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Economic Threshold Density of Multi Species Weed for Direct Seeded Rice

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Abstract

We conducted two experiments in 2009 and 2010 at central part of Bangladesh to examine the effects of multispecies weeds on grain yield and to determine the economic threshold (ET) of weeds in direct seeded rice (DSR). The treatments consisted of 0, 5, 10, 20, 40, 80, 160 weeds m^{-2} and control (unweeded). *Scirpus maritimus* L. and *Cyperus difformis* L. were the most dominant weed species in year 1 and 2, respectively. Grain yield losses due to weed interference increased with weed population density increase. Panicle m^{-2}, grains $panicle^{-1}$, 1000-garin weight and grain yield varied significantly due to different weed density in both years of the study. Estimated ET were 5 and 7 weeds m^{-2} in year 1 and 2, respectively, assuming a weed free rice grain yield 5 ton ha^{-1}, a crop price $ 210 ton^{-1}, and weed control cost $ 30 ha^{-1}.

Keywords: Economic thresholds, Direct seeded rice, Yield loss, Weeds

Introduction

Irrigated rice cultivation depends on water supply but scarcity of water threatens the sustainability of the irrigated rice production system and food security (Turmuktini *et al.*, 2012). Direct seeded rice (DSR) is water and labor saving technique of cultivation (Mahajan *et al.*, 2006). It eliminates the need of seedling rising, maintaining and subsequent transplanting. Weeds are considered as a serious problem in DSR (Johnson *et al.*, 1998) because they emerge before or at the same time as the rice (Oerke *et al.*, 1994; Johnson *et al.*, 1998; Mallik, 2001). Due to presence of weeds, yield losses occur in lowlands situation whatever it is rainfed or irrigated systems. This situation is more severe in direct seeded systems where weed management is hampered by labour shortages, limited water control, scarce resources and inadequate management practices. Rice yields were reduced by 63% in a transplanted system and 70-76% in DSR (Singh *et al.* 2005). Weeds cause rice yield losses by 30-40% in Bangladesh (BRRI, 2006; Mamun, 1990), 36 to 56% in the Philippines (Rao and Moody, 1994) and 40 to 100% in South Korea (Kim and Ha, 2005). Thus weed must be controlled in economic means. In recent time, use of herbicides is one of the most promising and cost effective farmer-initiated weed control method in Bangladesh. Mazarura (2013) reported that herbicides controlled weeds well after transplanting and more so with delay in the application. The economics of herbicide use must be determined by a combination of yield loss, crop price, crop yield productivity, and herbicide and application costs. These factors must be considered in order to apply weed yield loss models in Bangladeshi agriculture. Weeds compete for water, nutrients and light and cause the reduction in both

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quantity and quality of rice yield. Effective weed control is therefore important especially during the critical weed free period, which is the first 4-6 weeks of the crop's production cycle (Bertha *et al*., 2013). Concentrated efforts must be made to achieve food security by increasing food grain production (Mahendran, 2013). Again, weed density is one of the most important factors in competition with the crop. Determination of weed economic damage threshold is an important component for dynamic decision of integrated weed management. The weed economic threshold is the weed population at which the cost of control is equal to the crop value increase of the present weeds control (Weaver and Ivany, 1998; Pester, 2000). In Germany, weed management is done successfully through threshold approach (Gerowitt and Heitefuss, 1990). The threshold values in cereal crops were 20-30 plants m^{-2} for grass weeds and 40-50 plants m^{-2} for broadleaved weeds [excluding *Galium aparine* L. and *Fallopia convolvulus* (L.) A. Love]. The economic threshold of wild oat (*Avena fatua* L.) in wheat was estimated between 3 to 30 and 8 to 12 plants m^{-2} in USA and UK, respectively (Cousens, 1987). We have hypothesized that a complementary economic simulation including the crop grain prices and cost of weed control. Furthermore, most of the studies evaluate the interference between a single weed species and the crop. But, there are several weed species that could reduce crop yield in the field situation. Therefore, most of these studies have not had an important role in control decision-making (Swinton *et al*., 1994). Therefore, the objectives of this study were: i) to evaluate the effect of multispecies weeds on rice yield and its components, and ii) to determine the economic threshold of weeds in DSR using regression equations.

