Published March, 2001

RICE

Water-Seeded Rice Cultivars Differ in Ability to Interfere with Watergrass

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ABSTRACT

The repeated use of a limited number of herbicides has led to the development of resistant weed species in California rice (*Oryza sativa* L.). Competitive rice cultivars could help reduce herbicide dependency and decrease selective pressure for resistance. We conducted field experiments to determine if differences in competitive ability existed between two semidwarf cultivars of water-seeded rice. Cultivars M-202 and A-301 were grown on Stockton clay soil at two seed rates (84 and 168 kg ha^{-1}) in 1996 and four seed rates (56, 112, 168, and 224 kg ha^{-1}) in 1997. Molinate (*S*-ethyl hexahydro-1*H*-azepine-1-carbothioate) and propanil [*N*-(3,4-dichlorophenyl)propanamide] were used to control a mixed infestation of watergrass [*Echinochloa oryzoides* (Ard.) Fritsch, *E. phyllopogon* (Stapf) Koss] in 1996 and 1997, respectively. Molinate (0 and 4.5 kg a.i. ha^{-1}) was applied in 1996, and propanil (0, 1, 2 and 4 kg a.i. ha^{-1}) was applied in 1997. M-202 was taller, produced more leaf dry weight, had greater light interception, and reduced watergrass biomass more than A-301 in both years of the study. The more competitive M-202 also had higher yields than A-301 under weedy and weed-free conditions. Watergrass growth was not affected by rice seed rates in either year. This study suggests that herbicide rates could be reduced and weed control could be improved if more competitive cultivars were developed for water-seeded rice.

Herbicides have improved weed control and contributed substantially to yield increases in U.S. rice production (Hill and Hawkins, 1996). However, the extensive use of herbicides in U.S. rice has also led to problems with drift injury to other crops (Smith et al., 1977; Hill and Hawkins, 1996), water pollution (Cornacchia et al., 1984), the development of propanil-resistant barnyardgrass [*Echinochloa crus-galli* (L.) Beauv.] in Arkansas (Baltazar and Smith, 1994), and the development of bensulfuron-methyl {methyl 2-[[[[[(4,6-dimethoxypyrimidin-2-yl) amino]carbonyl]amino]sulfonyl]methyl]benzoate} resistant broadleaf and sedge species in California (Pappas-Fader et al., 1994). The widespread and repeated use of bensulfuron on the same fields led to the detection of resistant weed species only 4 yr after its introduction in California rice (Hill and Hawkins, 1996). Recently, biotypes of watergrass, the most economically important weed in California rice, have been found with resistance to most of the grass herbicides currently available for use in California (Fischer et al., 2000). Of the herbicides currently available for California rice growers, only the newly introduced herbicides carfentrazone-ethyl {ethyl *a*, 2-dichloro-5-[4-(difluoromethyl)-4,5-dihydro-3-methyl-5-oxo-1*H*-1,2,4-triazol-1-yl]-4-fluorobenzenepropanoate} and triclopyr [(3,5,6-trichloro-2-pyridinyloxy)acetic acid], which do not control grass species, face no immediate or potential limitations due to weed resistance or restrictions in acreage use.

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Published in Agron. J. 93:326–332 (2001).

