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Full Length Article

Growth and Nutrients Competition between Weedy Rice and Crop Rice in a Replacement Series Study

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Abstract

This study examined competitive ability of two rice varieties with a weedy rice biotype in pot experiment. In the first experiment, each of the rice variety was grown with the weedy rice in a replacement series experiment, with five proportions of crop to weedy rice at 100:0, 75:25, 50:50, 25:75 and 0:100. In the second experiment, cv. SPR1 crop rice and weedy rice were grown in monoculture and in 50:50 mixtures with mixed or separated roots. The weedy rice was more competitive than the two crop rice varieties, with proportionately greater number of tillers, grain yield, total dry weight and accumulation of nutrients in shoot of the weedy rice when grown at 75:25 crops to weed proportion. The competition between crop and weedy rice was predominantly in the roots, as the advantage of weedy rice in growth, yield and nutrients accumulation largely disappeared when the roots were separated. These results are in agreement with invasiveness of the weedy rice in crop field. The difference between crop rice varieties found here suggests that competitiveness against weedy rice could be selected for as part of the strategy for weedy rice control, with a focus on the root traits.

Keywords: Competitiveness; Weedy rice; Crop rice; Replacement series; Nutrient; Monoculture; Mixed culture

Introduction

Weedy rice infests in most of the world's rice growing regions. Infestation can be especially serious in direct-seeded rice in America, the Caribbean, South and Southeast Asia (Mortimer *et al*., 2000; Rao *et al*., 2007; Chauhan and Johnson, 2010). In Thailand, weedy rice has become a serious problem over the whole country, after having been first observed in 2001 in Kanchanaburi province, where direct-seeded high yielding varieties (HYVs) were double-cropped. After the first appearance in a farmer's rice field, the few weedy rice plants quickly took over from the crop rice and spread over the entire village within three years (Maneechote *et al*., 2004). Weedy rice has now spread through intensive rice area in the Central Plain to the Lower North, where direct seeded HYVs are grown twice to three times a year, and have been found in the aromatic Thai jasmine rice area in the North East (Pusadee *et al*., 2013; Wongtamee *et al*., 2017). The area of invasion has been estimated to be more than 32000 ha by 2007, yield depression of 1.1% with 1% increase in infestation (Maneechote, 2007).

Weedy rice in Thailand originates from interspecific hybridization between cultivated rice (*Oryza sativa*) and common wild rice (*Oryza rufipogon* Griff.), which has been found to be phenotypically and genotypically diverse (Niruntrayakul, 2008). This was also reported in the Philippines that weedy rice originated from the multiple origins as shown by their phenotypic relationships with other rice types (Apuan *et al*., 2011). The main populations of weedy rice in Thailand were classified by farmers into three groups by their appearance, "Khao Harng" (seed with long awn, shatters), "Khao Deed" (awnless seed, shatters), and "Khao Dang" (red rice with reddish pericarp, shatters little or none) (Maneechote *et al*., 2004). The first generations of weedy rice appeared as the awned type, but later evolved into the awnless type (Wongtamee *et al*., 2017). Without the awn weedy rice seed may appear indistinguishable from cultivated rice seed, so may be inadvertently planted by farmers and dispersed.

Compared with crop rice, weedy rice has been reported to germinate and emerge a day or two earlier, from greater depths by longer coleoptile, exhibit more rapid seedling growth, become taller and produce tillers more

