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Effects of Crop Rotation and Tillage Depth on Weed Competition and Yield of Rice in the Paddy Fields of Northern Iran

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ABSTRACT

Crop rotation is one of the essential practices in sustainable agricultural systems, because of its effects on soil fertility and other benefits including a reduction in weed competition. A field experiment was conducted at Chaparsar Rice Research Station, Tonekabon, Iran, from 2002 to 2003 to assess the influence of crop rotation, time of planting, and tillage depth on rice (*Oryza sativa* L.) yield and density and the biomass of three important paddy weeds. Treatments included the crop rotations of continuous rice and rice-soybean-rice, in combinations with planting times and no tillage, minimum tillage, and chisel plowing. Crop rotation had a significant effect on the growth of barnyardgrass (*Echinochloa crus-galli*), arrowhead (*Sagittaria sagittifolia*), and water plantain (*Alisma plantago-aquatica*) weeds. Continuous rice planting produced the highest density of barnyardgrass, arrowhead, and water plantain weeds, compared with a rice–soybean-rice rotation. Weed biomass and weed densities were lower in the rice-soybean-rice rotation than in continuous rice. There were a 62.5 and 80% reductions in the weed density and weed biomass respectively, in the rice-soybean-rice rotation compared with continuous rice planting. Fewer barnyardgrass, arrowhead and water plantain growth were observed in no-tillage treatments than in minimum tillage and chisel. Therefore, rice yield in rotation treatments increased by 17 and 21% in 2002 and 2003, respectively, compared to continuous rice planting.

Key words: Crop rotation, Iran, Paddy fields, Weed competition.

INTRODUCTION

Crop rotations can help in controlling weeds, supplying soil nutrients, improving soil tilth, and reducing soil erosion (Santos *et al*., 1993). The positive effect of long-term rotations on crop yields has been recognized and exploited for centuries. Although in the last few decades its benefits in terms of yield seem to have been ignored by many farmers, it is now evident that crop rotation increases yield and that the practice is essential in sustainable agricultural systems (Crookston, 1984). For example, a legume crop can lower the fertilizer needs for the following crop. A generally proposed cause for such effects is an increased N availability for the cereal crop from symbiotic N_2-fixation of the preceding legume which can lead to significant increases in the available soil N pool (Baldock *et al*., 1981; Pierce and Rice, 1988). Cereal yield increases after legumes were also reported without significant legume effects on the levels of total soil N (Hesterman *et al*., 1987).

Crop rotation may be an effective practice for controlling serious weeds because it introduces conditions that affect weed growth and reproduction and thus reduces weed density (Ball, 1992; Derksen *et al*., 1993; Blackshaw *et al*., 1994). In addition, Forcella and Lindstrom (1988) reported that,

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after seven to eight years of weed management, the number of weed seeds was about six times greater in a continuous crop than in a rotated system. Crop rotation has been reported as a tool to control weed densities in many parts of the world (Ball, 1992; Bullock, 1992; Clements, 1994). In rice crops, losses due to the competitive effects of weeds are estimated at 10 to 15% of potential production (Smith, 1983; Pons, 1985; Pons and Kruif, 1985; Zoschke, 1990; Baltazar and De Datta, 1992; Moody, 1993).

The three main weeds causing problems in the Iranian paddy fields are barnyardgrass (*Echinochloa crus-galli*), arrowhead (*Sagittaria sagittifolia*), and water plantain (*Alisma plantago-aquatica*). The objective of this study was to determine the effect of crop rotation, tillage types and planting times on weed density, weed biomass and rice yield.

MATERIALS AND METHODS

A field experiment was carried out at the Chaparsar Rice Research Station, Tonekabon, Iran (36° N; 51° E), from 2002 to 2003. The soil was a sandy loam with 1.67 to 2.2% organic matter, pH 7.5, and a low to medium natural fertility at the beginning of the study (10 mg kg^{-1} of P, 54.5 mg kg^{-1} of K, and 14% Total N). Means of temperature and average annual rainfall of the station are 15°C and 1100 mm, respectively.