Several management practices other than chemical control are used to reduce weed infestations in U.S. rice production. These include weed-free seed, crop rotation, land leveling, water management, and fertilizer management (Hill and Hawkins, 1996). Cultivars have been identified that interfere with weed growth in wheat (*Triticum aestivum* L.), barley (*Hordeum vulgare* L.), and other crops (Callaway, 1992; Christensen, 1995; Lemerle et al., 1996a); however, research on competitive cultivars in U.S. rice has been limited. This may be traced, in part, to the influence of studies conducted on tropical rice that compared newly introduced semidwarf cultivars with their taller predecessors and concluded that rice yields were inversely correlated with competitive ability (Jennings and Aquino, 1968; Jennings and De Jesus, 1968; Jennings and Herrera, 1968; Kawano et al., 1974). Given the apparent tradeoff between yield and competitive ability, Jennings and Aquino (1968) suggested that there would be little reason to develop competitive cultivars as long as alternative control methods were readily available. However, several recent studies that were also conducted on tropical rice suggest that competitive cultivars can be used under weed-free conditions without substantially lowering yields. Fischer et al. (1997) grew 14 semidwarf cultivars (indica and japonica types) under weed-free conditions and with junglerice [*Echinochloa colona* (L.) Link] at Palmira, Colombia. They found no negative correlation between competitive ability and weed-free yields. Average weed-free yields for the 2 yr of the experiment were 7.5 to 7.9 Mg ha^{-1}, which is comparable to yields in the USA (Hill and Hawkins, 1996). Under weedy conditions, the best competitor yielded 2.4 to 3.0 Mg ha^{-1} than the weakest competitor, but both had similar yields in monoculture. Johnson et al. (1998), working in the Ivory Coast, compared an African rice (*Oryza glaberrima* Steudel) cultivar and two rice cultivars with and without weed competition and found significant differences among the cultivars in their competitive ability but no significant difference in the yields under weed-free con-

Abbreviations: DAS, days after seeding.

ditions. Garrity et al. (1992) evaluated 25 upland rice cultivars (improved semidwarf, intermediate height, and traditional tall cultivars) in field experiments in the Philippines. In this study, several intermediate height (1.0 to 1.15 m) cultivars were found to be as competitive as the tall (1.4 m) traditional cultivars. The intermediate height cultivars were ranked among the top cultivars for yield in the International Upland Rice Nursery, suggesting that weed suppression could be combined with a high yield potential.

While the suppressive ability of cultivars has been studied in tropical rice, relatively little has been done in temperate rice. We are currently examining the relationship between yield and competitive traits in water-seeded rice. However, even if competitive ability can be improved without compromising yields, breeders are unlikely to select for competitive traits until the potential for improved weed control or reduced herbicide inputs has been demonstrated. The objective of this study was to determine if watergrass control and herbicide inputs were significantly affected by differences in the relative competitive ability of two commercially available water-seeded rice cultivars.

MATERIALS AND METHODS

The 1996 field experiment was conducted at the Rice Experiment Station at Biggs, CA. The experimental design was a split-plot in a randomized complete block with five blocks. Main plot treatments were molinate (0 and 4.5 kg a.i. ha^{-1}) applied on 24 June 1996 to control watergrass, and subplot treatments were the cultivars M-202 and A-301. Both cultivars are modern semidwarf varieties currently used in California rice production. M-202 is a medium-grain early maturing variety while A-301 is an aromatic, intermediate maturity long-grain variety. M-202 reaches 50% heading approximately 8 d earlier than A-301. Sub subplot treatments were 84 and 168 kg ha^{-1} rice seed. Main plots were separated by levees to prevent herbicide movement. Rice was dry-seeded in 0.10-m rows (sub-subplots were 2 by 2 m) on 30 May 1996 and flooded 1 d later. All of the plots were sprayed with bensulfuron-methyl (0.07 kg a.i. ha^{-1}) on 24 June 1996 for broadleaf and sedge control. The soil was a Stockton Clay Adobe (fine, montmorillonite, thermic, Typic Pelloxerts). Nitrogen and P fertilizer were applied with an airplane at rates of 110 kg N ha^{-1} and 28 kg P ha^{-1} and incorporated with a harrow before flooding. Aboveground biomass was harvested within 0.25-m^2 quadrats at 45, 63, 90, and 139 d after seeding (DAS).

