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Author(s): Barney P. Caton, Theodore C. Foin and James E. Hill

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Mechanisms of competition for light between rice (*Oryza sativa*) and redstem (*Ammannia* spp.)

Barney P. Caton

Corresponding author. Department of Environmental Studies, University of California, Davis, CA 95616

Theodore C. Foin

Department of Environmental Studies, University of California, Davis, CA 95616

James E. Hill

Department of Agronomy, University of California, Davis, CA 95616

Redstem is an important weed in California water-seeded rice fields because of its aquatic habit, wide distribution, interference with harvest, and resistance to the herbicide bensulfuron. Our objective was to understand the mechanisms of competition for light between rice and redstem, with the goal of improving redstem control. A replicated greenhouse experiment was done in 1993 and 1994. Rice was water-seeded at a rate of 400 seeds m^{-2} , and redstem was seeded simultaneously at approximate densities of 0, 50, and 100 seeds m^{-2} in continuously flooded 0.77 m^2 basins. Plants were harvested once at final harvest in 1993 and twice in 1994, with an additional nondestructive sampling 34 days after seeding (DAS). Despite slower early growth, redstem height exceeded rice height about 45 DAS. At the midseason harvest in 1994 (56 DAS), no effects of redstem competition on any rice response variables were detected. However, at final harvest (110 and 118 DAS, 1993 and 1994, respectively) redstem competition at both treatment densities reduced rice tiller density, panicle density, shoot drymass, and grain drymass. Redstem competition reduced rice growth only after penetrating the canopy. Shade cast by redstem through rice maturity decreased shoot and grain production and increased tiller mortality. Lodging caused by redstem further affected rice growth. Season-long competition from redstem at mean densities of 67 and 110 plants m^{-2} reduced rough rice yields 31 and 39%, respectively, making redstem the most competitive broadleaved rice weed yet studied. Improved understanding of rice–redstem interactions indicates that using alternative herbicides to bensulfuron is unlikely to increase yield losses to redstem, and that control may be improved by increasing rice plant densities or slightly delaying early season chemical control. Because these strategies are mechanistic, they may also be useful for controlling other rice weeds with growth patterns similar to redstem.

Nomenclature: Bensulfuron, 2-[[[(4,6-dimethoxy-2-pyrimidinyl)amino]carbonyl]amino]sulfonyl]methyl]benzoic acid; redstem, *Ammannia coccinea* Rottb. AMMCO and *A. auriculata* Wild. AMMAU; rice, *Oryza sativa* L. M202.

Key words: Competitive ability, crop–weed competition, integrated weed management, tillering, weed biology, AMMCO, AMMAU.

Weeds are the most serious pests in U.S. rice culture (Hill et al. 1994), and much research on rice–weed competition has been done in the last few decades. However, Hill et al. (1994) listed the following as needs in temperate rice weed management: better understanding of weed biology, investigation of the management benefits of different cropping systems, and improved weed control programs for managing herbicide resistance. Research has shown the seriousness of weed competition in rice but so far has had a limited impact on weed management programs. This may be generally true for most crops (Norris 1992). The two main reasons cited for this are that competition experiments have not provided basic knowledge about weed biology or a detailed mechanistic understanding of plant interactions.

These problems may be addressed by focusing empirical research on the identification of competitive mechanisms (Norris 1992; Kropff 1993b). Rather than simply measuring the impact of a weed on a crop, this approach attempts to identify how weeds affect growth and yield through a number of potential mechanisms. Research with representative weed species or types may help identify all important mechanisms and also the biological determinants of competitive ability. This understanding then allows the development of

models that extend the analysis to other weeds and allow evaluation of weed control strategies (Doyle 1991; Firbank and Watkinson 1986; Kropff 1993a).