The experiment was arranged as a split-split-plot design with four replications. Main plot treatments included tillage depth: no tillage, minimum tillage (5 cm depth) and chisel tillage (20 cm depth). The sub-plot treatments included planting times: 4 May, 15 August, and 26 August 2002 and 2003, and the sub-sub-plot treatments included soybean cultivars: 1-17, M-12, M4, and Williams. The main-plot treatments were completely randomized and replicated four times before the subplot and the sub-sub-plots treatments were randomly attributed to each main plot. Main plot size was 18 m × 12 m, sub-plot size was 18 m × 4 m and sub-sub-plot size was 4.5 m × 4 m. This experiment was arranged in two-year crop rotations of continuous rice and soybean-rice. The control was planting rice in a continuous crop using chisel tillage.

The soybean cultivars were planted in 45 cm rows apart and 4 seeds per meter. In all the plots, a plant population of 88,888 plants ha^{-1} was the objective. No synthetic fertilizer was used during this experimental period. The experimental area was tilled conventionally before the first crop season. At thinning, about 10 days after sowing (DAS), seedlings were reduced to one plant per each planting hole.

The first crop (rice) was transplanted at the seedling stage at a length of 15 cm in April 2002 and 2003. Above ground weed biomass (g m^{-2}) and weed density (plants m^{-2}) were assessed in 50 × 50 cm quadrats at 60 days after transplanting (DAT) the rice seedlings. At sampling time, weeds were severed at the soil surface, identified, and separated into species groups. The weed shoots were oven-dried at 80°C for 72 hours and weighed.

The rice yield in the central rows was harvested from the center of a 1.3 m width × 10 m length of each rice plot by hand. At the end of the crop cycle, the plants were harvested, and their biomass left at soil surface, as mulch for the next crop.

Data were subjected to analysis of variance followed by separation of means by the least significant differences (L.S.D) tests, at the $P \leq 0.05$ level, using Genstat and Minitab Softwares.

RESULTS

Compared to those of continuous rice in 2002 and 2003, rice yield following soybean was about 20% higher in all treatments. Throughout the two years of the experiment, the rice yields in rotation with soybean were higher compared with continuous rice. Rice yields from rotation plots were 17 and 21% higher in 2002 and 2003, respectively, compared with continuous rice plots. This was in

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sharp contrast to the strong suppressive effects of rice-soybean-rice rotation on barnyardgrass, arrowhead and water plantain densities. Results of ANOVA did not detect ($P\leq0.05$) any differences in yield of soybean cultivars (Table 1).

A survey conducted on 132 paddy fields in Northern Iran indicated that barnyardgrass, arrowhead, and water plantain weeds are present in all samples (data not shown). Crop rotation had an effect on the numbers of weed species for all, but more variable for tillage treatments. Weeds observed in soybean-rice rotations generally belonged to the *Poaceae*, *Polygonaceae*, *Lemnaceae*, *Azollaceae*, *Cyperaceae* and *Juncaceae* families.

In general, a higher weed density was recorded in continuous rice compared with the rice-soybean-rice rotation plots. For example, during 2002, a 50-75% reduction in barnyardgrass, arrowhead and water plantain weeds density per square meter were observed in the rice-soybean-rice rotation compared with continuous rice (Table 2). The lowest absolute numbers of weeds were observed in the rice-soybean-rice rotation.

The influence of tillage, planting time and crop rotation on weed density varied between treatments (Table 2). Tillage had a significant effect ($P<0.05$) on the number and weed species in all treatments in both 2002 and 2003. Rotation plots combined with no tillage had the lowest means in the weed density in the experimental years. Rotation plots combined with no tillage had on average 28 and 67% fewer weed density compared with minimum and chisel tillage in 2002 and 2003, respectively. Rice-soybean-rice rotations had a negative effect on the germination of weeds when compared with continuous rice. Barnyard grass, arrowhead and water plantain growth were greater in continuous rice in both years compared with plots in rotation with soybean (Table 2).

The most dramatic effect was seen in 2003

Table 1. Effects of rice-soybean-rice rotation on rice yield (kg ha^{-1}) in experimental years^{a}.