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profusely, have more open or spreading habit, with weaker culms more susceptible to lodging, produce more straw and larger leaf area (Kwon *et al*., 1992; Delouche *et al*., 2007). These characteristics would appear to give weedy rice advantage over cultivated rice when growing together in a series ratio mixture and root separation. A study has demonstrated in the field experiment in China that the geographical origin, mixture proportion, and genetic diversity of the weedy rice biotypes are important factors decreasing growth and yield of the cultivated rice (Dai *et al*., 2014). However, so far the competitiveness has not been directly measured in term of nutrients competition ability in the mixture and separate systems. This research evaluated the growth and nutrient competition between crop rice and weedy rice. A similar ratio of weedy rice and crop rice growing in mixed and separated root pot condition would allow investigating in-depth competition of direct nutrient uptake among both crops. This paper describes with a replacement series experiment that allows effects of one plant genotype on another to be measured, while the overall density is held constant (De Wit, 1960; Harper, 1977). This has been successfully employed in studies of crop-weed competition (e.g., between wheat and rye grass in Rerkasem *et al*., 1980) as well as nitrogen fixation in legume and non-legume intercrops (e.g., between maize and rice bean in Rerkasem *et al*., 1988), and suggested as a method for assessing interference, niche differentiation, resource utilization and productivity in mixtures (Jolliffe, 2000).

Materials and Methods

Plant Materials

An awnless biotype of weedy rice with seed collected from farmer's rice field in the Central Plain of Thailand and multiplied in pots was used in this study in both experiments. Seed of the two crop rice varieties, cv. Suphan Buri 1 (SPR1) and cv. Pathum Thani 1 (PTT1), which were widely cultivated in the areas where weedy rice has become widespread, was obtained as breeder seed from Phitsanulok Rice Research Center were used in the experiment 1 and only cv. Suphan Buri 1 (SPR1) was used in the experiment 2.

Experimental Procedure

Experiment 1: Two sets of crop: weed combinations were planted in a pot experiment with weedy rice in mixtures with the two crop rice varieties, cv. SPR1 and cv. PTT1. The pots used were 30 cm in diameter and 40 cm in height, each filled to 30 cm depth with dry sandy loam soil of San Sai series. In each pot pre-germinated seeds of weedy rice and crop rice were sown in a replacement series in one of five proportions of crop to weedy rice at 100:0, 75:25, 50:50, 25:75 and 0:100, totalling 8 plants per pot. The pots were arranged in a completely randomize design with four replications. At 10 days after sowing (DAS), the pots were filled with water to 5 cm above the soil surface and maintained until crop maturity. Fertilizer in form of 16-20-0 (% N-P_2O_5-K) was applied at 2.96 g kg^{-1} soil at 30 DAS and urea (46% N) was applied at 0.61 g kg^{-1} soil at 70 DAS.
Experiment 2: The similar experiment design, growing condition and management were carried as in the experiment 1, with only one set of crop: weed combinations were planted in this experiment with weedy rice in mixtures with the one crop rice variety, cv. SPR1. Seeds of weedy rice and crop rice were sown in a replacement series in one of three proportions of crop to weedy rice at 100:0, 50:50 and 0:100. The pot mixture between crop and weedy rice was grown in two conditions with mixed and separated root systems. The pot was divided into two sections by using hard plastic sealed with silicone to completely separate root system of crop rice and weedy rice, while mixed root was not separated as in experiment 1.

Data Collection

Both experiments were harvested at maturity and recorded for number of tillers, number of panicles and dry weight of shoot and grain were determined after oven dried at 75^{o}C for 48 h.

Nutrient Analysis

The straw and grain from the SPR1 sub-experiment were analyzed for nitrogen (N) by Kjeldahl method (Jackson, 1967), phosphorus (P) by dry ashing followed by the molybdovanado phosphoric acid method (Murphy and Riley, 1962) and potassium (K) by dry ashing and atomic absorption spectrophotometry.

Statistical Analysis

The data was analysed by analysis of variance (AOV) with mean comparing by least significant difference (LSD) at 95% confidence interval. Competitiveness of the genotypes was determined as the measurement for each parameter in mixture relative to the respective value in monoculture (i.e., RY, for relative yield); sum of the relative values (i.e., RYT, for relative yield total) for each species indicated overall performance of the mixture (De Wit, 1960; Harper, 1977). Without interference, the performance of each species in the mixture would be indicated by the relative performance that is equivalent to its proportion in mixture. Competitive advantage of a species is indicated by the value for relative performance greater than its proportion in the mixture, and disadvantage by the relative performance less than its proportion in the mixture. Ability of the mixture to out-perform the species in monoculture, by one or both species accessing different pools of resource when grown together, is indicated by the sum of the relative values (e.g., RYT, for relative yield total) that is greater than 1.