Materials and Methods

Experimental site

We executed two field experiments at Agronomy field of Bangladesh Rice Research Institute fields in the Gazipur district of Bangladesh during aman season (June to November) in 2009 and 2010. Same field was used in both years (90^0 33´ E longitude and 23^0 77´ N latitude). The field was infested by natural weed species. Soil of the experimental field belongs to the Shallow Red Brown Terrace Soils. The experiential soil characters in the two seasons are shown in Table 1. The region belongs to sub-tropical humid climate. Weather conditions during experimental periods are presented in Fig. 1.

Table 1: Soil description of experimental site in year 1 and 2

Year	Soil texture	Organic matter	Sand (%)	Silt (%)	Clay (%)	pH
Y-1	Loamy	1.4	47	35	18	6.2
Y-2	Loamy	1.5	45	38	17	6.3

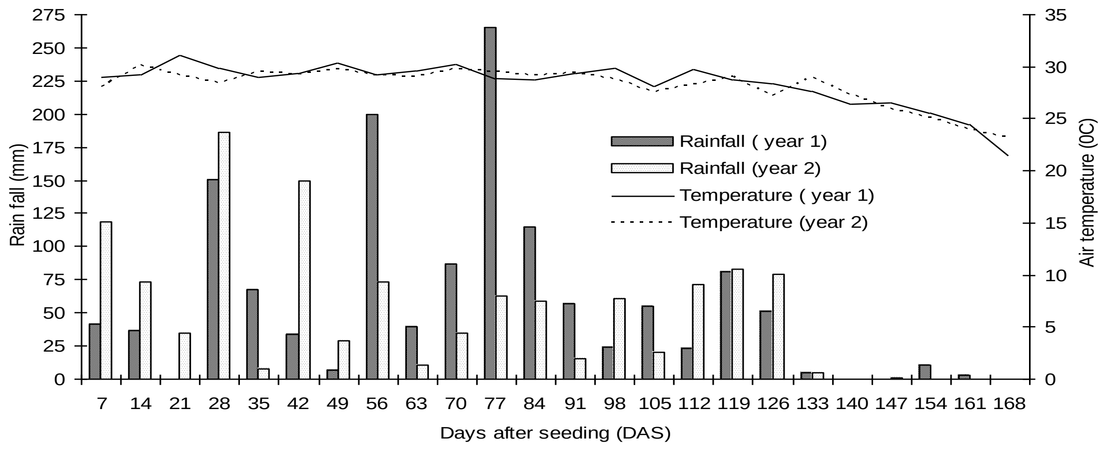

Figure 1: Weekly rainfall distribution and temperature during growing seasons

Experimental setup

Rice (cv. RRRI dhan49, popular variety of Bangladesh, was sown on 05 and 07 July in year 1(2009), year 2 (2010), respectively. Unit plot size was 1m × 1m and total twenty four plots were used for the experiment in both years. Before sowing, the plot was kept weed-free by hand weeding. Basal application of fertilizer at a rate of 90 kg N ha^{-1} as urea, phosphorus of 20 kg P ha^{-1} as triple superphosphate and 35 kg K ha^{-1} as muriate of potash were broadcast uniformly and incorporated into the soil of all plots. Except urea all other fertilizers were applied before rice sowing and urea were top dressed in three installments at 15, 30 and 45 days after sowing (DAS). Pesticides and herbicides were not applied during crop growth. A randomized complete block design with three replicates was used. Rice seeds at a rate of 40 kg ha^{-1} were sown by hand broad-casting. Treatments consisted of 0, 5, 10, 20, 40, 80, 160 weeds m^{-2} and control (unweeded). Weeds of different species were maintained from 10 to 50 DAS at 10 days interval. Newly emerged weeds were uprooted ton maintain desired weed number m^{-2}.

