Mixed weed infestations: Prediction of crop losses for economic weed management in rice

(Keywords: competition, weed mixtures, rice, thresholds)

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Abstract. Weed control in Latin America is costly and heavily dependent upon herbicides. Often irrigated rice farmers spray herbicides in late post-emergence at 30 to 44 days after emergence (d.a.e.). The economic benefits from such late applications are often unclear. Two experimental approaches involving density series of *Eclipta alba, Leptochloa filiformis, Eleusine indica,* a 1:1 mixture of *Echinochloa colona* and *E. crusgalli*, and a range of rice densities were used to estimate crop losses for late weed infestations, and the benefit of increasing rice densities to reduce weed competition. The experiments were conducted in Colombia, and current values of rice and farming inputs were used for economic analysis. With farmers obtaining average yields (5600 kg/ha) only weed densities larger than about 20 plants/m^2 would justify herbicide applications after 30 d.a.e. Opportunities to reduce herbicide use are even greater in low-yielding farms (3500 kg/ha), where

herbicides would pay off only at weed densities larger than about 30 plants/m^2. Handweeding could be an alternative to herbicide use at weed densities higher than about 25 plants/m^2. Using high rice densities, providing large numbers of tillers/m^2, was economical even at large weed infestations (> 100 plants/m^2). Omitting the late post-emergence herbicide application would reduce weed control costs in Colombia by 28%.

1. Introduction

Knowledge of the effect of weed densities on crop yields has been used to establish economic thresholds for weed management (Smith, 1988; Coble, 1986). If the value of the losses predicted for a given weed density is lower than the cost of their control, then use of thresholds would leave weeds uncontrolled or would search for a cheaper control measure. Thus, crop loss predictions allow for the selection and integration of weed management practices. Most weed infestations consist of mixtures of several species. An experimental approach to predict crop losses by weed interference should consider the interactions within mixtures of different weed species present at diverse densities and proportions (Roush et al. 1989).

Application of post-emergent herbicide mixtures 30 to 44 days after rice emergence (d.a.e.) is common among irrigated rice farmers in Colombia and other Latin American regions, where weed control is heavily dependent on herbicides and represents one of the costliest inputs. Often irrigated rice fields cannot be permanently flooded with a continuous weed-suppressive water film due to inadequate field levelling and/or water availability. Rice under such conditions demands a weed-free period of about 70 to 80 d.a.e., for optimum yields if weed infestations are heavy (Fischer, et al. 1992). However, the need for late herbicide applications at lower weed densities still needs to be justified. Wilkerson et al. (1991) have estimated the combined effects of multi-species weed complexes by ranking weed species according to their degree of competitiveness against a given crop. Knowing the relative competitiveness of each weed, and based on the number of plants per unit area of each weed species, a total competitive load was calculated. Yield loss was then regressed against this total competitive load. Multiple regression analysis has also been used to study competition by mixed weed stands (Johnson, III and Coble, 1981).

Farmers frequently use high seeding rates (300 kg seed/ha or more) to reduce weed competition. The contribution of this practice to the economics of weed control in rice needs to be established. Competition experiments, if conducted for several crop densities, should also serve to evaluate the economic feasibility of increasing crop densities as a weed management option.

The objective of this research was to establish the economic convenience of late post-emergent herbicide applications, handweeding, or high crop densities to manage weeds in irrigated rice using two different approaches for predicting losses that result from multi-specific weed infestations.

2. Materials and methods

Experiments were conducted in the field at CIAT, Colombia with the semi-dwarf rice cultivar Oryzica 1. The soil was clay in texture with 3.5% organic matter, 40 ppm P, 0.7 meq K/100 g, CEC = 25 meq/100 g, and pH 8. A flush of irrigation was provided twice a week to briefly flood the field, allowing the water to infiltrate. A permanent water film was not maintained. Yields of hulled grain (rough rice) at 14% moisture was determined at harvest. The following two experimental approaches were followed:

2.1. *Weed density series*

The objective of this experiment was to quantify the effect of late mixed-weed infestations on rice yields by first establishing the relative competitiveness of each weed growing by itself with rice. This experiment was seeded on September 1991, when rice was drilled into dry soil at the rate of 100 kg seed/ha in rows 17 cm apart. Eight d.a.e. propanil 2.0 + bentazon 1.0 kg ai/ha were sprayed, and with additional handweeding the crop was kept weed-free for 30 d.a.e. Twenty 2.8-by 3-m plots were arranged in four randomized complete blocks. As from 30 d.a.e. one of the following species was allowed to emerge and grow in each plot: *Eleusine indica* (L.) Gaertn, *Echinochloa* spp[1], *Leptochloa filiformis* (Lam.) Beauv., and *Eclipta alba* (L.) Hassk. Other emerging weed species were handweeded. Thus a late weed infestation, against which farmers usually spray, was obtained. Each set of plots with a given weed species represented a range of densities (including weed-free checks) resulting from the natural emergence of such weed. Shortly after emerging weed populations were thinned or seedlings transplanted, as needed, to ensure uniform plant distribution within each