Treatments	2002 Yield (kg ha^{-1})	2003 Yield (kg ha^{-1})
Continuous rice	2350^{a}	2185^{a}
Rice-soybean-rice	2750^{b}	2643^{b}

^{a} Within columns, means followed by the different letters are significantly different at $P\leq0.05$ as determined by the L.S.D. test.

Table 2. Effects of rice-soybean-rice rotation on density of *E. crus-galli*, *S. sagittifolia*, and *A. plantago-aquatica* weeds at 60 days after transplanting rice seedlings during 2002 and 2003^{a}.

Treatments	Weed density (plants m^{-2})		
	E. crus-galli	*S. sagittifolia*	*A. plantago-aquatica*
Continuous rice	43^{a}	16^{a}	9^{a}
Rice-soybean-rice × No tillage	16^{b}	6^{b}	4.37^{b}
Rice-soybean-rice × Minimum tillage	20.48^{bd}	7.68^{bc}	5.6^{b}
Rice-soybean-rice × Chisel tillage	26.72^{ec}	10.02^{cd}	7.29^{ac}
Rice-soybean-rice × 4 May planting	19.78^{b}	7.36^{bc}	4.14^{b}
Rice-soybean-rice × 15 August planting	24.51^{cd}	9.12^{bcd}	5.13^{b}
Rice-soybean-rice × 26 August planting	30.53^{e}	11.36^{cd}	6.39^{bc}

^{a} Within columns, means followed by the different letters are significantly different at $P\leq0.05$ as determined by the L.S.D. test.

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where an average of 75% reduction of weeds was observed in the crop rotation treatments combined with no tillage compared with the continuous rice treatment (Table 2). Compared with the continuous rice treatment, soybean cultivar planting times on 4 May, 15 August, and 26 August, 2002 and 2003 significantly (54, 43, and 29%, respectively) reduced the weed densities (Table 2).

The results of this study showed that crop rotation plus no tillage was the most useful combination of treatments that reduced the primary barnyardgrass, arrowhead, water plantain weeds in infested rice fields. A total of six weed types were recorded in the rice crop. The most abundant weeds were *Paspalum distichum*, *P. dilatatum*, *Cyperus* spp., *Carex nigra*, *Sorghum halepense*, and *Polygonum decipiens*.

Rice-soybean-rice rotation reduced density and dry matter (g m^{-2}) of weeds by about 62.5 and 80%, respectively, in comparison with continuous rice (Table 2 and 3). These reductions may be important in crop production systems since weed competition in rice is considered to be critical during the first week of growth (Moody, 1993), especially when no herbicides were used during the experiment.

DISCUSSION AND CONCLUSIONS

One of the major findings in our study is the reduction in barnyardgrass, arrowhead, and water plantain densities observed in treatments with no tillage and the rice-soybean-rice rotation compared with continuous rice. As suggested by Doran (1980), crop residue left on the soil surface after harvest may prevent seeds from reaching the surface and therefore reduce the spread of weeds and their severity. No-tillage, in most cases resulted in lower weed density.

The results obtained under these experimental conditions confirm that crop rotation, planting times, tillage practices, and the interaction of these factors, can influence the growth of barnyardgrass, arrowhead and water plantain weeds. While the severity of some weeds may be decreased with no and minimal tillage, others may be increased or not affected (Sumner *et al*. 1981; Cook and Haglund, 1991). A decrease in incidence of weeds caused by barnyardgrass, arrowhead and water plantain weeds has been observed in no tillage practice (Dreksen *et al*., 1993; Loeppky and Derksen, 1994; Lafond and Derksen, 1996) and with certain crop rotations (Crookston *et al*., 1991; Vyn *et al*., 1998). Frick and Thomas (1992) also observed a similar pattern in weed surveys in different cropping systems.

Compared to continuous rice, increased levels of N_2 fixation from decomposing soybean roots and nodules will lead to an increase in early root and shoot growth in rice rotation.

