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Modeling the Competition Effect of *Sagittaria trifolia* and *Monochoria vaginalis* Weed Density on Rice in Transplanted Rice Cultivation

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벼 기계이앙재배에서 벼와 물달개비 및 벗풀 경합에 따른 예측모델

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ABSTRACT Field experiments were conducted to investigate the competition relationships of main paddy weeds with transplanted rice grown in paddy conditions. Data were used to predict crop yield as a function of weed density using a rectangular hyperbola model and determine weed economic threshold (ET) levels. The rectangular hyperbola (equation 2) was fitted to rice yield to estimate weed-free rice yield (Y_o) and weed competitivity (β). Its competitivity for *M. vaginalis* was 0.0007445, 0.0005713, 0.000988 and 0.0008846 in Daejeon, Suwon, Iksan and Naju, respectively. The competitivity at harvest represented by parameter β ranged from 0.001611 in Naju to 0.002437 in Iksan for *S. trifolia*. The ET levels of main paddy weeds in machine transplanted rice cultivation were well estimated based on the herbicides applied and its application cost. Therefore, our results can be used to support decision-making on herbicide application for weed management in transplanted rice cultivation.

Key words: competition; competitivity; economic threshold (ET); rice; weed density.

INTRODUCTION

Competition is commonly defined as the mutually adverse effects of plants which utilize the same resources which are in short supply. Competition occurs only when the resources are below their combined

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demands. Grime (1979) defined competition as the tendency of neighboring plants to utilize the same quantum of light, iron or mineral nutrient, molecule of water, or volume of space. The competitive ability of a species is then determined by the capacity to capture and exploit resources rapidly. Worldwide, a 10% loss of agricultural production can be attributed to the competitive effect of weeds, in spite of intensive weed control in most agricultural systems (Zimdahl 1980). Without weed control, yield losses could range from 10～100%, depending on the competitive ability of the crop (Van Heemst 1985). *Monochoria vaginalis* (Burm. f.) K. Presl ex Kunth and *Sagitaria. trifolia* L. (Arrowwhead) are also one of the most important weed species in machine-transplanted rice fields (Park *et al.* 2001) and direct water-sown rice fields (Park *et al.* 2002) in Korea.

Accurate prediction of weed-crop interactions is required for the integrated weed management (Swanton and Murphy 1996). Mathematical models that summarize the quantitative knowledge of the impact of weed interference on crop yield can provide useful information to support weed management decisions (Vandevender *et al.* 1997). Many efforts have 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 these 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). Therefore, this study was conducted to investigate competition relationships of *M. vaginalis* and *S. trifolia* with transplanted rice. The aims of the study were to predict crop yield as a function of weed density using the rectangular hyperbola as a prediction model and to determine the economic threshold levels for *M. vaginalis* and *S. trifolia* in a transplanted rice production system.

MATERIALS AND METHODS

Field experiments

Field experiments were conducted to evaluate competition effects of main weeds on transplanted rice at major rice cropping regions in Korea (Table 1). The experiments were laid-out in a completely randomized block design with three replicates. The plot size was 2 m × 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} at 25 May in 2005. The target densities of main paddy weeds were artificially adjusted by sowing seeds and planting tubers with thinning, transplanting, or hand-weeding to remove naturally occurring background weeds (Table 1). Background weeds were controlled by paper-mulching. The experiments were likewise laid-out in a completely randomized block design with three replicates. The plot size was 2 m × 2 m.

An N-P_2O_5-K_2O basal fertilizer was applied at a rate of 55-67-225 kg ha^{-1} before harrowing, followed by top-dressing of 22 kg ha^{-1} of N at rice tillering stage, 10 days after transplanting (DAT), and 33-29 kg ha^{-1}

Table 1. Weed species and densities for rice-weed competition studies in different locations.