Results

Experiment 1

There was little interference between crop and weedy rice on their grain yield when the crop rice was cv. SPR1, but the interference was much more significant with cv. PTT1 (Fig. 1a). Grain yield of cv. PTT1 declined with increasing proportion of weedy rice to 50:50 mixture, while the highest weedy rice grain yield was found at 75:25 (crop: weed). Competition effect on grain yield was represented in the replacement series graph, with cv. PTT1 showing deviation below the dotted line and its accompanying weedy rice below the dotted line at 75:25 (crop: weed) and smaller depression in the case of cv. SPR1 (Fig. 1b).

Interference was found between crop and weedy rice on shoot dry weight with both crop rice varieties, but the effects were stronger in cv. PTT1 than cv. SPR1, but the interference was much more significant with cv. PTT1 (Fig. 2a). Shoot dry weight per plant of both crop rice varieties declined with increasing proportion of weedy rice, but more sharply in cv. PTT1. The weedy rice produced higher above ground dry weight with increasing proportion of crop rice, more sharply in association with cv. PTT1 than cv. SPR1. Competition effect was represented in replacement series graph showing greater competitive advantage of the weedy rice and disadvantage of crop rice in association cv. PTT1 and less in association with cv. SPR1 (Fig. 2b).

Weedy rice had more tillers than both crop rice varieties of cv. SPR1 and cv. PTT1 in all mixture (Fig. 3a). Interference between the weedy and crop rice in mixtures in their tillering was indicated by a replacement graph plotted with number of tillers in mixture relative to that in monoculture, with the dotted lines representing performance equivalent to the proportion without interference (Fig. 3b). The relative number of tillers of cv. PTT1 was lower than its proportion in the mixture (under the dotted line), while those of the weedy rice was proportionately greater (above the dotted line). Interference in tillering was less obvious between cv. SPR1 and weedy rice.

In mixture, the number of panicles per plant of weedy rice and cv. SPR1 crop rice were not different from their respective number in monoculture, but with cv. PTT1 the number of panicles of both crop and weedy rice were affected by their proportion in mixtures (Fig. 4a). The number of panicles in cv. PTT1 declined with increasing proportion of weedy rice in the mixture, while the weedy rice produces significant more panicles with greater proportion of crop rice. Compared with fewer than 4 panicles per plant in the monoculture, the weedy rice produced significantly more panicles in the presence of cv.

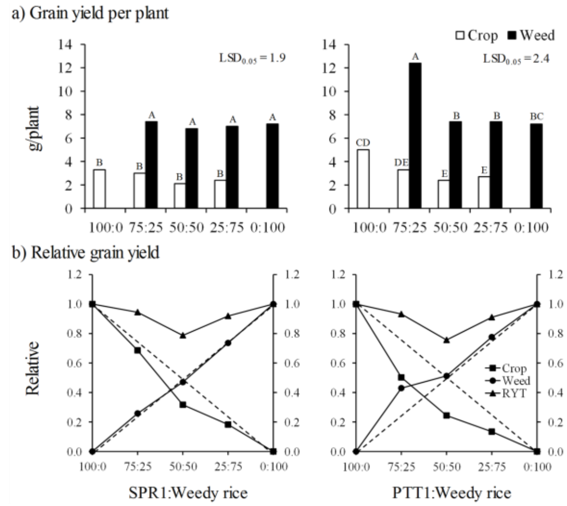

Fig. 1: Grain yield per plant (a) of cv. SPR1 and cv. PTT1 in the presence varying proportion of weedy rice at maturity. Different letters above bars indicate significant difference between crop and weedy rice over all proportions in each crop rice variety by LSD at $p<0.05$. Relative of grain yield (b) in cv. SPR1 with weedy rice and cv. PTT1 with weedy rice in different plant proportion at maturity. Each symbol showed average of four replicates. Dotted lines indicate performance equivalent to proportion of each genotype in mixture without interference