[1]/ A mixture of similar proportions of *E. colona* Link and *E. crus-galli* (L.) Beauv.

plot. Sixty-two d.a.e. weed populations and rice tillers were counted within two 0.25 m^2 quadrats in each plot, each quadrat included sections of 3 rice rows. The experiment was fertilized with 115 kg N/ha, 60 kg P/ha, and 72 kg K/ha. For each weed species a linear regression was obtained between the number of weed plants/m^2 and the natural logarithm of rice yield (as % of the weed free check). The linear coefficient (slope) in each regression expressed the competitiveness of each species with rice. The relative competitiveness (RC) of the weeds was established dividing the coefficient of linear regression of each species by that of the most competitive species. The competitive load was defined as:

$$CL = RC \times \text{weed density (plants/m}^2\text{)},$$

and the total competitive load was:

$$TCL = \Sigma \text{ CL of each species in the mixture}$$ (Wilkerson, et al. 1991).

Current prices, and data from a survey of Colombian rice farmers conducted by CIAT[2] were used for economic analysis.

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[2]/ CIAT, 1991. Rice Program, Socieconomics, Annual Report 1991. Cali, Colombia. Pp. 202-220 (unpublished).

2.2. *Rice density series and mixed weed infestations*

In this experiment the simultaneous effects on rice yields of diverse rice seeding densities and various late-infesting weed mixtures were studied. The experiment was conducted concurrently with the one above in a similar field, and under the same conditions. A randomized complete blocks design with split-plots and four replications was used. Four rice seeding rates were assigned to the main plots (75, 150, 200, and 300 kg seed/ha). The natural emergence and growth of three weed species (*Leptochloa filiformis, Echinochloa* spp[3], and *Eleusine indica* (L.) Gaertn) was permitted in the subplots as from 30 d.a.e. Thus weeds appeared in mixtures at various densities and proportions. Single species infestations at different densities, and weed-free checks were also established. Uniformity of infestations, control of other weeds, and weed and rice tiller counts were achieved as in the previous experiment. Data were subjected to multiple regression analysis.

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[3]/ See footnote in page 5.

3. Results and discussion

3.1. *Weed density series*

The range of weed populations for each species, as evaluated 62 d.a.e., is shown in Table 1. Given its late emergence *L. filiformis* and *E. alba* posed no significant competition to rice (Figure 1). According to the regression slopes in Figure 1 RC values for *E. indica*, and *Echinochloa* spp., were 1 and 0.8, respectively. Thus a single yield loss function was obtained when weed densities in the field mixtures were expressed in terms of TCL (Figure 2). With this new function the TCL that would justify a herbicide application[4] after 30 d.a.e. can be estimated. A herbicide application was considered economically justified when the gross margin (value of potential losses - the cost of controlling them with herbicides) was positive. With an expected yield of 5600 kg/ha[5] a late herbicide application would be required to preserve rice yields only at quite high weed densities

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[4] The herbicide treatment most farmers use for late applications against grasses consists of fenoxaprop-ethyl at 0.1 kg ai/ha, followed by spot applications of paraquat (0.2), at a cost 45 US dollars/ha (CIAT, unpublished).

[5]/ See footnote in page 6.

(Table 2). A TCL = 15.6/m^2 would thus be an economic threshold for late herbicide applications in flush-irrigated rice. For similar cultural conditions the proportion of rice yield lost to weed competition tended to hold the same for different yield levels (Fischer, et al. 1992). Therefore, the sensitivity of our loss function to different yield levels was studied. Farmers in the low productivity bracket (3500 kg/ha) need higher infestations than those obtaining higher yields to justify (gross margins > 0) herbicide use (Table 2). It is thus the low input farmers who would have the best chances to reduce herbicide use. Previous studies in Colombia with a heavy weed infestation (> 200 plants/m^2), and under similar conditions, indicated that non-flood irrigated rice required a weed-free period of about 70 to 80 d.a.e. to avoid yield losses (Fischer, et al. 1992). The information presented here indicates that for chemical control, and average farm yields, this period would be considerably shorter if competitive loads after 30 d.a.e. were less than 15.6/m^2 (Table 2). Omitting the late post-emergence herbicide application would reduce weed control costs by about 28% in Colombia[6]. If weeds were hand removed at the

[6]/ Average estimated cost of herbicide applications in irrigated rice in Colombia is 159 US dollars for 3 applications at about 9, 18, and 30-44 d.a.e. (Fischer, et al. 1992).

current cost of labour (63 US dollars/ha), gross margins of weed control would be favorable only at infestations 1.5 times higher than the above economic threshold for chemical control (Table 2).