Table 3. Effects of rice-soybean-rice rotation on dry matter of *E. crus-galli*, *S. sagittifolia*, and *A. plantago-aquatica* weeds at 60 days after transplanting rice seedlings during 2002 and 2003[a].

Treatments	Weed dry matter (g m^{-2})		
	E. crus-galli	*S. sagittifolia*	*A. plantago-aquatica*
Continuous rice	105[a]	95[a]	88[a]
Rice-soybean-rice × No tillage	21[b]	33[b]	36[b]
Rice-soybean-rice × Minimum tillage	29[c]	38[b]	43[b]
Rice-soybean-rice × Chisel tillage	35[cd]	68[cd]	60[c]
Rice-soybean-rice × 4 May planting	27[bc]	35[b]	40[b]
Rice-soybean-rice × 15 August planting	30[c]	57[c]	56[c]
Rice-soybean-rice × 26 August planting	39[d]	74[d]	67[c]

[a] Within columns, means followed by the different letters are significantly different at $P \le 0.05$ as determined by the L.S.D. test.

The reduction in weed competition due to crop rotation observed in this experiment is in agreement with previous field investigations in which cropping sequence reduced weed density (Blackshaw *et al*., 1994; Loeppky and Derksen, 1994). In addition, Walker and Buchanan (1982) and Copeland *et al*., (1993) cited the allelophathic potential of residues on weed control. These results suggest that the use of a rice-soybean-rice rotation in sustainable rice production may be a useful practice for reducing weed competition in a reduced tillage system.

In summary, our study indicated that rice-soybean-rice rotation was the most useful treatment for the management of paddy weeds. In this study, rice-soybean-rice rotations appeared much more effective in controlling weed densities than continuous rice planting. Further studies are needed to confirm the long-term impact of rotation on paddy weeds to determine the mechanisms of action responsible for these effects observed.

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اثرات تناوب زراعی بر رقابت علف های هرز و عملکرد برنج در شالیزارهای شمال ایران

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چکیده

در سیستم های کشاورزی پایدار، تناوب زراعی یک عملیات ضروری برای کاهش رقابت علف های هرز و حاصلخیزی خاک محسوب می‌شود. بدین منظور آزمایش مزرعه‌ای در سالهای ۱۳۸۰ و ۱۳۸۱ برای تعیین اثرات تناوب زراعی، زمان کاشت و عمق شخم بر عملکرد برنج و تراکم و وزن خشک ۳ علف هرز مهم شالیزارهای شمال ایران در ایستگاه تحقیقات برنج چپرسر در منطقه تنکابن انجام گرفت. تیمارها شامل، کاشت مداوم برنج و تناوب برنج- سویا- برنج همراه با زمان‌های مختلف کاشت و سطوح مختلف شخم (شخم صفر، شخم حداقل و شخم با چیزل) بودند. تناوب زراعی دارای اثر معنی‌داری بر رشد علف‌های هرز سوروف (*Echinochloa crus-galli*)، تیرکمان آبی (*Sagittaria sagittifolia*) و بارهنگ آبی (*Alisma plantago-aquatica*) بود. کاشت مداوم برنج باعث تراکم بیشتر علف های هرز

سوروف، تیرکمان آبی و بارهنگ آبی در مقایسه با تیمار برنج- سویا- برنج گردید. وزن خشک و تراکم علف‌های هرز مزارع برنج در تناوب برنج- سویا- برنج کمتر از تیمار کاشت مداوم برنج بود. تراکم و وزن خشک علف‌های هرز در تناوب برنج- سویا- برنج نسبت به کاشت مداوم برنج به ترتیب ۶۲/۵ و ۸۰ درصد کاهش یافت. همچنین، میزان رشد علف‌های هرز سوروف، تیرکمان آبی و بارهنگ آبی در تیمار شخم صفر کمتر از تیمار شخم حداقل و شخم با چیزل بود. نتایج این تحقیق نشان داد که عملکرد برنج در تناوب برنج- سویا- برنج در سالهای ۱۳۸۰ و ۱۳۸۱ به ترتیب ۱۷ و ۲۱ درصد در مقایسه با کاشت مداوم برنج افزایش یافت.