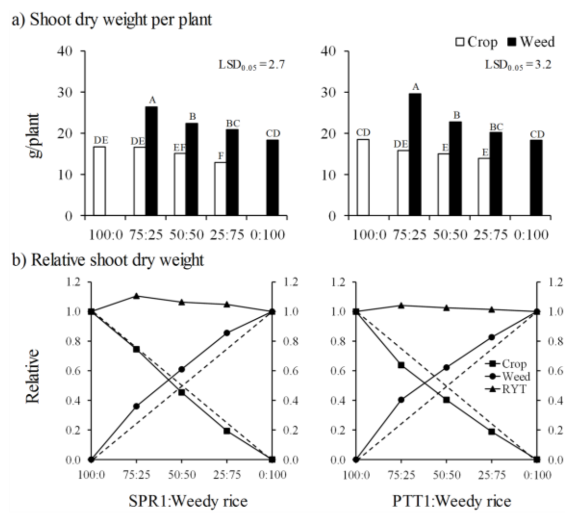

Fig. 2: Shoot dry weight per plant (a) of cv. SPR1 and cv. PTT1 in the presence varying proportion of weedy rice at maturity. Different letters above bars indicate significant difference between crop and weedy rice over all proportions in each crop rice variety by LSD at $p<0.05$. Relative of total plant dry weight (b) in cv. SPR1 with weedy rice and cv. PTT1 with weedy rice in different plant proportion at maturity. Each symbol showed average of four replicates. Dotted lines indicate performance equivalent to proportion of each genotype in mixture without interference

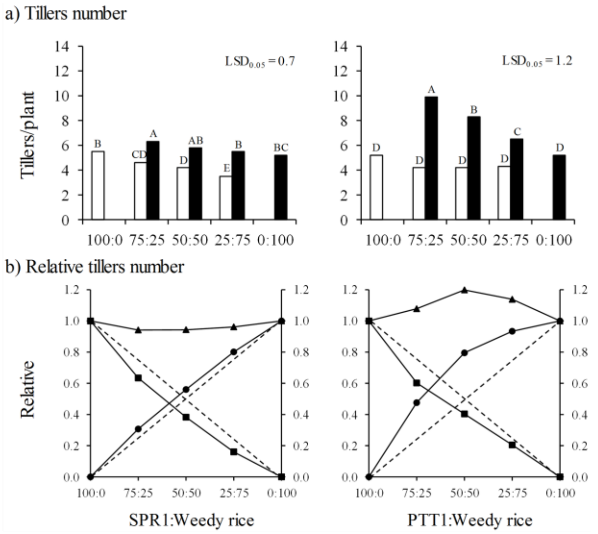

Fig. 3: Tillers number (a) and relative of tillers number (b) of cv. SPR1 and cv. PTT1 with weedy rice in the presence varying proportion of weedy rice. Different letters above bars indicate significant difference between crop and weedy rice over all proportions in each crop rice variety by LSD at p<0.05