So far we have considered the use of competition information to derive economic thresholds based only on grain yields. However, there are often other reasons for controlling weeds besides preserving yields. Grain quality and avoidance of weed seed buildup in the soil (Cussans, et al. 1986) may be important reasons for conducting weed control below threshold densities. In such cases crop loss information would rather be used to compare the economic feasibility of potential weed management alternatives to be integrated in weed management programmes.

3.2. Rice densities and mixed weed infestations

Final weed populations and range of rice tillers as counted 62 d.a.e. appear in Table 1. In a multiple regression model to explain rice yields as a function of the number of rice tillers/m^2 and the densities (No. plants/m^2) of three weeds (*E. colona, L. filiformis*, and *E. indica*) only tillers and *L. filiformis* significantly ($p = 0.0001$) affected rice yields. Although not recorded, *L. filiformis* emerged somewhat earlier than the other weeds, and thus was more competitive with the crop. Maximum yields in the absence of weeds were obtained with 794 tillers/m^2, about 313 kg rice seed/ha, which is very close to the densities usually sown by farmers.

Under the conditions of this experiment a weed-free crop with 624 tillers/m^2 (a density of about 260 kg/ha) would yield 69% of the maximum yield. If such crop has an infestation of 11 *L. filiformis* plants/m^2 weed-free yields could be restored by increasing tillering by 2.6%, which would leave a favourable gross margin while herbicide use would not be economical (Table 3, Case 1). Herbicide use could be economically justified only with weed infestations of 28 plants/m^2 or higher (Table 3, Case 2). Weed-free yields could be maintained under a heavy late weed infestation by using the highest tillering obtained in this experiment (Table 3, Case 3). This could also have been achieved using herbicides, but with a less favourable gross margin (Table 3, Case 3). The value of using high rice densities to offset weed competition must be weighed against the risk of increased pest incidence (Castaño, 1985) or lodging (Vergara, 1985).

The previous experiments strongly suggest that with the high rice densities presently used by many farmers in the region, there may be good scope for reducing herbicide inputs. Only relatively high weed infestations justified herbicide use after 30 d.a.e. The experimental approaches presented also illustrate ways of generating crop loss data from mixed-weed infestation. Such information would also allow for the economic evaluation of other weed management alternatives (such as crop rotations, land preparation, land leveling, etc.), and lead to a judicious reduction in herbicide dependence whenever feasible.

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Figure 1. Yield losses when each of four annual weeds competed at various densities with rice, having emerged 30 days after the crop. For Y=yield loss as percent of the weed-free yield, and X=No. plants/m^2, regressions for each species were: E. spp., $Y=101-4.9Ln(X+1)$, $R^2=0.68$, $p<0.001$; E. indica, $Y=102-6.5Ln(X+1)$, $R^2=0.33$, $p<0.01$; E. alba, $Y=99-2.8Ln(X+1)$, $R^2=0.06$, $p>0.1$; L. filiformis, $Y=100-0.3Ln(X+1)$, $R^2=0.006$, $p>0.1$.

Figure 2. Predicted effects on rice yields of the competitive load (X) imposed by four annual weeds (Echinochloa spp, Eleusine indica, Eclipta alba, and Leptochloa filiformis) growing at various densities in mixed stands with rice expressed as percent of the weed-free yield (%Y).

Table 1. Basic statistics of weed infestations and rice tiller densities counted 62 d.a.e. in the competition experiments.

Experiment	Variable	Min.	Max.	Average	S^2	n
Weed density series		----------	(No./m^2)	---------		
	L. filiformis	0	96	29.3	1255.5	20
	E. alba	0	232	51.1	2614.2	20
	E. indica	0	240	108.1	4933.8	20
	Echinochloa spp.[1/]	0	130	48.7	1723.3	20
Rice density and mixed weed infestations						
	L. filiformis	0	144	40.3	1083.5	102[2/]
	Echinochloa spp.	0	144	47.2	1564.6	102
	E. indica	0	166	58.6	1667.6	102
	Rice tillers	136	794	434.5	23043.9	102

1/ A mixture of equal proportions of *E. crus-galli* and *E. colona*.

2/ Each plot consists of a mixture of weeds and rice stems at densities within the ranges that appear on the table.

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