The 1996 split-plot design was repeated at the Rice Experiment Station in 1997 with modifications. Main plot treatments were four propanil rates (0, 1, 2, and 4 kg a.i. ha^{-1}), and sub-subplots treatments were four rice seed rates (56, 112, 168, and 224 kg ha^{-1}). Only three blocks were used in 1997. Propanil was used in 1997 because molinate-resistant watergrass was reported in fields near, but not on, the Rice Experiment Station in 1996. The range of seed and herbicide rates was increased in 1997 to characterize more fully the relationship between those factors and the competitive ability of the cultivar. Rice was presoaked and hand-broadcast into flooded plots on 19 May 1997. Nitrogen and P fertilizer was applied with an airplane at rates of 110 kg N ha^{-1} and 28 kg P ha^{-1} and incorporated with a harrow before flooding. The soil was corrugated before flooding with 13-cm-wide grooves. Propanil was applied on 8 June 1997 to control watergrass. An experimental herbicide was applied on the same date for broadleaf and sedge control. Plants were harvested on 15 July (62 DAS) and at maturity (145 DAS) within 0.25-m^2 quadrats.

Plant height was measured from the base of the stem to the tip of the longest leaf for uprooted plants at all but the last harvest. Plants were harvested at rice maturity by cutting stems near the soil surface; height was not measured. Tiller density and aboveground dry weight were determined for watergrass at each harvest. Grain dry weight was determined for rice at the final harvest. Irradiation was measured with a Decagon Sunfleck Ceptometer (Decagon Devices, Pullman, WA) in the plots that received the maximum herbicide control 51 DAS in 1996 and 16 DAS in 1997. The average of 10 randomly placed subsamples per plot was used to calculate the percent of light interception by the canopy [irradiation at the surface of the water/(irradiation above the canopy – light reflected by the canopy)]. An analysis of variance was conducted for each experiment to determine the importance of treatment effects on rice and weed response variables. Regression analysis was used to fit relationships between propanil rate and (i) watergrass dry weight, (ii) watergrass tillering, and (iii) rice yields. Watergrass weight, tillers, and rice yields in 1997 were square root transformed to correct for a lack of normality and heterogeneous variance. All statistical analyses were conducted using SAS procedures (SAS Inst., 1990).

RESULTS

Cultivar, Herbicide, and Seed Rate Effects on Watergrass

In 1996, watergrass dry weight and tillering were significantly affected by herbicide rate and cultivar but not by rice seed rate (Table 1). There was a significant interaction between herbicide and cultivar treatments.

Table 1. Analysis of variance for herbicide, cultivar, and seed rate effects on watergrass (WG) growth and rice yields.

	1996					1997			
Source	df	WG DW†	WG tillers	WG height	Rice grain DW	df	WG DW	WG tillers	Rice grain DW
Herbicide (H)	1	**	*	*	NS	3	**	**	**
Cultivar (C)	1	*	*	NS	*	1	**	**	**
H × C	1	*	*	*	NS	3	NS	NS	**
Seed rate (S)	1	NS	NS	NS	*	3	NS	NS	NS
H × S	1	NS	NS	NS	NS	9	NS	NS	*
C × S	1	NS	NS	NS	NS	3	NS	NS	NS
H × C × S	1	NS	NS	NS	NS	9	NS	NS	NS

* Significant at the 0.05 level.
** Significant at the 0.01 level.
† DW, dry weight.

Table 2. The effect of herbicide and cultivar on watergrass growth at 90 d after sampling (DAS) in 1996 from an experiment at Biggs, CA.

	Molinate and bensulfuron	Bensulfuron	Molinate and bensulfuron	Bensulfuron
	Watergrass DW† g m^{-2}		Watergrass tillers m^{-2}	
M-202	0	18	0	30
A-301	0	88	0	49
LSD (0.05) Herbicide	6		8	
LSD (0.05) Cultivar	8		5	

† DW, dry weight.