Weed species	Densities (plants m^{-2})	Experimental location
MOOVA	0, 4, 24, 48, 96, 192, 384, 576	Suwon, Daejeon, Iksan, and Naju
SAGTR	0, 1, 4, 8, 24, 48, 96, 192	Suwon, Daejeon, Iksan, and Naju

Sagittaria trifolia (SAGTR), *Monochoria vaginalis* (MOOVA).

of N-K_2O at rice panicle initiation stage. To determine the competition between rice and the weeds, the number of rice tillers was recorded every 20 days until 100 DAT, and dry weights of rice and the weeds were measured after sampling from an area of 0.5 m^2 at 30, 60 and 90 DAT in Suwon in 2005. At maturity, rice was sampled from an area of 1.0 m^2 and grain yield was measured after polishing.

Prediction model and statistical analyses

Wilson *et al.* (1995) reported that weed biomass increased hyperbolically with weed density at a fixed crop density. It is thus assumed that weed biomass (W) has a hyperbolic relationship with initial weed density as follows :

$$W = CX/(1+\alpha X) \quad (1)$$

Where, parameter C is biomass of an individual weed plant without inter-specific competition and α is a measure of the weed intraspecific competition. Dry weights of the weeds were fitted to equation 1 to estimate parameters for predicting weed biomass at different periods.

Rice biomass and grain yields were fitted to the equation, rectangular hyperbola (Cousens 1985) in equation 2, to estimate parameters for predicting rice biomass and yields as a function of weed density as follows :

$$Y = Y_0/(1+\beta X) \quad (2)$$

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 main weeds were estimated by equating the cost of controlling each weeds with the value of rice yield gained by herbicide application. Their calculation was based on the equation developed by Cousens (1987) as follows :

$$ET = (C_h + C_a)/(Y_o PLH) \quad (3)$$

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).

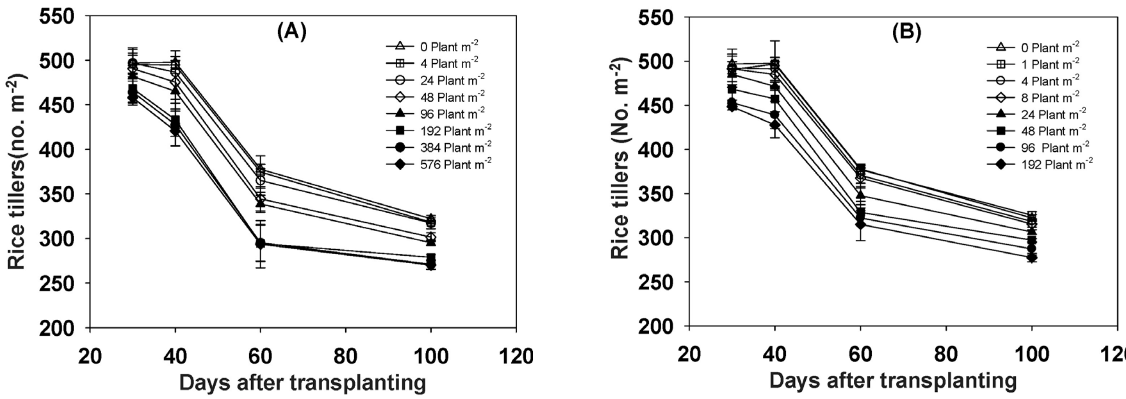

Fig. 1. Changes in the number of tillers of rice as affected by competitions with *M. vaginalis* (A) and *S. trifolia* (B) infested at a range of densities.

Table 2. Parameter estimates for the prediction of rice dry weights as a result of competition between rice and weeds. The numbers in parentheses are standard errors.

Timing (DAT)	*M. vaginalis*		*S. trifolia*	
	Y_o	β	Y_o	β
30	89.6 (0.83)	0.000082 (0.00004)	89.1 (0.9)	0.000254 (0.00014)
60	572.3 (4.50)	0.000370 (0.00004)	576.9 (3.1)	0.000780 (0.00009)
90	1091.7 (9.6)	0.000469 (0.00005)	1070.8 (12.2)	0.000966 (0.00019)

Y_o, weed free rice yield (t ha^{-1}); β, a measure of weed competitivity.