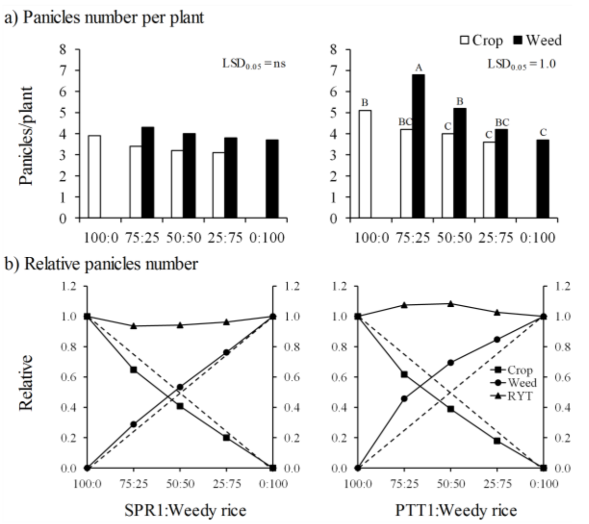

Fig. 4: Panicles number per plant (a) of cv. SPR1 and cv. PTT1 in the presence varying proportion of weedy rice at maturity. Different letters above bars indicate significant difference between crop and weedy rice over all proportions in each crop rice variety by LSD at p<0.05. Relative of panicles number (b) in cv. SPR1 with weedy rice and cv. PTT1 with weedy rice in different plant proportion at maturity. Each symbol showed average of four replicates. Dotted lines indicate performance equivalent to proportion of each genotype in mixture without interference

PTT1 at 50:50 and almost 7 panicles per plant at 75:25 (crop: weed). The competition effect was represented in the

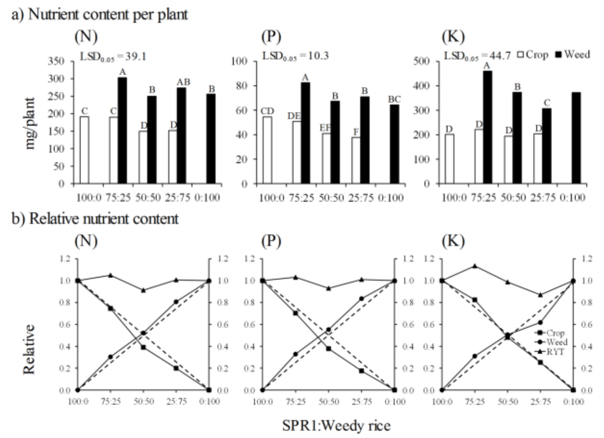

Fig. 5: Nutrient content per plant (a) of cv. SPR1 in the presence varying proportion of weedy rice. Different letters above bars indicate significant difference between crop and weedy rice over all proportions in each crop rice variety by LSD at p<0.05. Relative of nutrient content (b) in cv. SPR1 with weedy rice in different plant proportion at maturity. Each symbol showed average of four replicates. Dotted lines indicate performance equivalent to proportion of each genotype in mixture without interference

replacement series graph showing the advantage of weedy rice over cv. PTT1 and less interference in the case cv. SPR1 (Fig. 4b).

Interference from weedy rice was found in the accumulation of N and P in the crop rice cv. SPR1, whereas the N, P and K content of weedy rice were affected by the presence of crop rice (Fig. 5a). Nitrogen and P content in the crop rice declined with increasing proportion of weedy rice but its K content were unaffected. The N, P, K content of weedy rice was more variable, although the highest content of all three nutrients were found at 75:25 (crop: weed) mixture. Competition effects represented in the replacement series graph showed advantage of weedy rice over crop rice for N and P, but not for K (Fig. 5b).

Experiment 2

Grain yield, shoot and root dry weight were not different between crop rice and weedy rice in monoculture, when grown together with mixed roots the weedy rice significantly out-performed the crop rice in all growth and yield parameters but the advantage of weedy rice largely disappeared when the roots were separated (Fig. 6). The advantage of weedy rice over crop rice when they were grown together with mixed roots and separated was also found in the accumulation of nutrients (Fig. 7). The contents of N, P and K contents of the crop rice and weedy rice were little different in monoculture, and when grown together but with separate roots. But growing together with mixed roots approximately twice as much N, P and K were accumulated by the weedy rice as by the crop rice.