Controlling resistant weeds is an increasing concern among California rice growers. *Ammannia* spp. are two co-existing species of obligate aquatic weeds in California, *A. coccinea* and *A. auriculata* (Graham 1979). They are not ecologically distinct (Bayer and Hill 1992), so we use a single common name, redstem, for them in this paper. Redstem is important because it is the second most widely distributed weed in California rice fields (Barrett and Seaman 1980). Many redstem populations are resistant to bensulfuron, the most popular herbicide for broadleaved and sedge weeds in California (Pappas-Fader et al. 1993). Redstem is thought to penetrate rice canopies later in the growing season, interfere with harvest operations, and reduce rice yield and quality (Bayer and Hill 1992). Redstem also often lodges rice because it is top-heavy and prone to lodge (Caton et al. 1996). Lodging may reduce grain filling and increase required harvest time.

We chose redstem for competition research because of its potentially serious impact on rice. Our objective was to understand the mechanisms of competition between water-

seeded rice and redstem. Here we report the results of experiments in which redstem was grown at varying densities in rice (cv. M202). We focus on aboveground processes because redstem growth in rice is very dependent on light capture (Caton et al. 1996). We compare these results with earlier research on water-seeded rice growth in monoculture (Miller et al. 1991) and develop a general description of rice and redstem competitive interactions. Finally, we discuss the implications of this research for managing redstem and similar weeds in water-seeded rice.

Materials and Methods

Plant Material and Culture

Redstem seeds were collected in 1992 from mature plants near the Rice Experiment Station at Biggs, CA. Additive competition experiments with redstem in rice were conducted in a University of California at Davis greenhouse in 1993 and 1994. The experiments were seeded on May 28, 1993, and June 22, 1994. A high-yielding, early-maturing rice cultivar, M202, was hand-seeded at a constant density of 400 seeds m^{-2} . Redstem was seeded at treatment densities of 0 (control), and approximately 50 or 100 seeds m^{-2} , using a dropper because of the small seed size. All seeds were soaked in water for 48 h before seeding. Plants were grown in 0.77 m^2 basins filled with approximately 0.25 m^3 of Capay silty clay soil. Nitrogen was hand-incorporated before flooding at 110 kg N ha^{-1} . The basins were continuously flooded with 5 to 10 cm of water. Volunteer weeds were removed by hand, and small amounts of copper sulfate were used to control algae the 1st month. High and low temperatures were recorded daily. In 1994, but not in 1993, we noted whether or not plots had lodged about 1 mo before maturity. Lodging was judged to have occurred when 50% of the rice tillers were bent nearly to the water surface. No monoculture plots lodged in either year.

Experimental Design and Sampling

Both experiments were randomized complete block designs, with 1 treatment replicate harvested from each of 4 blocks. Plots were sampled once in 1993 and 3 times in 1994. Five randomly selected plants of each species were nondestructively sampled 34 days after seeding (DAS) in 1994. Plant heights and leaf or tiller number were measured for redstem and rice plants. Plants were also harvested 56 DAS (August 17) in 1994, soon after maximum tillering. The midseason harvest in 1994 had only 3 blocks because 2 plots failed. No midseason harvest was made in 1993. Final harvests in 1993 and 1994 were made after rice maturity, 110 DAS (September 15) and 118 DAS (October 18), respectively.

At each harvest, 0.33 m^2 quadrats were sampled by pulling up whole plants. Samples were kept in cold storage (4 C) during processing. For each species, the number of plants, and tillers or branches were counted. A random subsample of ten (1994) or twenty (1993) plant heights were measured for both species. For the redstem subsample, internode lengths and the number of leaves and branches were also measured. The leaf areas of the redstem subsample were measured with a Delta T "MK2" scanner in 1993. Leaf areas of the 1994 redstem subsamples were determined from

linear regression of leaf area on leaf drymass, using data from previous experiments (Caton et al. 1996; $r^2 = 98.5$ and 94.9% for midseason and final harvests, respectively). Rice panicle density (final harvest only) was determined in 1993 from the rice subsample. In 1994, panicles of the whole sample were counted. Samples were separated by species, dried to constant mass at 60 C, and weighed. Rice grain was subsequently separated by hand, redried, and weighed.