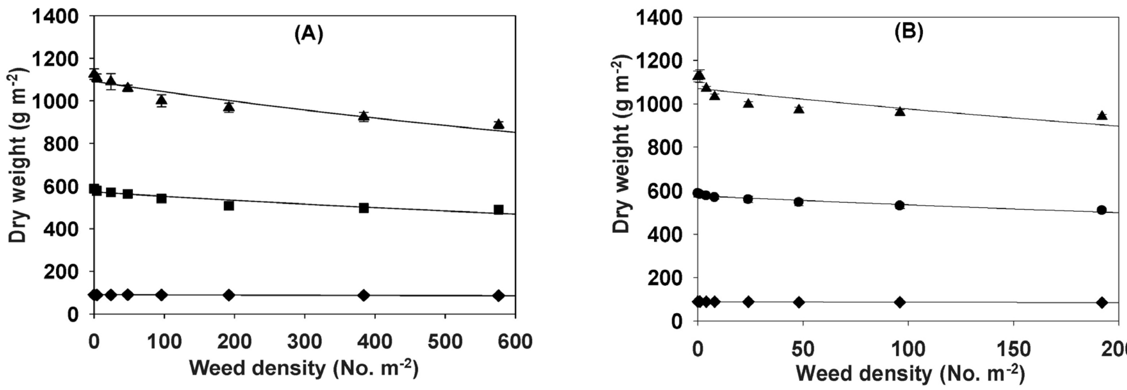

Fig. 2. Dry weights of rice as affected by *M. vaginalis* (A) and *S. trifolia* (B) infestations at a range of plant densities. They were observed at 30 (◆), 60 (■) and 90 (▲) days after rice transplanting. The vertical bars represent the standard deviations and the continuous lines are fitted lines calculated using equation 1 and estimated parameters (Table 2).

RESULTS AND DISCUSSION

Competition of rice with weeds

Monochoria vaginalis and *Sagitariatrifolia* reduced significantly the number of rice tillers in proportion to weed density at all measurements, and their effects became larger over time (Fig. 1). Both weeds exhibited similar trends on their competition effects to rice tillering.

To quantify competition effect on the rice growth, dry weight of rice was measured at 30, 60 and 90 DAT. Both *M. vaginalis* and *S. trifolia* caused significant reduction in rice dry weight at all times from 30 DAT, but reduction was greater when measured at later stages (Fig. 2).

The reduction of rice dry weight was well described by the rectangular hyperbola. The competitivity of *M. vaginalis* was 0.0000821, 0.00037 and 0.000469 at 30, 60 and 90 DAT, respectively, while that of *S. trifolia* was 0.000254, 0.00078 and 0.000966, respectively, indicating that *S. trifolia* was slightly more competitive with transplanted rice than *M. vaginalis* (Table 2).

Prediction of rice yields under rice-*Monochoria vaginalis* and *Sagittaria trifolia* competition in the rice cropping regions

The rectangular hyperbola (equation 2) was fitted to rice yield to estimate weed-free rice yield (Y_o) and weed competitivity (β) of *M. vaginalis* and *S. trifolia*. In rice and *M. vaginalis* competition, the estimated weed-free rice yield was 5.129∼5.806 t ha^{-1} (Table 3). Its competitivity (β) was 0.0007445, 0.0005713, 0.000988 and 0.0008846 in Daejeon, Suwon, Iksan and Naju, respectively. Based on the parameter estimates

Table 3. Parameter estimates for the prediction of rice grain yields as a result of competition between rice and *Monochoria vaginalis*. The numbers in parentheses are standard errors.

Region	Parameter estimates		R^2
	Y_o	β ($\times 10^{-4}$)	
Daejeon	5.806 (6.41)	7.5 (0.00007)	0.887
Suwon	5.172 (3.40)	5.7 (0.00004)	0.960
Iksan	5.273 (7.94)	9.9 (0.00011)	0.863
Naju	5.129 (6.32)	8.9 (0.00008)	0.892

Y_o, weed free rice yield (t ha^{-1}); β, a measure of weed competitivity.

Table 4. Parameter estimates for the prediction of rice grain yields as a result of competition between rice and *Sagittaria trifolia*. The numbers in parentheses are standard errors.

