for machine broadcasting [8]	Puddled – 0 cm standing water [8]
Direct seeding					
Dry seeding [10]	No	40–160 kg ha^{-1} [11][f]	By hand or machine[10]	0[10]	Dry or moist soil [10]
Wet seeding (primed or pre-germinated) [10,12]	No	40–160 kg ha^{-1} [11]	By hand or machine (including aircraft) [10,12,13]	2–5 [12]	Puddled – 0–5 cm standing water [10,12]

[a] Numbers indicate source references as follows - 1, De Datta (1981); 2, Pasquin et al. (2008); 3, Yanes Figueroa et al. (2014); 4, Sanico et al. (2002); 5, Subedi (2013); 6, Litsinger and Estano, (1993); 7, Ghafoor et al. (2008); 8, Tang, (2002); 9, Chauhan et al. (2014); 10, Harris et al. (2002); 11, Phuong et al. (2005); 12, SOSBAI, (2010); 13, Wiryareja and Tjoe-Awie, (2006).
[b] Densities indicate sowing to seed nurseries for transplanting and seedling broadcasting and to fields for direct seeding.
[c] Lower seed densities are recommended for snail control, but actual densities used by farmers vary greatly and are often >200 g m^{-2}.
[d] Older seedlings ($\geq$28 days) are recommended to avoid snail damage, but younger seedlings may lead to better stands and higher yields.
[e] Transplanted at 6 to 8 seedlings per hill.
[f] Sown directly to field, higher seed densities are recommended for improved weed control.

These snails have been particularly problematic in East and South East Asia where they damage delicate rice seedlings during crop establishment (Naylor, 1996; Wada, 2004). More recently, apple snails have been introduced to Ecuador and Chile (west of the Andes) (Horgan et al., 2014a, 2014b), and to Pakistan (Baloch et al., 2012) – from where they are likely to spread to more of the Indian Sub-continent. *P. maculata* has also spread from South America to North America and Spain, where it also damages rice (Burlakova et al., 2010; European Food Safety Authority, 2012). In invaded regions, apple snail densities have remained high and, without proper management, the snails can completely destroy recently sown or transplanted rice fields in only a few days (Halwart, 1994; Naylor, 1996). Several effective cultural methods have been developed to reduce snail densities and/or damage to rice seedlings. These mainly relate to reducing water levels in the rice paddy during the vulnerable crop stages to prevent snails from moving or feeding, and ensuring that rice seedlings are sufficiently large and robust to be mechanically resistant to the snails by increasing the age at which the seedlings are transplanted (Litsinger and Estano, 1993; Sanico et al., 2002; Teo, 2003; Wada, 2004; Yanes Figueroa et al., 2014). These cultural control methods are best suited for transplanted rice. Problems can arise when farmers adopt direct seeding in snail-infested areas because the tiny developing cotyledons of direct seeded rice are highly vulnerable to apple snails. In such cases farmers regularly use molluscicides (Wiryareja and Tjoe-Awie, 2006; SOSBAI, 2010).

It seems apparent that direct seeding cannot now be applied in many wet tropical regions without the use of molluscicides. Because of problems associated with chemical molluscicides (Jelnes, 1987; Calumpang et al., 1995; Zidan et al., 2000; Joshi et al., 2004; Horgan et al., 2014b), and faced with the continuing range expansion of apple snails in rice growing regions, there is a need to find sustainable, environmentally friendly methods to manage snail damage while at the same time reducing labor costs. One likely avenue to reduce costs while avoiding excessive snail damage is by seedling broadcasting. Seedling broadcasting is a method by which rice seedlings are produced in wet or dry seedbeds or in polyvinyl chloride (PVC) trays until they are ready for transplanting, at which time the seedlings are broadcast (either manually or by machine) to the prepared rice paddy (Tang, 2002)(Table 1). Seedling broadcasting has been developed to reduce labor costs and to reduce the time between the harvest of one crop and establishment of a second crop (Tang, 2002). Seedling broadcasting is also likely to reduce transplanting shock and improve early plant vigour in the field thereby reducing potential losses from competing weeds. Because seedling broadcasting is a specialized form of transplanting, we suggest that the method might also lead to lower damage from snails during crop establishment compared to other labor-saving crop establishment methods such as direct seeding. In the present study, we specifically examine the potential for seedling broadcasting to reduce damage to rice from apple snails. We compared four different methods – representative of broad categories of rice crop establishment - for their ability to produce good rice stands in snail-infested ponds. To our knowledge, the potential of seedling broadcasting to reduce snail damage has not been addressed previously.

2. Materials and methods

2.1. Seedbed preparation and management

Ten raised seedbeds were prepared in a screenhouse at the International Rice Research Institute (IRRI) in Los Baños, The Philippines (14°11′N, 121°15′E). The seedbeds were prepared using paddy soil, with two seedbeds in each of five concrete bays. 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). The replicated seedbeds were raised above the water level (height ca. 20 cm) and were each separated by greater than 5 m, were protected from rats and insects using insect-