Degree days (C d) were used to standardize rice and weed growth across years. Degree days were calculated¹ using the single triangle method, with a baseline of 10 C, upper limit of 35 C, and a vertical cutoff.

Data Analysis

Data were analyzed by ANOVA across years as a randomized complete block design, with blocks, treatments, years, and the year by treatment interaction as main factors (Little and Hills 1978). When possible, data homogeneity and normality were tested with Bartlett's test and the Anderson-Darling normality test, respectively (Neter et al. 1990). Otherwise, ANOVA residuals were used diagnostically. When \log_e -transformations did not solve heterogeneity or non-normality problems, the untransformed data were analyzed with the Kruskal-Wallis nonparametric test (e.g., most comparisons between the two species) (Neter et al. 1990).

Multiple regression analysis was done by forward addition of independent or indicator variables (Neter et al. 1990). We identified potentially useful variables by best subsets regression. At each step, the full (variable added) and reduced (without variable) models were compared by F-test. After analyzing the residuals for appropriateness, significant variables were retained. When necessary, we transformed data for linear regression. Standard (informal) diagnostics were used to check for correlations between independent variables (i.e. multicollinearity) (Neter et al. 1990). Reported values for r^2 are adjusted values.

Results and Discussion

Mean low and high greenhouse temperatures were 16.9 C and 33.4 C in 1993, and 15.61 C and 33.8 C in 1994. Degree days accumulated were 793 C d at the midseason harvest in 1994, and 1,635 and 1,724 C d at final harvests in 1993 and 1994, respectively. The degree day value for M202 maturity is 1,434 C d.²

Stand Establishment

Mean treatment rice plant densities (Table 1) were all within the optimal production limits for water-seeded rice of 222 to 451 plants m^{-2} (Miller et al. 1991). No treatment effect on rice plant density was detected 56 DAS in 1994 ($P > 0.50$), but redstem competition had a marginal effect over both years at final harvest ($P = 0.082$). Final densities also varied between years ($P < 0.001$). A competitive effect was apparent only in 1993. Mean final redstem plant densities were also different between years ($P < 0.001$), and, like rice, were higher in 1993 than in 1994 (Table 1).

Because seeding rates were constant in both years, variation in rice densities suggests that environment affected germination and establishment. Higher establishment in 1993 was probably due to warmer early season temperatures

TABLE 1. Summaries by year and treatment of final plant, tiller, and panicle densities of water-seeded rice and redstem (*Ammannia* spp.) final plant densities^a grown in competition.

Weed density	Density											
	Rice						Redstem					
	Plant			Tiller			Panicle			Plant		
	1993	1994	Mean	1993	1994	Mean	1993	1994	Mean	1993	1994	Mean
	# m ⁻²											
None	342	236	289	650	636	643	650	608	629	—	—	—
Low	327	227	277	608	531	570	570	522	546	81	54	65
High	261	236	248	517	502	509	493	496	494	128	91	110

^a Dashes indicate none present.

(data not shown). Environmental variation is expected, but this result contrasts with earlier experiments in which rice establishment was simply a linear function of seeding rates (Miller et al. 1991).

Plant Heights

Redstem plant height developed more slowly than rice height (Figure 1), which agreed with earlier pot competition experiments (Caton et al. 1996). In 1994, rice was taller than redstem 34 DAS, but shorter than redstem by 56 DAS (both $P < 0.001$). Over both years, redstem height was much greater than rice height at final harvest ($P < 0.001$). Redstem penetrates the rice canopy later than some other tall rice weeds. This is ecologically important because it helps explain the timing of redstem effects on rice growth.