Differences between the cultivars were detected only in plots that did not receive molinate because molinate eliminated watergrass from the treated plots (Table 2). Although M-202 appeared to suppress watergrass more than A-301 throughout the season, significant differences ($P < 0.05$) were detected only at 90 DAS (Table 2). In the absence of molinate, the weight of watergrass grown with M-202 at 90 DAS was 20% of the weight of watergrass grown with A-301. Watergrass grown with M-202 had 61% as many tillers as watergrass grown with A-301. Watergrass height was not significantly affected by the cultivar of rice (data not shown).

Watergrass weight and tillering were also significantly affected by the herbicide rate and cultivar in 1997 (Table 1). Rice seed rate had no detectable effect on the watergrass growth. Watergrass weight and tillers had a parabolic response to the rate of propanil (Fig. 1 and 2; fitted relationships given in Table 3). There was no interaction between herbicide rate and cultivar in 1997 (Table 1). M-202 suppressed watergrass weight and tillers more than A-301 for all propanil rates. At the standard propanil rate in 1997 (4 kg a.i. ha^{-1}), M-202 suppressed watergrass weight to 29% of the weight of watergrass grown with A-301 (Fig. 1). Similarly, M-202 suppressed watergrass tiller production as much at 2 kg ha^{-1} a.i. propanil as A-301 did at 4 kg ha^{-1} a.i. propanil (Fig. 2).

Table 3. Regression equations for watergrass dry weight, tillers, and rice yields at final harvest in 1997 as a function of propanil rate.†

Cultivar	*n*	Equation	r^2
		Watergrass dry weight	
M-202	48	$Y = 28.3 - 9.9X + X^2$	0.79
A-301	48	$Y = 31.4 - 9.0X + 0.9X^2$	0.70
		Watergrass tillers	
M-202	48	$Y = 18.1 - 6.1X + 0.6X^2$	0.79
A-301	48	$Y = 19.5 - 3.9X + 0.3X^2$	0.66
		Rice yields	
M-202	48	$Y = 9.0 - 6.5X$	0.71
A-301	48	$Y = 2.6 - 6.4X$	0.77

† All dependent variables were square root transformed to correct for lack of normal distribution and heterogeneous variance. Regression equations are based on transformed data.

Cultivar, Herbicide, and Seed Rate Effects on Rice Yields

The grain weight of rice was not significantly affected in 1996 by the presence or absence of molinate (Table 1). While differences in watergrass weight between herbicide treatments were significant in 1996, these differences were apparently not great enough to affect rice yields. Bensulfuron, used primarily to control broadleaf and sedge species, can also provide partial control of grass species (Bayer and Hill, 1992) and may have reduced watergrass weight in 1996. Bensulfuron was not used in 1997, and watergrass weight was an order of magnitude greater than in 1996. M-202 produced 11 to 17% more grain weight than A-301 (Table 4). Grain yields were significantly lower at the rate of 168 kg ha^{-1} seed than at the 84 kg ha^{-1} seed treatment (Table 4).

Rice yields were significantly affected by herbicide rate and cultivar in 1997 but not by rice seed rate (Table 1). The interaction between cultivar and herbicide treatments in 1997 was significant; M-202 produced more grain weight than A-301 for all propanil rates, except when no propanil was applied (Fig. 3). In the absence of chemical control, watergrass nearly eliminated both cultivars from the plots. Yields of both cultivars in-