Biological measurement

Weed height and rice plant height were taken at 10 days interval from 30 to 60 (DAS). Then relative weed height (RWH) was calculated. Weed sample were collected at 60 DAS. Weeds samples were classified by species, counted, dried and the dry weight of each species was recorded. Absolute number and dry weight of each species were used for computing the community characters. The contribution of an individual weed species to the weed community was determined by its two-factor summed dominance ratio (SDR) (Janiya and Moody, 1989). This was calculated using relative weed density (RD) and relative dry weight (RDW), as follows:

$$\text{RD (\%)} = \frac{\text{Density of individual weed species in the community}}{\text{Total density of all weed species in the community}} \times 100 \quad \ldots\ldots\ldots\ldots\ldots \quad [1]$$

$$\text{RDW (\%)} = \frac{\text{Dry weight of a given oven dried weed species}}{\text{Dry weight of all oven dried weed species}} \times 100 \quad \ldots\ldots\ldots\ldots\ldots \quad [2]$$

$$\text{SDR} = \frac{\text{RD} + RDW}{2} \quad \ldots\ldots\ldots\ldots\ldots \quad [3]$$

$$\text{RWH} = \frac{\text{Weed height}}{\text{Plant height}} \quad \ldots\ldots\ldots\ldots\ldots \quad [4]$$

Estimation of yield loss

The percentage of yield loss (YL) of each infested plot was calculated by following equation:

$$\text{YL (\%)} = \frac{\text{Ywf} - \text{Y}}{\text{Ywf}} \times 100 \quad \ldots\ldots\ldots \quad [5]$$

Where, Y_{wf} is the grain yield in weed-free plots and Y is the grain yield from each infested plot.

The relationship between yield loss and weed density for each year was described using the rectangular hyperbolic model proposed by Cousens (1985). The model is as follows:

$$\text{Y} = \text{Y}_{wf}\left[1 - \frac{\text{id}}{100\,(1 + \text{id/a})}\right] \quad \ldots\ldots\ldots \quad [6]$$

Where, Y is the predicted crop yield, Y_{wf} in the estimated weed-free crop yield, i is the initial slop, d is the weed density (no. m^{-2}) and a is the asymptote.

Estimation of economic threshold weeds density

As the response of crop yield to weed density was nonlinear, single-season threshold was calculated by extending Eq. [6] as described by O'Donovan (1991) as

$$\text{E} = \left[\frac{1 - (\text{CP} - \text{H})/\text{CP}}{(\text{r} - \text{s}) + \text{s}\{(\text{CP} - \text{H})/\text{CP}\}}\right] \quad \ldots\ldots\ldots \quad [7]$$

Where, E is the economic threshold weed density (weeds m^{-2}), C is the expected weed-free crop yield (ton ha^{-1}), P is the crop market price (\$ ton^{-1}), H is the cost of the herbicide and its application (\$ ton^{-1}), and r is i/100 and s is i/a.

Statistical analysis

The data on yield and yield parameters were recorded. Grain yield was adjusted at 14% moisture content. Constant straw weight was recorded after repeated sun drying. Collected data were analyzed for analysis of variance following MSTAT-C and means were compared by DMRT (Gomez and Gomez, 1984).