Biomass Development

Rice Biomass

Redstem competition did not reduce rice shoot drymass (DM) (g m^{-2}) at mid-season in 1994 ($P > 0.20$), but it

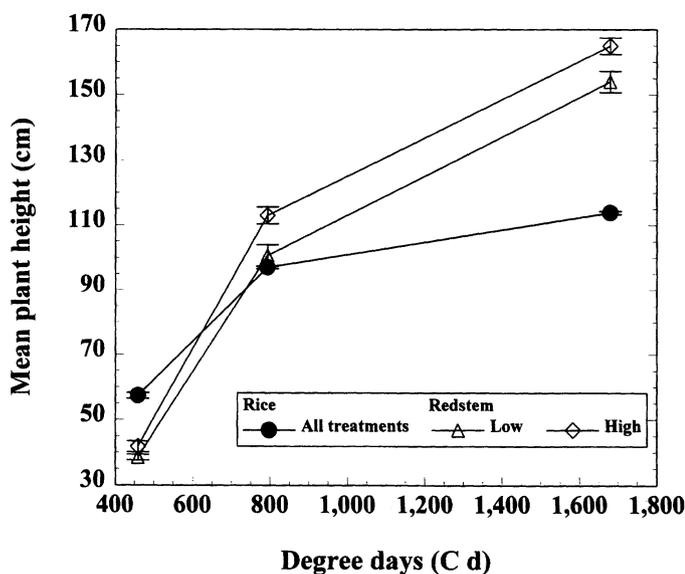


FIGURE 1. Development of rice and redstem (*Ammannia* spp.) plant height (cm). Rice height (●) is the mean over all treatments; redstem heights (open symbols) are treatment means. Bars show mean standard errors. Means for the final harvest are from the 1993 and 1994 experiments; means at mid-season dates are from the 1994 experiments only.

did reduce final rice shoot DM in both years ($P < 0.001$) (Table 2). This suggests that competition was not severe until after redstem grew taller than rice. No effect on rice straw DM was detected ($P > 0.13$), suggesting that grain DM was most affected (see below). Tiller density was x^2 -transformed in the equations for rice shoot DM:

$$(1993) \text{ DM}_R = 899 + 0.00216 \times (D_T)^2 - 136 \times L_W \quad [1]$$

$$(1994) \text{ DM}_R = 899 + 0.00282 \times (D_T)^2 - 136 \times L_W \quad [2]$$

where DM_R is rice shoot DM, D_T = rice tiller density, and L_W is redstem leaf area per plant (cm^2) ($r^2 = 79.8$; $P < 0.03$ for all variables). From Equations 1 and 2, rice shoot DM was higher in 1994, all else being equal. This was found despite no difference between years having been detected by ANOVA ($P > 0.47$), probably because of yearly differences in the relationship between tiller density and shoot DM.

Redstem Biomass

As expected, total redstem shoot DM (g m^{-2}) varied by treatment at every harvest ($P < 0.03$ for both) (Table 2). No difference was detected between years ($P > 0.12$), despite higher densities in 1993. The equation for final redstem shoot DM is as follows:

$$\text{DM}_W = 178 + 2.87 \times D_W + 1.34 \times L_W - 0.531 \times D_T \quad [3]$$

where DM_W is redstem shoot DM, D_W is redstem plant density ($\# \text{ m}^{-2}$), L_W is redstem leaf area per plant (cm^2), and D_T is rice tiller density ($\# \text{ m}^{-2}$) ($r^2 = 63.2\%$; $P < 0.002$ for all variables). The term for rice tiller density is important because it shows that rice suppressed redstem growth.

Rice Tiller Dynamics

Understanding weed competition effects on rice tiller density ($\# \text{ m}^{-2}$) and tillers per plant is crucial, because tillers are the most important yield component in water-seeded rice (Breen 1995; Miller et al. 1991).

Stand-level Dynamics

As with rice biomass, redstem competition did not reduce rice tiller density at midseason in 1994 ($P > 0.27$) but did

TABLE 2. Main effects summaries for plant drymass components^a of water-seeded rice and redstem (*Ammannia* spp.) at maturity when grown in competition.