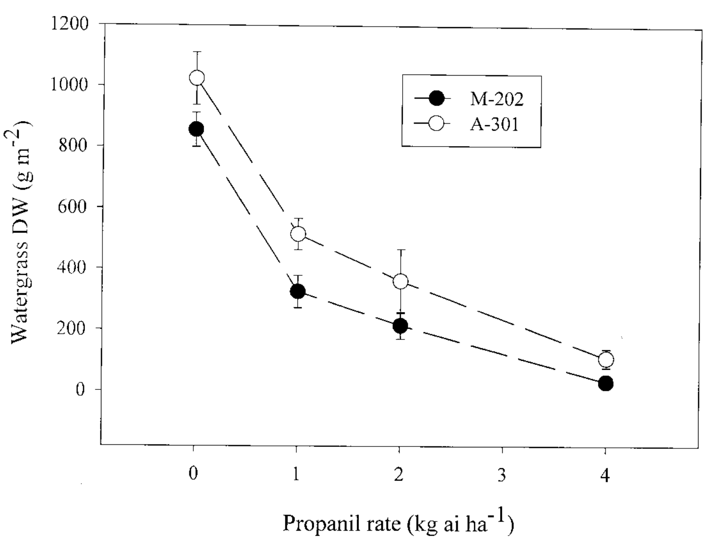

Fig. 1. Response of watergrass dry weight (DW) to rice cultivar and propanil rates at 145 d after seeding (DAS) in 1997 from an experiment at Biggs, CA. Regression equations fitted for each cultivar are given in Table 3. Bars extending beyond symbols denote standard error.

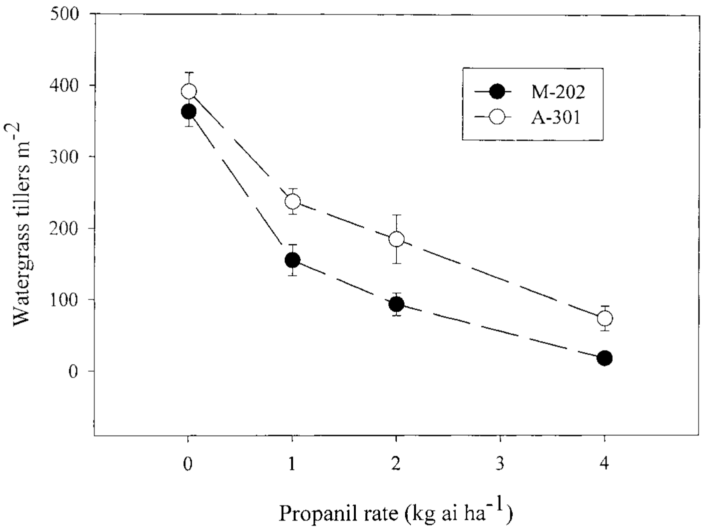

Fig. 2. Response of watergrass tillers to rice cultivar and propanil rates at 145 d after seeding (DAS) in 1997 from an experiment at Biggs, CA. Regression equations fitted for each cultivar are given in Table 3. Bars extending beyond symbols denote standard error.

creased linearly in response to propanil rate (Fig. 3; fitted regression relationships given in Table 3). There was a significant interaction between herbicide rate and seed rate (Table 1). At the highest herbicide rate, the rice yields declined as seed rate increased (data not shown). However, at lower herbicide rates, yields were unaffected or increased slightly as seed rate increased.

Growth Differences between Cultivars

There were no significant differences in plant or tiller densities between M-202 and A-301 in either year for plots that were treated with the full herbicide rate. In 1996, M-202 produced 40 plants m^{-2} ± 7.0 SE and 45 tillers m^{-2} ± 8.6 SE at 45 DAS compared with 40 plants m^{-2} ± 7.0 SE and 37 tillers m^{-2} ± 7.9 SE for A-301, respectively. At 63 DAS in 1997, mean plant densities were 78 plants m^{-2} ± 12 SE and 69 plants m^{-2} ± 9 SE for M-202 and A-301, respectively. In 1997, M-202 produced 194 tillers m^{-2} ± 10 SE compared with 206 tillers m^{-2} ± 20 SE for A-301. Differences in competitive ability between M-202 and A-301 were therefore not related to stand establishment.

In 1996, M-202 had a significantly greater leaf weight than A-301 at 45 and 63 DAS and was always taller (Table 5). Tiller production peaked at 63 DAS in 1996 and declined more rapidly for M-202 than for A-301. Although yields for A-301 were lower than for M-202, A-301 produced significantly more tillers than M-202 at the last two harvests. This suggests that yields per tiller were lower for A-301. In 1997, M-202 was significantly taller and produced more leaf weight than A-301 at 62 DAS. Plant height was 73 cm ± 1.5 SE for M-202 vs. 62 cm ± 2 SE for A-301. M-202 produced 46% more leaf dry weight than A-301 (60 g ± 4 SE vs. 41 g ± 4 SE). Leaf weight and height were not measured at final harvest in 1997. Tillering was similar for both cultivars in 1997.