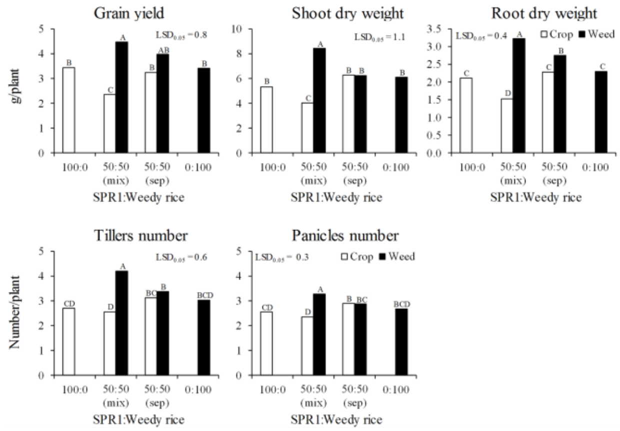

Fig. 6: Grain yield, shoot and root dry weight, tiller number and panicle number per plant of crop (cv. SPR1) and weedy rice grown in three different proportions and cultured practices (mixed and separated root systems)

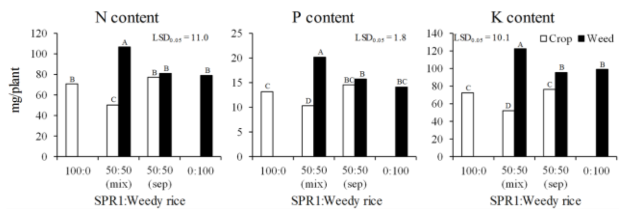

Fig. 7: Nutrient content (N, P and K) of crop (cv. SPR1) and weedy rice grown in three different proportions and cultured practices (mixed and separated root system)

Discussion

This study has demonstrated quantitatively the stronger competitive ability of weedy rice over crop rice, by the competitive advantage gained by the traits that enabled it to capture more resources for growth.

These included better light interception from more profuse tillering and being taller (data not shown), thus over shading the crop rice. This combined with underground advantage of the weedy rice in its accumulation of nutrients contributed to greater productivity in total plant dry weight, number of panicles per plant and grain yield. The competition of two crop rice varieties against the awnless weedy rice type on the basis of tillers number, grain yield and total dry weight were evaluated using a replacement diagram. The relative performance of each crop rice variety with the weedy rice that fell below the non-interference dotted line that represents their proportion in the mixture indicated competitive disadvantage of the crop rice against the weedy rice. The relative yield total (RYT) of dry weight of mixtures exceeding 1 indicates that species in the mixture are able to access different pools of limiting resources (Fleming *et al*., 1988). Such advantage might be expected in cereal-legume intercrops where the legume can access the N_2 supply from the air through biological fixation (Ofori and Stern, 1987), and in which the RYT > 1 has been demonstrated for yield as well as nitrogen (Rerkasem and Rerkasem, 1988; Loomis and Conner, 1992). That the weedy rice and crop rice were accessing the same pool of resources in the present study was indicated by the RYT for dry weight and grain yield that never exceeding 1. The recent study was in agreement with the previous study in the field experiment that yield and yield component of the cultivated rice were significantly reduced by increasing the mixtures of weedy rice due to the effect of plant height, tiller number, flag leaf area and reached the minimum value when the ratio of cultivated to weedy rice was 20:80 (Dai *et al*., 2014) and the competition effect is also difference among Asian weedy rice variants (Chauhan and Johnson, 2010). Previous study indicated that N fertilizer management can be affected on weedy rice competition but the response depended on weedy rice originate (Chauhan and Johnson, 2011). This field experiment reported that weedy rice plant from Malaysia produced a similar shoot biomass to the cultivated rice plant per unit addition of N, while the Philippine and Vietnam weedy rice produced a greater shoot biomass with each addition unit of N compared to cultivated rice. The above ground may probably result from the underground competitions such as ability on nutrient uptake.