Weed density	Drymass											
	Rice						Redstem					
	Shoot ^b			Grain ^c			Shoot			Leaf ^d		
	1993	1994	Mean	1993	1994	Mean	1993	1994	Mean	1993	1994	Mean
None	1,858	2,008	1,933	683	931	807	—	—	—	—	—	—
Low	1,567	1,467	1,517	538	576	557	254	442	348	71	84	77
High	1,294	1,540	1,417	416	567	491	532	524	528	147	122	134

^a Dashes indicate none present.

^b Total aboveground drymass.

^c Rough rice drymass.

^d Calculated as (mean leaf drymass of redstem subsamples) × (plant density).

reduce tiller density at the final harvest in both years ($P < 0.05$). Thus, redstem competition did not affect rice tiller formation but did increase tiller mortality. This further supports the idea that competitive effects became more severe after redstem grew taller than rice. Three equations describe final tiller density:

$$(1993) D_T = 372 + 0.825 \times D_R - 0.13 \times DM_W \quad [4]$$

$$(1994 \text{ unlodged}) D_T = 372 + 1.17 \times D_R - 0.13 \times DM_W \quad [5]$$

$$(1994 \text{ lodged}) D_T = 372 + 1.17 \times D_R - 0.416 \times DM_W \quad [6]$$

where D_T is rice tiller density ($\# \text{ m}^{-2}$), D_R is rice plant density ($\# \text{ m}^{-2}$), and DM_W is redstem shoot DM (g m^{-2})

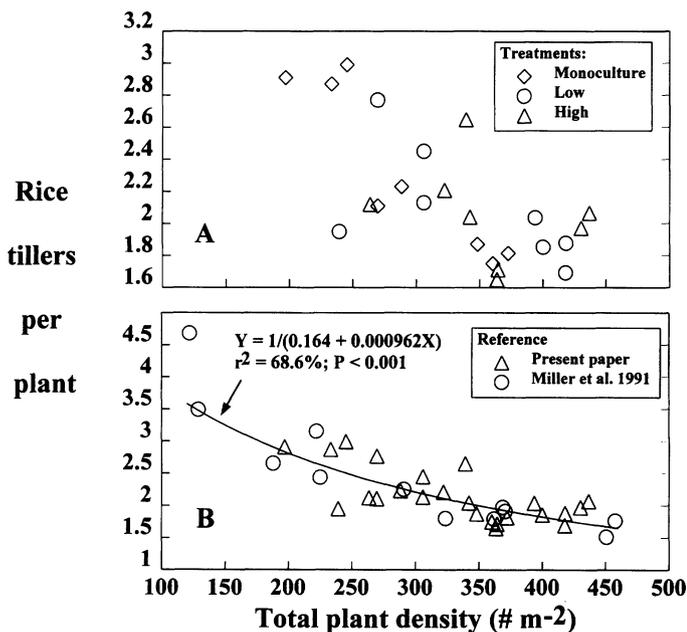


FIGURE 2. The response of rice tillers per plant to total plant density for (A) 1993 and 1994 competition experiments, and (B) 1993 and 1994 experiments plus the monoculture data from Miller et al. 1991. Symbols are plot values, except that data from Miller et al. 1991 are means for treatments and years.

($r^2 = 73.4\%$; $P < 0.002$ for all variables). It is unclear why redstem shoot DM was a better predictor than a more direct measure of shading ability, such as leaf DM or leaf area. Regardless, tiller losses were clearly mitigated by higher rice plant densities.

Plant-level Dynamics

No treatment effects on rice tillers per plant were detected at either mid-season ($P > 0.97$) or final harvest ($P > 0.24$). This may be because rice plant densities in control plots nearly overlapped total plant densities in the weed treatments (Figure 2a). The number of rice tillers per plant was clearly affected by redstem density through total plant density, and also by lodging:

$$(\text{Unlodged}) N = 3.79 - 0.00471 \times D_{TOT} \quad [7]$$

$$(\text{Lodged}) N = 3.35 - 0.00471 \times D_{TOT} \quad [8]$$

where N is tillers per plant and D_{TOT} is total plant density ($r^2 = 60.9\%$; $P < 0.006$ for both variables). Higher mean tillers per plant in 1994 than in 1993 ($P < 0.005$) corresponded with lower total plant densities.