There was no interaction between seed rate and cultivar for light interception in 1996. At 51 DAS, under weed-free conditions, M-202 intercepted 28% more light than A-301 (Table 6). There was a significant interaction between seed rate and cultivar in 1997. The data were reanalyzed using an analysis of variance to compare M-202 and A-301 at each seed rate. M-202 intercepted significantly more light than A-301 at all seed rates except 224 kg ha^{-1} seed. At 168 kg ha^{-1} seed, M-202 intercepted five times more light than A-301. Early advantages in height and leaf production may explain why M-202 intercepted more light than A-301.

Table 4. Effect of cultivar and seed rate on rice grain dry weight (DW) at Biggs, CA in 1996.

	Rice seed rate		
	kg ha^{-1}		
	84	168	Means
	Rice grain DW		
	g m^{-2}		
M-202	1016	852	936
A-301	848	756	800
Means	932	800	
LSD (0.05) Cultivar	109		
LSD (0.05) Seed rate	53		

Table 5. Growth differences between rice cultivars during the 1996 field season at Biggs, CA averaged across herbicide and seed rates.

	Tillers		Height		Leaf DW†	
DAS‡	M-202	A-301	M-202	A-301	M-202	A-301
	no. m^{-2}		cm		g m^{-2}	
45	276 (28)§	260 (24)	43 (1)	38 (1)**	37 (4)	24 (3)*
63	748 (36)	816 (52)	66 (2)	54 (1)**	228 (4)	186 (3)**
90	596 (28)	772 (48)**	94 (1)	77 (1)**	249 (7)	268 (8)
139	552 (20)	636 (24)**	–¶	–	–	–

* Significant at the 0.05 level.
** Significant at the 0.01 level.
† DW, dry weight.
‡ DAS, days after sampling.
§ Standard error of the means are enclosed in parentheses.
¶ Dashes indicate that no data was available for that harvest.

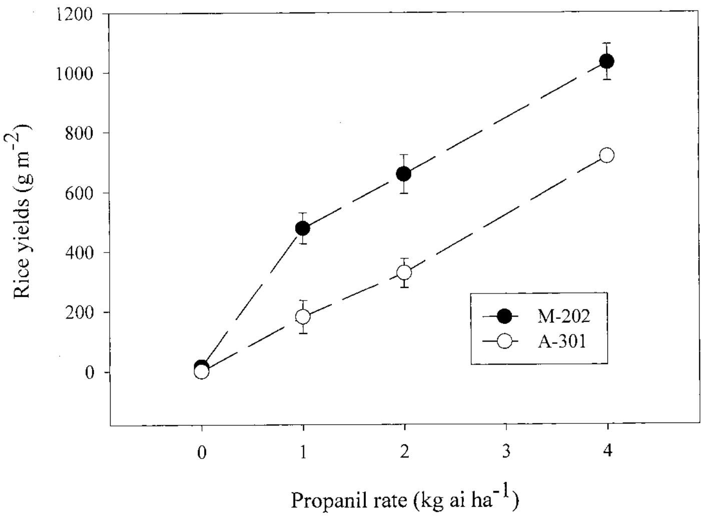

Fig. 3. Response of rice yields to cultivar and propanil rates at 145 d after seeding (DAS) in 1997 from an experiment at Biggs, CA. Regression equations fitted for each cultivar are given in Table 3. Bars extending beyond symbols denote standard error.