The competitive effects of weedy rice on crop rice vary by proportion of the weedy rice. Weedy rice showed higher competitive ability when its proportion in mixture was lower. The highest effect of weedy rice competition was found at 75:25 (crop: weed). This supports our argument that intraspecific competition among the weedy rice plants themselves was stronger than interspecific competition of weedy rice to crop rice. In addition, nutrients analysis of cv. SPR1: weedy rice combination in dry matter also showed the competitive effects of weedy rice on crop rice (Fig. 5b). The relative yield totals (RYT) of N and P content in mixtures did not exceed1. Relative N and P content of weedy rice in mixtures were above the non-interference line, while N and P content crop rice were below the non-interference line, indicating that the weedy rice was able to capture more of the nutrients than the crop rice when growing together (Fleming *et al*., 1988). Lack of deviation from non-interference line of relative performance indicates that the resource is either not limiting or there is no competitive advantage between the species in mixture (Harper, 1977). The relative K content of both crop and weedy rice found here to closely follow the non-interference line therefore suggest that under the condition of this experiment K was either not limiting or that the nutrient, unlike N and P, was equally accessible to crop and weedy rice.

Competition between crop and weedy rice was significantly influenced by the crop rice varieties involved. This may be seen in tillering, dry weight and grain yield of the rice variety cv. PTT1 that was depressed more by increasing proportion of weedy rice in the mixture than those of the variety cv. SPR1. The weedy rice in association with cv. PTT1 also showed greater advantages than those the mixed with cv. SPR1. The relative competitive advantage/disadvantage of the two crop rice varieties can be more readily seen in the replacement diagrams, which showed greater deviation of P cv. PTT1 below the non-interference line and its accompanying weedy rice above the line, than cv. SPR1 variety with weedy rice curves. A previously study showed that crop rice grain yield of the semi-dwarf Lemont variety was depressed more by weedy rice than that of the tall Newbonnet variety (Kwon *et al*., 1991). Thus plant height, with cv. PTT1 about 10 cm shorter than cv. SPR1, could have contributed to relative competitive ability of the varieties against the weedy rice. Higher tillering capacity has been shown to more than compensate for shorter plant height, in the case of crop rice variety cv. PI 312777 against KatyRR weedy rice, while crop rice cv. Kaybonnet variety, which lowers tillers was less competitive than cv. PI 312777 (Estorninos *et al*., 2002). However in the present study, the higher tillering capacity of cv. PTT1 did not prevent the variety being depressed by weedy rice, and the weedy rice in mixture to gain more, in all parameters that were measured much greater extent than the less profusely tillering cv. SPR1.

The disappearance of the advantage of weedy rice over crop rice, in growth, yield and nutrient accumulation, when their roots were separated in the second experiment has established for the first time that root competition is the primary mechanism for competitiveness of weedy rice over crop rice, and therefore explaining invasiveness of the weedy rice in the rice field. A review of a large number of replacement and additive experiments found that root competition predominates in species mixtures in general, but shoot competition tended more intense in crop-weed studies (Wilson, 1988). The close genetic relationship between weedy rice and crop rice (Pusadee *et al*., 2013; Wongtamee *et al*., 2017) may be the reason behind the lack of shoot competition in this case. Our results are also supported by a previous report that weedy rice was more efficient than crop rice in nitrogen uptake from soil (Burgos *et al*., 2006). The root-competitiveness of the weedy rice found here appeared to be associated with the ability of the weedy rice to produce more roots in the presence of the crop rather than its nutrient uptake efficiency, as the N, P, K accumulated per unit root dry weight did not differ markedly between the crop and weedy rice.

Conclusion

The superior tillering capacity, better uptake of nutrients, general growth and seed yield of weedy rice agree with its invasiveness in the rice field. The difference between crop rice varieties found here suggests that competitiveness against weedy rice could be bred and selected for as part of the strategy for weedy rice control.

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