The dynamics of final rice tillers per plant in this study and in the Miller et al. (1991) study agreed strongly, but over a wider range the function is best described as the negative hyperbola:

$$N = 1/(0.164 + 0.000962 \times D_{TOT}) \quad [9]$$

where N is rice tillers per plant and D_{TOT} is total plant density ($\# \text{ m}^{-2}$) (Figure 2b). In our experiments, the final number of tillers per plant was more variable, but this may have been due to lodging, which never occurred in monoculture treatments.

Implications of Observed Tiller Dynamics

Equation 9 gives a minimum of about 1.6 tillers per plant at maturity at the highest optimum rice plant density (Figure 2b). This could be important for weed management because it suggests that adding a single rice plant produces more than 1 tiller at high stand densities. Thus, higher plant densities could mitigate tiller and yield loss while increasing crop interference (Equation 3). A minimum of 1.6 tillers per plant also helps explain why rice yield loss is not complete even when rice is grown with high densities of very competitive weed species (Hill et al. 1989; Smith 1988).

TABLE 3. Rice yield reduction^a by broadleaved weeds.

Weed species	Common name	Computer code	Competitive yield loss
<i>Ammannia</i> spp. ^b	Redstem, purple ammannia	AMMCO/AU	39%
<i>Heteranthera limosa</i> ^c	Ducksalad	HETLI	21%
<i>Sesbania exaltata</i> ^c	Hemp sesbania	SEBEX	19%
<i>Commelina diffusa</i> ^c	Dayflower	COMDI	18%
<i>Aeschynomene virginica</i> ^c	Northern jointvetch	AESVI	17%
<i>Eclipta alba</i> ^c	Eclipta	ECLAL	10%
<i>Sagittaria montevidensis</i> ^d	California arrowhead	SAGMO	0%
<i>Monochoria vaginalis</i> ^d	Monochoria	MOOVA	0%

^a Results of season-long competition experiments with optimum rice densities and high weed densities.

^b Present paper.

^c Smith 1988.

^d Breen 1995.

These results agree with Miller et al. (1991), except with their conclusion, “. . . the rice crop functioned more as a population of tillers than a population of plants.” While tillering plasticity appears to compensate for lower plant establishment (Figure 2b), this is more correctly attributed to individual plant responses (Harper 1964). Comparison of the studies confirms that in competition, tiller density depended more on rice plant density (Miller et al. 1991).

Rice Panicles

Over both years, redstem competition reduced rice panicle density ($P < 0.052$) (Table 1). No difference in fertility (percentage of final tillers with panicles) due to treatments was detected ($P > 0.88$). The competitive effects of redstem on major rice yield components seem mostly due to reductions in tiller density, but other yield components were not measured.

Rice Grain

Rice grain DM (g m^{-2}) was reduced by redstem competition over both years ($P < 0.001$) (Table 2). As with rice shoot DM, grain DM was higher in 1994 than in 1993 ($P < 0.03$). The equations for rice grain DM are as follows:

$$(1993) \text{ DM}_G = 78 + 0.94 \times D_P - 0.68 \times L_W \quad [10]$$

$$(1994) \text{ DM}_G = 78 + 1.37 \times D_P - 0.68 \times L_W \quad [11]$$

where DM_G is rice grain DM (g m^{-2}), D_P is rice panicle density ($\# \text{ m}^{-2}$), and L_W is redstem leaf area per plant (cm^2) ($r^2 = 84.0\%$; $P < 0.001$ for all variables). Lodging was a marginally useful variable (not shown, $P < 0.06$), reducing rice grain DM by about 110 g m^{-2} , all else being equal.

