한국잡초학회지
Korean J. Weed Sci. 31(3) : 289～293(2011)

DOI:dx.doi.org/10.5660/KJWS.2011.31.3.289
ISSN 0253-7468
www.kwss.or.kr

Prediction of Rice Yield and Economic Thresholds by Some Weeds-Rice Competition in Transplanted Rice Cultivation

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벼 기계이앙 재배에서 벼와 잡초 경합에 따른 벼 수량 및 요방제수준 예측

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ABSTRACT Field experiments were conducted to predict rice yield losses caused by *Echinochloa crus-galli* (L.)P. Beauv., *Bidens frondosa* L. and *Aeschynomeme indica* L. at a range of plant densities under machine transplanted rice cultivation in different regions of Korea in 2006, and to determine their economic threshold levels (ET). All data were fitted to Cousens' rectangular hyperbola to estimate parameters for predicting rice yield loss. The rice yield loss models of *Bidens frondosa* L. was predicted as y=5.43/(1+0.0113x), R^2=0.963, *A. indica* was y=5.47/(1+0.0332x), R^2=0.976 and *E. crus-galli* y= 5.43/(1+0.01552x), R^2=0.950. The mean competitivities represented by the parameter, whose reciprocal (1/β) is a weed density reducing crop yield by 50%. Those of *E. crus-galli*, *B. frondosa* and *A. indica* were 0.01552, 0.01113 and 0.0332 in normal-season machine transplanting of Korea, respectively. Single year mean economic thresholds (ET) of *A. indica* were 0.5, 0.6 and 0.7 plant m^{-2} with the application of flucetosulfuron, flucetosulfuron+imazosulfuron GR and flucetosulfuron+imazosulfuron+carfentrazone GR herbicides, respectively. Meanwhile ET values of 1.6, 1.9 and 1.9 plants m^{-2} for *B. frondosa*, 1.2, 1.4, and 1.4 plants m^{-2} for *E. crus-galli.*

Key words: economic threshold; interference; weed density.

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(Received September 6, 2011; Revised September 20, 2011; Accepted September 23, 2011)

INTRODUCTION

Since uncontrolled weeds can lead to rice yield losses as high as 80% (Smith 1983), weed control is an essential and intensive component of rice production. Accurate prediction of weed-crop interactions is required for integrated weed management (Swanton and Murphy 1996). Mathematical models that summarize the quantitative knowledge of the impact of weed competition on crop yield can provide useful information to support weed management decisions (Vandevender *et al.* 1997). Much effort has been made to develop such mathematical weed-crop interference models (Cousens 1985; Kropff and Spitters 1991), which are commonly used to quantify competitive relationships and predict yield loss. Among those models, the rectangular hyperbola based on weed density (Cousens 1985) has been most widely used to predict crop yield losses as a function of weed density in various crops, such as wheat (Kim *et al.* 2002), soybean (Cowan *et al.* 1998) and maize (Lindquist *et al.* 1996). Little effort has been made to investigate relationships of rice-weed competition, although Lindquist and Kropff (1996) introduced an ecophysiological model for irrigated rice-*Echinochloa* competition. Recently Ni *et al.* (2004) analyzed competition between wet-seeded rice and *E. crus-galli* using a response-surface model based on the rectangular hyperbola.

No study has been conducted to investigate the competition relationship between rice and paddy weeds. As some paddy weeds including *E. crus-galli* are very important in rice production, particularly in Korea and Japan, mathematical quantification and prediction of their competition impacts on rice are required for efficient weed control decision-making, from both economical and environmental viewpoints. Therefore, this study was conducted to investigate the competition relationships of *E. crus-galli*, *B. frondosa*, and *A. indica* with transplanted rice. The aims of the study were to (a) predict crop yield as a function of weed density using the rectangular hyperbola as a prediction model, and (b) determine the economic threshold levels for *E. crus-galli*, *B. frondosa*, and *A. indica* in a transplanted rice cropping system.