Region	Parameter estimates		R^2
	Y_o	β ($\times 10^{-3}$)	
Daejeon	5.698 (8.43)	2.17 (0.000310)	0.767
Suwon	5.194 (4.27)	1.83 (0.000162)	0.893
Iksan	5.288 (4.65)	2.44 (0.000194)	0.921
Naju	5.614 (6.23)	1.61 (0.000209)	0.787

Y_o, weed free rice yield (t ha^{-1}); β, a measure of weed competitivity.

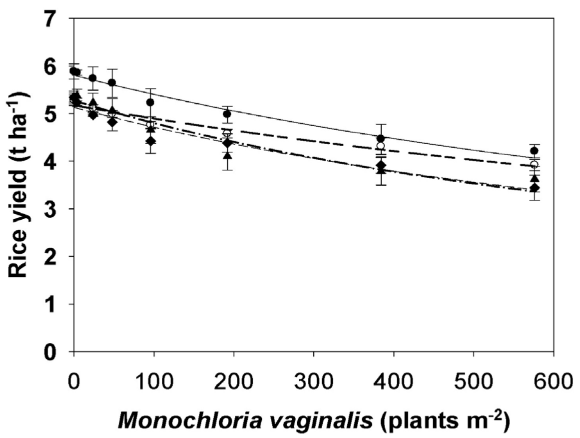

Fig. 3. Observed and predicted rice grain yields as a function of *M. vaginalis* density in Daejeon (●), Suwon (○), Iksan (▲) and Naju (◆) in 2005. The predicted rice grain yield (continuous line) was calculated using equation 2 and parameter estimates in Table 3. The vertical bars represent the standard deviation.

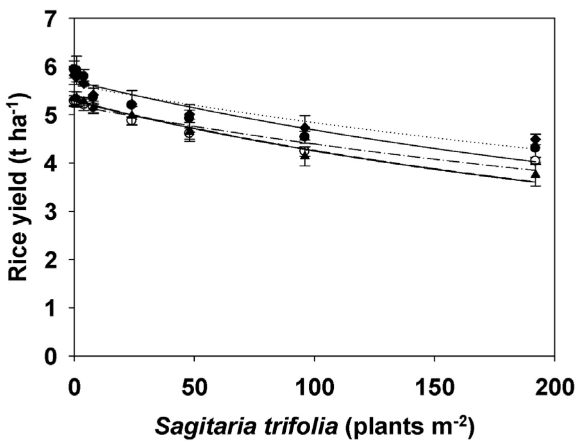

Fig. 4. Observed and predicted rice grain yields as a function of *S. trifolia* density in Daejeon (●), Suwon (○), Iksan (▲) and Naju (◆) in 2005. The predicted rice grain yield (continuous line) was calculated using equation 2 and parameter estimates in Table 4. The vertical bars represent the standard deviation.

and equation 2, rice yield as a function of *M. vaginalis* interference was simulated (Fig. 3).

In rice and *S. trifolia* competition, the estimated weed-free rice yield was 5.194~5.698 t ha^{-1} (Table 4). Its competitivity (β) ranged from 0.001611 in Naju to 0.002437 in Iksan. Based on the parameter estimates and equation 2, rice yield as a function of *S. trifolia* interference was simulated (Fig. 4).

Estimation of economic thresholds

In several regions, the estimated economic threshold (ET) of *M. vaginalis* with application of the flucetosulfuron was 22.1, 32.5, 18.4 and 20.3 plants m^{-2} in Daejeon, Suwon, Iksan and Naju, respectively, while with the application of middle one-shot herbicide, flucetosulfuron + imazosulfuron + carfentrazone-ethyl GR, the ET values obtained were 26.7, 39.2, 22.2 and 24.5 plants m^{-2} in Daejeon, Suwon, Iksan, Naju and Daegu, respectively (Table 5).

The ET ranged from 18.4 in Iksan to 32.5 plants m^{-2} in Suwon when the flucetosulfuron was used, while it ranged from 21.7 in Iksan to 39.2 plants m^{-2} in Suwon

Table 5. Parameter estimates and economic threshold (ET) of *M. vaginalis* in transplanted rice cultivation.