Adjusted to 14% moisture, mean rough rice yields were 9,200, 6,350, and 5,600 kg ha^{-1} in the monoculture, low, and high redstem density treatments, respectively. Low and high density redstem competition reduced rice yields by 31 and 39%, respectively. Rough rice yields in monoculture were fairly typical for California rice culture, which average nearly $8,000 \text{ kg ha}^{-1}$, the highest regional yields in the world (Hill et al. 1991).

Relative Rice Yield Reduction by Redstem

Redstem competition caused severe rice yield losses, but they were less than losses caused by the most important grass

weeds (e.g., 80% by watergrasses, *Echinochloa oryzoides* and *E. phyllopogon*) (LeStrange 1981; Smith 1988). Nevertheless, at high densities, redstem reduced rice yields much more than other broadleaved weeds (Table 3), making it the most competitive broadleaved weed yet studied. Redstem competitive ability may be related to its height, since most of the other broadleaved weeds studied are shorter than semi-dwarf rice varieties.

Description of Competition for Light Between Rice and Redstem

Given conditions of simultaneous seeding, typical fertility rates, and continuous flooding, describing the sequence of important events mediating competitive interactions between rice and redstem is possible. Rice initially grew taller than redstem, but redstem elongated and penetrated the rice canopy before the stage of maximum tillering. Before this, redstem did not affect rice production or tillering, but after this redstem plants reinitiated branching, which produced large amounts of leaf area above the rice canopy (Caton et al. 1996). Shading subsequently reduced rice production and increased plant and tiller mortality. The top-heavy morphology of redstem also caused lodging late in the season, which further reduced rice growth and yield.

Rice tillering also responds to light quality (Barnes et al. 1993), but this response has been hypothesized to affect early season allocation patterns (Ballaré 1994; Sánchez et al. 1993). Because no early reductions in tiller density or number per plant were detected, this suggests redstem did not affect canopy light quality early in the season.

Nutrient competition could also have contributed to decreased rice production and increased tiller mortality, but evidence suggests this was probably minor. Redstem allocation in rice competition greatly favors shoot growth over root growth, suggesting that light capture is more important than nutrient capture (Caton et al. 1996). This response probably minimizes the ability of redstem to capture soil nutrients and also the effects of nutrient competition on rice. Therefore, although some nutrient competition undoubtedly occurred, competition for light probably explains most of the interactions between rice and redstem.

Redstem Management

Understanding the mechanisms of redstem competition for light in rice allows management recommendations and

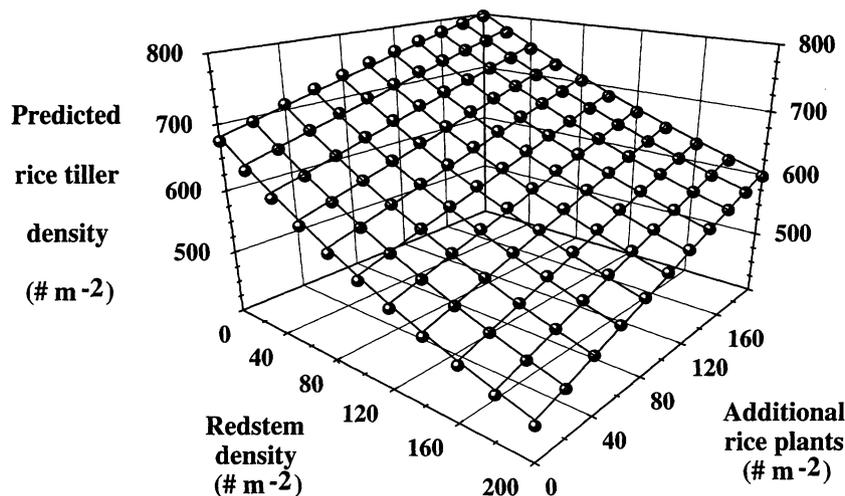


FIGURE 3. Predicted rice tiller densities with additional plant establishment across redstem (*Ammannia* spp.) densities. The baseline rice density is 230 plants m^{-2} . Values were calculated by multiplying total rice plant density by rice tillers per plant. Rice tillers per plant were computed from the equation $Y = 1/(0.164 + 0.000962 \times D_T)$, where D_T is total plant density ($\# m^{-2}$) (Equation 9 in text).

suggests control strategies. We are testing some of the following ideas with field and modelling experiments.