MATERIALS AND METHODS

Field experiments were conducted to evaluate competition effects of *E. crus-galli*, *A. indica* and *B. frondosa* on transplanted rice in major rice cropping regions in Korea. Experiments with *E. crus-galli*, *A. indica* and *B. frondosa* were conducted in Daegu and Suwon in 2006. The experiments consisted of three replicates of a completely randomized block design. The plot size was 2×2 m. Thirty-day-old-seedlings of rice (*Oryza sativa* cv. Ilmibyeo) were transplanted at a density of 23.8 hills m^{-2} (14×30 cm^2 space) equivalent to about 72 rice seedlings m^{-2} on 25 May in 2004. The densities of *E. crus-galli* and *A. indica* were 0, 1, 8, 24, 48 and 96 plants m^{-2}. The densities *of B. frondosa* were 0, 1, 8, 48, 96 and 192 plants m^{-2}. The plant densities were artificially adjusted by sowing seeds of *E. crus-galli*, *A. indica* and *B. frondosa*, with hand-weeding to remove naturally occurred background weeds.

Fertilizer was applied as a basal release with N, of 55, 67, and 225 kg ha^{-1} respectively before harrowing, followed by top-dressing of 22 kg ha^{-1} of N at the tillering stage of the rice, 10 days after transplanting (DAT), and 33 and 29 kg ha^{-1} of N and K_2O at the panicle initiation stage of the rice. To investigate competition between rice and the weeds, rice was sampled from an area of 1.0 m^2 and grain yield measured after polishing.

Rice grain yields were fitted to the following equation 1, rectangular hyperbola (Cousens 1985), to estimate parameters for predicting yields as a function of weed density.

$$Y = \frac{Y_o}{1 + \beta X} \quad [1]$$

where Y_o is weed-free rice yield (t ha^{-1}), β is a measure of weed competitivity (a weed density of 1/β reduces the rice yield by 50%) and X is weed density.

Economic thresholds (ET) of *E. crus-galli*, *A. indica* and *B. frondosa* were estimated by equating the cost of controlling these weeds with the value of rice yield gained by herbicide application. Their calculation was based on the equation developed by Cousens (1987) as follows :

$$ET = (C_h + C_a)/(Y_o PLH) \quad [2]$$

where C_h is herbicide cost (US\$ ha^{-1}), C_a is application cost (US\$ ha^{-1}), Y_o is weed free rice yield (t ha^{-1}), P is value per unit of crop (US \$ t^{-1}), L is proportional loss per unit weed density, and H is herbicide efficacy, a proportional reduction in weed density or weed biomass by the herbicide treatment. All statistical analyses were conducted using Genstat (Genstat Committee, 2002).

RESULTS AND DISCUSSION

By fitting the rectangular hyperbola (equation 1) to rice yield, weed-free rice yield (Y_o) and weed competitivity (β) of the three weeds were estimated. In competition with *E. crus-gall*, the estimated weed-free yield were 5.42 t ha^{-1} (Fig. 1) and those of competition with *A. indica* and *B. frondosa* was 5.47 and 5.43 t ha^{-1}, respectively. The competitiveness represented by the parameter, whose reciprocal (1/β) is the weed density that reduces crop yield by 50%. Those of *E. crus-galli*, *B. frondosa* and *A. indica* were 0.01552, 0.0113 and 0.0332, respectively for normal-season machine transplanting in Korea. Based on parameter estimates and equation 1, rice yield as a function of *E. crus-galli* competition was calculated (Fig. 1). There is good agreement between calculated and observed yield as *E. crus-galli* density increases, showing that competition between rice and *E. crus-galli* was described well by the hyperbolic model. Fit of the model was also good for rice in competition with *B. frondosa* and *A. indica.*

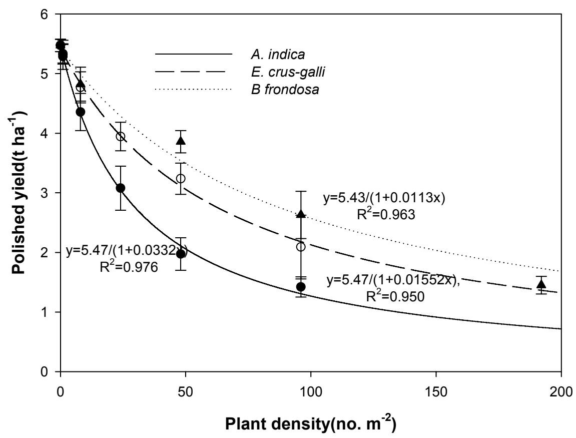

Fig. 1. Observed and predicted rice yield as a function by densities of *A. indica*, *E. crus-galli*, and *B. frondosa* in Suwon and Daegu, Korea. The predicted rice grain yield (continuous line) was calculated using equation 1.