DISCUSSION

The potential loss of herbicides due to resistance is a serious problem for California rice (Hill and Hawkins, 1996) and weed control worldwide (Holt et al., 1993; Warwick, 1991). Efforts to conserve existing herbicides should focus on decreasing the selective pressure for resistant biotypes (Holt and LeBaron, 1990). Recommended approaches include using combinations of herbicides, crop and/or herbicide rotations, herbicide-resistant crops, more cultivation, and techniques to maintain susceptible plants in the population (Holt et al., 1993; Gressel and Segel, 1990; Holt and LeBaron, 1990; Maxwell et al., 1990; LeBaron and McFarland, 1990). The use of competitive cultivars within an integrated weed management program may also be a cost-effective approach for reducing the selective pressure for resistance. Competitive cultivars may allow lower herbicide rates to be used, thereby reducing the selective pressure for herbicide resistance. Several authors have reported that competitive crops or cultivars can strongly influence weed suppression at lower herbicide rates (Christensen, 1994; Salonen, 1992). Lemerle et al. (1996a) reported that strongly competitive wheat cultivars suppressed annual ryegrass (*Lolium rigidum* Gaud.) more than less competitive cultivars at lower-than-recommended rates of diclofop-methyl {methyl (*RS*)-2-[4-(2,4-dichlorophenoxy)phenoxy]propionate}. In our study, when combined with a herbicide that provided at least partial control of watergrass, M-202 suppressed significantly more watergrass weight than A-301 in two successive years. To achieve equivalent levels of watergrass suppression, higher rates of herbicides were required with A-301 than with M-202. For example, M-202 treated with 2 kg ha^{-1} propanil suppressed watergrass tillers m^{-2} as much as A-301 treated with 4 kg ha^{-1} propanil. Because M-202 has not been directly selected for competitive ability, reducing the herbicide inputs in water-seeded rice with more competitive cultivars seems possible.

Table 6. The effect of cultivar and seed rate treatments on percent of light interception in plots at Biggs, CA that received molinate in 1996 and the standard rate of propanil in 1997.†

	51 DAS‡ 1996			16 DAS 1997			
	Rice seed rate			Rice seed rate			
	kg ha^{-1}						
	84	68	Means	56	112	168	224
	Percent of light intercepted						
	%						
M-202	72 (4)§	77 (5)	74 (3)*	7 (2)**	16 (5)**	36 (4)**	24 (5)**
A-301	52 (7)	65 (6)	58 (5)	1 (0)	2 (0)	7 (4)	9 (3)

* Significant at the 0.05 level.
** Significant at the 0.01 level.
† Seed rate had no significant effect on light interception in 1996 according to ANOVA. In 1997, there was significant seed rate × cultivar interaction. Data were reanalyzed using ANOVA to compare cultivars at each seed rate.
‡ DAS, days after sampling.
§ Standard error of the means are enclosed in parentheses.

Cultivars that are more competitive might improve watergrass suppression even at currently recommended herbicide rates. M-202 suppressed watergrass weight more than A-301 at the recommended propanil rate, and differences in watergrass suppression were detected between cultivars even when watergrass weight was not great enough to cause yield losses. Weeds that escape control despite herbicide application or because weed densities did not reach an economic threshold for treatment (Coble and Mortensen, 1992) can contribute seed that reduces yields in subsequent years (Cousens, 1987). Competitive cultivars that reduce the seed production of weeds beyond levels achieved by herbicides alone may provide a cost-effective method for reducing inputs to the soil seed bank. Finally, if resistant watergrass biotypes are less fit than susceptible plants, competitive cultivars may reduce the proportion of resistant plants in the population. Maxwell et al. (1990) simulated the importance of competitive ability in reducing the proportion of resistant plants in a population following the suspension of a herbicide. When the competitive ability of the crop was increased along with the proportion of susceptible biotypes, fewer resistant plants were present after the recovery period. Decreasing the proportion of resistant plants in a population is critical if the herbicide to which the plants are resistant is to be brought back into rotation.