The primary cultural control strategy suggested is increasing rice plant density to higher optimum levels, e.g., 350 to 450 plants m^{-2} . This may have two positive effects. First, increasing rice plant densities should mitigate tiller loss (Equations 4 to 6). Second, increasing tiller density should increase crop interference (Equation 3). The effect of increased rice plant densities on tiller density is shown graphically in Figure 3. Using mean rice plant density in 1994, 230 plants m^{-2} , as a baseline value, we calculated the effect of increased rice or redstem plant density on tillers per plant with Equation 9. This value was multiplied by rice plant density to find tiller density. Notably, at redstem densities as high as 100 plants m^{-2} , the recommended tiller density of 700 tillers m^{-2} (Miller et al. 1991) could be achieved with an increase of 200 rice plants m^{-2} (Figure 3). This total of 430 rice plants m^{-2} might result from a rate of 800 seeds m^{-2} (ca. 210 kg ha^{-1}) (Miller et al. 1991), or perhaps less if early temperatures were warm (see above). Higher rice plant establishment would clearly reduce tiller losses to redstem competition, but it might have some negative effects. For example, higher rice plant densities may be correlated with increased rates of disease (J. F. Williams, personal communication). Potential losses to disease and competition should both be considered in decisions about seeding densities.

This research also allows evaluation of alternative chemical control strategies for resistant redstem populations. Widespread bensulfuron resistance has required some growers to use other broadleaved weed herbicides, such as MCPA [(4-chloro-2-methylphenoxy)acetic acid] or 2,4-D [(2,4-dichlorophenoxy)acetic acid]. However, late application (35 DAS or more) is a perceived disadvantage of MCPA and 2,4-D (Bayer and Hill 1992). Given that redstem has no emergence advantage over rice, these results show that waiting 35 DAS for application is unlikely to result in redstem competitive losses.

The slow growth of redstem also suggests that chemical control for non-resistant populations be delayed. Many growers apply bensulfuron very early, often within 1 wk of

planting, but it may be effective up to 30 DAS (Bayer and Hill 1992). A short delay might increase redstem control: when redstem emerges 2 wk after rice, it is so disadvantaged that it cannot penetrate the canopy (unpublished data). Thus, delaying herbicide application 1 wk or more may enable the rice canopy to completely suppress postherbicide redstem growth. Given an appropriate field situation, this could maximize crop interference and reduce the number of herbicide applications needed for acceptable redstem control.

These management strategies are based on competitive mechanisms, so they may be useful for other weeds with growth similar to redstem. This research suggests that redstem belongs to a class of rice weeds that grow taller than rice near or after the stage of maximum tillering. Smith (1988) similarly described the following weeds: eclipta (*Eclipta prostrata* L.), hemp sesbania (*Sesbania exaltata* A.W. Hill), northern jointvetch (*Aeschynomene virginica* B.S.P.), and spreading dayflower (*Commelina diffusa* Burm. f.). Notably, they are all broadleaved weeds. The grass weed red rice (*Oryza sativa* L.) was also in this group, but it seems different because it reduced rice yields before maximum tillering (Smith 1988). Because these broadleaved weeds have growth similar to that of redstem, they may affect rice growth by the same mechanisms and may also be susceptible to the same control strategies (e.g., increased plant densities and delayed herbicide treatments).

Sources of Materials

¹ Degree Day Utility version 2.0, U.C. Statewide Integrated Pest Management Project, University of California, Davis, CA 95616-8621.

² CALEX/Rice program, Software Distribution, Statewide Integrated Pest Management Project, University of California, Davis, CA 95616-8621.

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