Results

Vegetative growth of rice and weed

Relative weed height (RWH) at 40, 50 and 60 DAS significantly affected by different weed densities in year 1 but not in year 2 (Table 2). During both years, RWH more or less increased with the increases of weed densities and advances of crop growing period (from 30 to 60 DAS). Relative weed height was increased by 19 and 25 % at 30 DAS, 18 and 42 % at 40 DAS, 23 and 11% 50 DAS and 16 and 6 % at 60 DAS in control over 5 weeds m^{-2} in year 1 and 2, respectively. Except 30 DAS, comparatively higher RWH was recorded in year 1 than that of year 2 with the advance of growing period. Numerically higher RWH was recorded from control plot whereas lower from 10 and 20 weeds m^{-2} in year 1 and 5, 20, 40 weed m^{-2} in year 2 at 30 DAS. Significantly maximum RWH was obtained from control plot which was identical with that of 80 weeds m^{-2} at 40 DAS in year 1. Relative weed height obtained from 5, 20, 40 and 160 weeds m^{-2} was statistically similar whereas minimum from 10 weeds m^{-2} in year 1 at 40 DAS. In year 2, higher RWH was found in control plot whereas lower in 5 weeds m^{-2} plot at 40 DAS. At 50 DAS, the highest RWH was recorded from control plots which was statistically similar with that of 20, 40, 80 and 160 weeds m^{-2} whereas lowest from 5 weeds m^{-2} that was statistically similar with that of 10 weeds m^{-2} in year 1. In year 2, higher RWH was found in control plot whereas lower in 10 weeds m^{-2} plot at 50 DAS. At 60 DAS, the highest RWH was found in 80 weeds m^{-2} plots which was statistically similar with that of 10, 20, 40, 160 weeds m^{-2} and control plot whereas lowest from 5 weeds m^{-2} in year 1. In year 2, numerically higher RWH was found in control plot whereas lower in 5 weeds m^{-2} plot at 60 DAS.

Table 2: Relative weed height at 30, 40, 50 and 60 days after sowing (DAS) in year 1 and 2

Weeds (no.m^{-2})	Relative weed height							
	30 DAS		40 DAS		50 DAS		60 DAS	
	Year-1	Year-2	Year-1	Year-2	Year-1	Year-2	Year-1	Year-2
5	0.62	0.38	0.71ab	0.76	0.75b	1.12	0.95b	1.21
10	0.60	0.39	0.69b	0.90	0.78b	1.10	1.02ab	1.25
20	0.60	0.38	0.78ab	0.85	0.83ab	1.12	1.09ab	1.27
40	0.64	0.38	0.77ab	0.90	0.85ab	1.18	1.06ab	1.27
80	0.70	0.40	0.87a	0.97	0.84ab	1.22	1.12a	1.24
160	0.67	0.49	0.79ab	1.10	0.86ab	1.25	1.04ab	1.27
Control	0.74	0.51	0.87a	1.08	0.92a	1.24	1.10ab	1.29

Values of a column followed by same letter are statistically similar at 5% probability

Weed vegetation

Twelve weed species inhabited control plot of direct seeded rice field. The infesting weed species were belonging to 6 families and 11 genera. This weed flora was ecologically categorized into 4 broadleaf species, 4 sedges and 4 grasses. The number of weed species was higher in year 2 (10 species) than in year 1 (9 species) (Table 3). The weed density and biomass was higher in year 1 than that of year 2. The sedges were *Scirpus maritimus* L., *Cyperus difformis* L., *Fimbristylis miliacea* L. and *Cyperus iria* L. *Echinochloa crus-galli* L., *Leersia hexandra* Sw., *Cynodon dactylon* L. Pers. and *Leptochloa chinensis* L. Ness. were grass and *Monochoria vaginalis B*urm. f., *Marsilea minuta* L. *Ludwigia octovalvis* Jacq. and *Sphenoclea zeylanica* Gaertn were broad leaf weed. The monocot weed species were *Scirpus maritimus* L., *Cyperus difformis* L., *Echinochloa crus-galli* L., *Monochoria vaginalis B*urm. f., *Fimbristylis miliacea* L., *Leersia hexandra* Sw., *Cynodon dactylon* L. Pers., *Marsilea minuta* L., *Cyperus iria* L. and *Leptochloa chinensis* L. Ness. whereas dicot were *Ludwigia octovalvis* Jacq. Raven. and *Sphenoclea zeylanica* Gaertn.