Region	Parameter estimates and economic thresholds (ET)											
	C_h (\$ ha^{-1})			C_a (\$ ha^{-1})	Y_o (t ha^{-1})	P (\$ t^{-1})	L (x 10^{-4})	H	ET (No m^{-2})		
	A	B	C						A	B	C
Daejeon	97.3	119.5	123.0	27.1	5.80	1442.5	7.44	0.9	22.1	26.1	26.7
Suwon	97.3	119.5	123.0	27.1	5.2	1442.5	5.71	0.9	32.5	38.2	39.2
Iksan	97.3	119.5	123.0	27.1	5.3	1442.5	9.87	0.9	18.4	21.7	22.2
Naju	97.3	119.5	123.0	27.1	5.1	1442.5	8.84	0.9	20.3	23.9	24.5

C_h, herbicide cost; C_a, application cost; A, flucetosulfuron GR, B, flucetosulfuron+azimsulfuron GR, C, flucetosulfuron+azimsulfuron+carfentrazone-ethyl GR; Y_o, weed free crop yield; P, value per unit of crop; L, yield loss per unit weed density; H, herbicide efficacy calculated as efficacy/100.

Table 6. Parameter estimates and economic threshold (ET) of *S. trifolia* in transplanted rice cultivation.

Region	Parameter estimates and economic thresholds (ET)										
	Ch (\$ ha^{-1})			C_a (\$ ha^{-1})	Y_o (t ha^{-1})	P (\$ t^{-1})	L (x 10^{-3})	H	ET (No m^{-2})		
	A	B	C						A	B	C
Daejeon	97.3	119.5	123.0	27.1	5.7	1442.5	2.16	0.9	7.8	9.2	9.4
Suwon	97.3	119.5	123.0	27.1	5.2	1442.5	1.824	0.9	10.1	11.9	12.2
Iksan	97.3	119.5	123.0	27.1	5.3	1442.5	2.431	0.9	7.5	8.8	9.0
Naju	97.3	119.5	123.0	27.1	5.1	1442.5	1.61	0.9	10.6	12.5	12.8

C_h, herbicide cost; C_a, application cost; A, flucetosulfuron GR, B, flucetosulfuron+azimsulfuron GR, C, flucetosulfuron+azimsulfuron+carfentrazone-ethyl GR; Y_o, weed free crop yield; P, value per unit of crop; L, yield loss per unit weed density; H, herbicide efficacy calculated as efficacy/100.

when the middle one-shot herbicide was used. In several regions, the estimated economic threshold (ET) of *S. trifolia* ranged from 7.5 in Iksan to 10.6 plants m^{-2} in Naju when the flucetosulfuron was used, while it ranged from 8.8 in Iksan to 12.8 plants m^{-2} in Daejeon when the middle one-shot herbicide was used (Table 6).

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. The economic threshold level depends on weed competition effects, rice yield and price, and herbicide cost. However, due to increasing import of low-priced rice from other countries, the rice price will be inevitably decreased yearly, which implies that the ET value will be increased accordingly (Moon *et al.* 2010). This market situation will require more accurate prediction of weed competition on rice yield and sophisticated decision-making for herbicide application (Moon *et al.* 2010).

요 약

본 연구는 벼에 대한 물달개비, 벗풀의 경합에 따른 수량피해 예측과 경제적인 잡초관리를 위한 방제필요밀도를 구명하고자 하였다. 수원, 익산, 나주와 대전지역에서 얻어진 성적을 종합한 예측모델식에 따르면 논에서 물달개비의 경합력은 대전 0.0007445, 수원 0.0005713, 익산 0.000988, 나주에서 0.0008846으로 추정되었다. 벗풀의 경합력은 나주 0.001611에서 익산

에서 0.002437의 범위를 보였다. 초종별 평방미터당 요방제 필요밀도는 물달개비는 중기제초제 처리시 22에서 39본으로, 벗풀은 8.8본에서 12.9본으로 추정되었다.

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