Developing rice cultivars to improve weed suppression will require the identification of traits or suites of traits that are related to competitive ability. While differences between two cultivars are not sufficient to draw inferences regarding the relative importance of particular rice traits, M-202 and A-301 differed substantially in their expression of traits related to light capture. M-202 was taller, had greater leaf weight, and intercepted more light early in the season than A-301. Competitive ability in rice is often associated with traits that are related to light capture (Khush, 1996). Plant height can be highly correlated with the competitive ability (Jennings and Aquino, 1968) but is not always important. For example, Fischer et al. (1997) found that leaf area index and tiller production were the key traits associated with rice competitiveness, not plant height. Garrity et al. (1992) found a strong correlation between height and competitive ability but also reported that cultivars of the same height differed in weed suppression by as much as 2 t ha^{-1}. On the other hand, Kawano et al. (1974) associated the plant height and leaf area with competitive ability while tillering ability was unimportant. Johnson et al. (1998) reported that their most competitive cultivar had a larger leaf weight, a higher specific leaf area, and earlier tiller production than less competitive cultivars.

In studies contrasting widely different rice plant types, a low yield potential was correlated with greater intraspecific shading, premature leaf senescence, and higher respiratory rates found in the more competitive types (Tanaka et al., 1966, p. 46; Jennings and Herrera, 1968; Jennings and de Jesus, 1968; Jennings and Aquino, 1968). Yields in our study were greater for the more competitive cultivar under both weedy and weed-free conditions. While two cultivars are insufficient to determine the exact relationship between competitive traits and yield in water-seeded rice, there was no evidence of a tradeoff between competitive ability and yield in our study. Within a fairly narrow range of plant types, differences in competitive ability may exist without substantial differences in yield. For example, Garrity et al. (1992) concluded that high-yielding but competitive cultivars of intermediate height could be developed in tropical rice production. Fischer et al. (1997) suggested that high-tillering but short-statured cultivars would improve weed suppression in Latin American rice without compromising yields.

It should be noted that, in this study and in those cited above, root growth and competition for nutrients were not determined. Several studies (Gibson et al., 1999; Perera et al., 1992; Assemat et al., 1981) have suggested that root competition plays a major role in the interaction between rice and *Echinochloa* spp. Gibson et al. (1999) found that the primary mechanism by which water-seeded rice reduced watergrass growth was through competition for N. Rice cultivars can differ in root growth and morphology (Slaton et al., 1990) and nutrient uptake rates (Teo et al., 1995). The relationship between root growth, competitive ability, and rice yields deserves more attention.

Differences in suppressive ability between M-202 and A-301 were more important than the effect of rice seed rate. There was no effect of rice seed rate on watergrass weight or tillering in either year of this study. Likewise, Yamagishi et al. (1978) found no reduction in barnyardgrass as rice density increased although Moody et al. (1983) reported improved weed control in transplanted and dry-seeded rice with higher crop plant densities. It has been suggested that optimal grain yields can be reached in direct-seeded rice using seed rates from 50 to 169 kg ha^{-1} (Wells and Faw, 1978; Huey, 1984; Jones and Snyder, 1987). Our seed rates fell within this range, and we saw no evidence of reduced yields at lower seed rates. The seed rates of water-seeded rice are already relatively high; higher rates might increase the risk of yield depressions due to intraspecific competition, lodging, or disease (Bayer and Hill, 1992). Increasing the competitive ability of rice cultivars seems more likely to improve watergrass control than manipulating the seed rates of water-seeded rice.

This study suggests that the development and use of more competitive cultivars might improve watergrass control, reduce herbicide inputs, and provide an additional tool to slow the development of herbicide-resistant weeds in water-seeded rice.

ACKNOWLEDGMENTS

We thank the personnel of the Rice Experiment Station for their cooperation and advice. The project was funded by the Rice Research Board and the California Statewide Integrated Pest Management Program. The authors are also grateful to two anonymous reviewers and to Associate Editor Dr. Paul Counce, whose comments improved the presentation of this paper.

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