Table 3: Weed density, dry weight and population composition in the weedy treatment

Weeds (no.m^{-2})	Biomass (g m^{-2})	Species	Family	Category	Relative density (%)	Relative biomass (%)
Year 1						
220	161.79	*Scirpus maritimus* L.	Cyperaceae	Sedge	44.40	45.01
		Cyperus diffornis L.	Cyperaceae	Sedge	40.31	13.09
		Echinochloa crus-galli L.	Poaceae	Grass	10.15	39.66
		*Monochoria vaginalis B*urm. f.	Pontederiaceae	Broad leaf	2.42	0.97
		Ludwigia octovalvis Jacq.	Onagraceae	Broad leaf	0.60	0.46
		Fimbristylis miliacea L.	Cyperaceae	Sedge	0.76	0.20
		Sphenoclea zeylanica Gaertn.	Sphenocleaceae	Broad leaf	0.76	0.17
		Leersia hexandra Sw.	Poaceae	Grass	0.30	0.30
		Cynodon dactylon L.	Poaceae	Grass	0.30	0.14
Year 2						
180	57.74	*Cyperus diffornis* L.	Cyperaceae	Sedge	63.15	50.55
		Echinochloa crus-galli L.	Poaceae	Grass	15.19	20.83
		Scirpus maritimus L.	Cyperaceae	Sedge	13.89	21.22
		Monochoria vaginalis Burm.f.	Pontederiaceae	Broad leaf	4.26	3.15
		Marsilea minuta L.	Marsiliaceae	Broadleaf	1.11	1.12
		Ludwigia octovalvis Jacq.	Onagraceae	Broad leaf	0.92	1.28
		Sphenoclea zeylanica Gaertn.	Sphenocleaceae	Broad leaf	0.74	0.73
		Cynodon dactylon L.	Poaceae	Grass	0.37	0.79
		Cyperus iria L.	Cyperaceae	Sedge	0.19	0.28
		Leptochloa chinensis L.	Poaceae	Grass	0.18	0.05

Weed ranking

In year 2, number of weed species was higher (10 species), in comparison with year 1 (9 species) (Figs. 1 and 2). Sedges were dominant weeds (0.22– 45 % SDR in year 1 and 0.25-57 % SDR in year 2) followed by grasses (0.3 – 25 % SDR in year 1 and 0.2-18% SDR in year 2) and broadleaf weeds (0.5 – 2 % SDR in year 1 and 0.75-4 % SDR in year 2). Three most dominant weeds in year 1 were *Scirpus maritimus* L., *Cyperus difformis* L., and *Echinochloa crus-galli* L. Dominant was *Scirpus maritimus* L. in year 1. In year 2, *Cyperus difformis* L., *Echinochloa crus-galli* L. and *Scirpus maritimus* L. were the most dominant weeds.

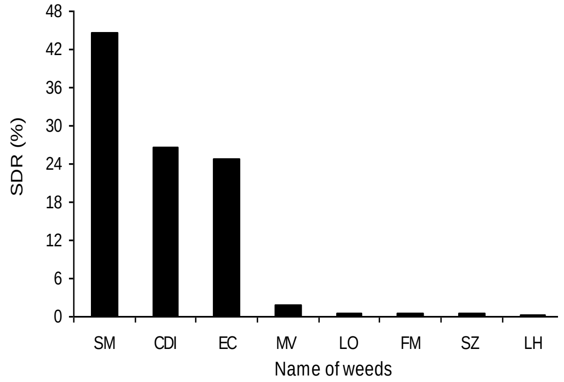

Figure 2: Weed ranking in weedy plot (year 1)

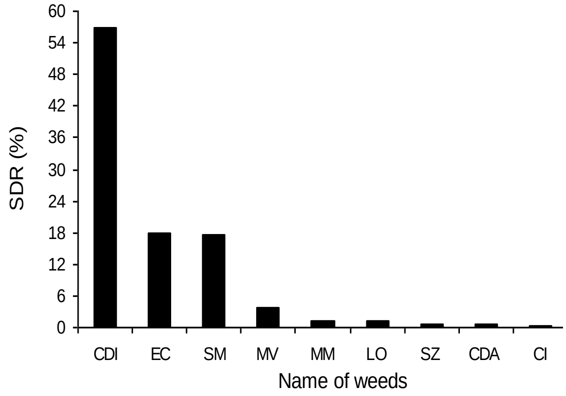

Figure 3: Weed ranking in weedy plot (year 2)