The relationship between rice yield and the other weed density was well explained by the rectangular hyperbola. Overall, the estimated weed competitivities of other weed species in transplanted rice cultivation revealed that *A. indica* showed the greatest competitivity (0.0332) followed by *E.crus-galli* and *B. frondosa*. The results of the competitivity obtained through this experiment clearly demonstrated the differences in rice sensitivity to the presence of the main paddy weeds. It likewise showed that the amount of rice yield reduction depends on weed species densities. *A. indica* was widely distributed on soils with texture ranging from sandy loam to clay and it can be a serious weed in rice paddies (Kretschmer & Bullock 1980). This weed grow very fast when temperatures are high during the middle growth stage of rice, reaching great heights at the late growth stage of rice that could even block the incoming light from penetrating into the rice crop hence considerably reducing its expected yield.

Single year economic thresholds of *E. crus-galli*, *B. frondosa* and *A. indica* were calculated by using eqn 2 and the parameter estimates in Table 1. The herbicide price to control weeds including the application cost was estimated to be 97.3 to 123.0 US \$ ha^{-1}. The price

Table 1. Parameter estimates and economic threshold (ET) of weeds in machine transplanted rice cultivation.

Weed species	C_a(\$ ha^{-1})[1]			C_h[3] (\$ ha^{-1})	Y_o[4] (t ha^{-1})	P[5] (\$ t^{-1})	L[6]	H[7]	Et(No m^{-2})		
	A[2]	B	C						A	B	C
A. indica	97.3	119.5	123.0	27.1	5.5	1442.5	0.032	0.9	0.5	0.6	0.7
B. frondosa	97.3	119.5	123.0	27.1	5.4	1442.5	0.011	0.9	1.6	1.9	1.9
E. crus-galli	97.3	119.5	123.0	27.1	5.5	1442.5	0.015	0.9	1.2	1.4	1.4

[1]C_a, application cost; [2]A-flucetosulfuron GR, B-flucetosulfuron+imazosulfuron GR, C-flucetosulfuron+imazosulfuron+ carfentrazone-ethyl for weeds; [3]C_h, herbicide cost; [4]Y_o, weed free crop yield; [5]P, value per unit of crop; [6]L, proportion of yield loss per unit weed density; [7]H, herbicide efficacy calculated as efficacy/100.

of grain rice was 1442.5 US \$ t^{-1} in 2010. Herbicide efficacy was assumed to be 0.90 regardless of year and herbicide.

The estimated economic thresholds (ET) of *A. indica* were 0.5, 0.6 and 0.7 plant m^{-2} with the application of flucetosulfuron, flucetosulfuron+imazosulfuron GR and flucetosulfuron+imazosulfuron+carfentrazone GR herbicides, respectively. Meanwhile those of *B. frondosa* were 1.6, 1.9 and 1.9 plants m^{-2} and 1.2, 1.4, and 1.4 plants m^{-2} for *E. crus-galli.*

The study had clearly demonstrated that the rectangular hyperbolic model effectively described the competition relationships between the weeds and rice, successfully predicted rice yields as a function of weed density and had estimated ET values. Therefore, these results can be used to support decision-making on herbicide application in machine transplanted rice cultivation. However, it has still some limitations in regard to the required herbicide dose in practical fields infested with multiple weed species.

요 약

본 연구는 벼에 대한 피, 자귀풀과 미국가막사리의 경합에 따른 수량피해 예측과 경제적인 잡초관리를 위한 방제필요 밀도를 구명하고자 하였다. 수원과 대구 지역에서 얻어진 성적을 종합한 예측모델식에 따르면 논에서 피, 자귀풀, 미국가막사리가 완전히 방제되었을 때의 쌀수량은 각각 5.5t, 5.5t, 5.4t 으로 예측되었다. 초종별 평방미터당 요방제 필요밀도는 자귀풀은 제초제 종류별로 0.5～0.7본, 피는 1.2～1.4본, 미국가막사리는 1.6～1.9본인 것으로 예측되었다.

ACKNOWLEDGEMENTS

This study was carried out with the support of “Research Program for Agricultural Science & Technology Development (Project No. 006340201)”, National Academy of Agricultural Science, Rural Development Administration, Republic of Korea.

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