SM= *Scirpus maritimus* L., CDI= *Cyperus difformis* L., EC= *Echinochloa crus-galli* L., MV= *Monochoria vaginalis* Burm. f., LO= *Ludwigia octovalvis* Jacq., FM= *Fimbristylis miliacea* L., SZ= *Sphenoclea zeylanica* Gaertn., LH= *Leersia hexandra* Sw., MM= *Marsilea minuta* L., CDA= *Cynodon dactylon* L. CI= *Cyperus iria* L. and LC= *Leptochloa chinensis* L.

Yield components and grain production

Number of panicles m^{-2} gradually decreased with the weed density in both seasons. The lowest number of panicles m^{-2} was recorded in the control plots for both years (121 in year 1 and 123 in year 2). The numbers of grains panicle^{-1} were significantly affected by the weed density in both years (Table 4). Significantly highest number of grains panicle^{-1} was recorded from weed free plots in both years (106 in year 1 and 114 in year 2). The number of grains panicle^{-1} gradually decreased with the weed density in both seasons. The lowest number of grains panicle^{-1} was recorded from control for both years. Weed density exerted significant influence on 1000-grain weight in both years (Table 4). The highest 1000-grain weight was recorded from weed free, while the lowest 1000-grain weight was recorded from control in both years. Similar 1000-grain weight was obtained from 5, 10, 20, 40, 80 and 160 weed m^{-2} in both years. The rice grain yield was significantly affected by the weed number m^{-2} in both years (Table 4). Rice grain yield decreased with the weed number m^{-2} in both years. Significantly the highest rice grain yields of 4.63 and 4.75 ton ha^{-1} were recorded from weed free plots which were 50 and 47 % higher than that of control in year 1 and 2, respectively. Grain yield obtained from weed free was similar with that of 5 weed m^{-2} in year 1 but higher in year 2. More than 3 ton ha^{-1} grain yield was found upto 40 and 160 weed m^{-2} in year 1 and 2, respectively. The lowest grain yield was recorded from control in both seasons. The numbers of panicles m^{-2} were significantly affected by the weed density in both years (Table 4).

Table 4: Grain yield and yield contributing characters of rice at harvest

Weeds (no.m^{-2})	Grain yield (ton ha^{-1})		Panicles (no. m^{-2})		Grains (no. panicle^{-1})		1000-grain weight (g)	
	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
0	4.63a	4.75a	227a	211a	106.00a	114.00abc	20.20a	18.87a
5	4.22ab	4.30b	194b	194b	103.00ab	120.00ab	18.93b	18.17ab
10	3.83bc	4.12c	184bc	182bc	102.00ab	123.33a	18.40bc	18.37ab
20	3.48cd	3.88d	166bcd	172c	99.00ab	114.00abc	18.42bc	18.28ab
40	3.12de	3.68e	156cd	174c	96.67ab	108.00bc	18.53b	18.55a
80	2.87def	3.45f	152d	173c	92.33ab	120.00ab	18.22bc	18.21ab
160	2.59ef	3.10g	141de	168c	89.00bc	103.67c	18.39bc	18.36ab
Control	2.31f	2.54h	121e	123d	76.33c	102.33c	17.51c	17.47b

Values of a column followed by same letter are statistically similar at 5% probability ($p = 0.05$)

As weed density increased, rice grain yield decreased hyperbolically. The relation between grain yield m^{-2} and weed density was represented by a rectangular hyperbola in both years. Significant yield reduction was noticed due to competition from different densities of weeds in year 1 and 2. The highest reduction (47.7% in year 1 and 34.9 % in year 2) was occurred when 119 and 130 weeds present m^{-2} in year 1 and 2, respectively. The percent reduction increased progressively with the weed density upto 119 and 130 weeds m^{-2} in year 1 and 2, respectively.

Weed economic threshold density

The equation described by O'Donovan (1991) was used to determine economic threshold of weed density. The estimated economic threshold of multispecies weed was 5 and 7 weeds m^{-2} in years 1 and 2, respectively, assuming a weed free rice grain yield 5 ton ha^{-1}, a crop price $ 210 ton^{-1}, and weed control cost $ 30 ha^{-1} (Table 5).

Table 5: Economic threshold weed density of direct seeded rice

Years	Economic threshold weed density (no.m^{-2})
Year 1	5
Year 2	7

Discussion

Yield of direct seeded rice (DSR) was greatly affected by weeds. Determination of economic threshold (ET) of weed density consisted of the number of weeds in DSR is one possible way to improve farming methods. Obtained results from both seasons have clearly showed the effects of weed density on yield reduction of DSR. Rice grew faster than weeds at early stage in both years. Rice plants grew rapidly upto 40 DAS than weeds. This offers an apparent advantage to the rice plants in terms of light interception. After 40 DAS weeds grew rapidly than rice plants. In DSR, the rice seeds are sown in saturated soil moisture. Tanaka (1976) found that sedges and grasses accounted for more than 90% of the total dry weight in saturated condition. In addition, Bhagat *et al.* (1999) also reported that the dominance of *Echinochloa crus-galli* and *Lepthocloa chinensis* was favoured by the saturated condition. Mamun *et al*. (2011) reported that *Paspalum disticum* and *Echinochloa crusgalli* was the dominant weed species in translated rice. In our field trial sedges were observed as main weeds in both years followed by broadleaves. This succession was due to ability of the weeds to produce more seeds which contribute to additional soil seed bank. Increasing weed density reduced the number of panicle m^{-2} of rice plants in both years. Sultana (2000) observed about 52% reduction in tillers due to competition from weeds. Fazlul *et al.* (2003) also observed significantly highest number of total tillers produced in weed-free treatments. Begum *et al*. (2009) found that significantly higher percentage of fertile grains per panicle was produced in weed free plots and weed density of 250 m^{-2} compared with the rest of weed density treatments. Similar result was observed for other species e.g., red rice density of 5 plants m^{-2} were not effective to reduce fertile rice grain, but weed densities to 108 and 215 plants m^{-2} reduced fertile rice grain (Diarra *et al*., 1985). The 1000-grain weight is a genetic character widely used in yield estimation and varietal selection in rice (Iqbal *et al*., 2008). The highest 1000-grain weight was obtained in weed-free, while 1000-grain weights were significantly lowered in the treatments with higher weed densities. Islam *et al.* (1980) also reported variation in 1000- grain weight due to weed infestation, while Rao and Moody (1992) reported that weed competition did not affect the grain index of the rice. It is now generally acknowledged that at low weed population densities the yield loss response tends towards linearity. As density increases, weeds begin to compete intraspecifically, and yield loss approaches an asymptote (Cousens 1985). The wisdom of continuing to conduct labor-intensive weed interference experiments, for the sole purpose of reinforcing this well-established conclusion, has been questioned (Cousens 1987; Norris 1992). The rice plants produced the highest grain yield m^{-2} when grown in the absences of weeds. Grain yield was reduced due to competition from weeds. After a certain weed density the magnitude of yield reduction was reduced; in other words the yield m^{-2} was increased slightly. In this concept the determination of economic threshold is a basic requirement for Integrated Weed Management System. Again, technologies of rice cultivation with biological crop management and organic based fertilizers are required that can increase rice production and sustainable agriculture (Turmuktini *et al*., 2012).

Conclusion

Scirpus maritimus L. and *Cyperus difformis* L. were the most dominant weed species in year 1 and 2, respectively. The density of 40 or more weeds per m^2 is competitive to rice. The weed infestation levels 40 or more weeds per m^2 offered higher competition and affected rice yield. Estimated economic threshold of multispecies weed was 5 and 7 weeds m^{-2} in years 1 and 2, respectively, assuming a weed free rice grain yield 5 ton ha^{-1}, a crop price $ 210 ton^{-1}, and weed control cost $ 30 ha^{-1}.

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