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Weed succession as affected by repeated applications of the same herbicide in direct-seeded rice field

(Kesan penggunaan racun herba yang sama berulang kali dalam kawasan penanaman padi tabur terus terhadap sesaran rumpai)

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Key words: weed succession, direct-seeded rice, *Echinochloa crus-galli, Bacopa rotundifolia*

Abstrak

Kajian jangka panjang terhadap penggunaan racun herba berulang kali telah dijalankan di stesen MARDI Seberang Perai. Lapan perlakuan racun herba telah digunakan untuk mengkaji perubahan populasi rumpai, selama 10 musim berturutan bermula dari luar musim 1996 hingga luar musim 2001. Hanya sekali penggunaan racun herba dilakukan pada peringkat tanaman yang disyorkan pada setiap musim. Rumpai (residu) disampel untuk pengiraan dan penentuan berat kering pada 60 hari lepas tabur. "*Summed dominance ratio*" (SDR) untuk setiap perlakuan dikira dengan membandingkan kedominanan rumpai dan komposisinya antara musim.

Penggunaan sesejenis racun herba berulang kali sangat mempengaruhi kedominan dan komposisi spesies rumpai. Rumpai yang noksius iaitu *Echinochloa crus-galli* dominan di dalam petak yang menggunakan 2,4-D amine berulang kali. Manakala, *Monochoria vaginalis,* rumpai daun lebar menjadi dominan apabila molinat/propanil, bentiokarb/propanil, pretilaklor, quinklorak, propanil dan fenoksaprop-ethil digunakan berulang kali. Spesies rusiga saka, *Scirpus grossus* antara rumpai yang dominan dengan penggunaan quinklorak, propanil, pretilaklor, bentiokarb/propanil, fenoksaprop-ethil dan bensulfuron berulang kali. Seterusnya, rumpai ini menjadi paling dominan hanya pada musim-musim tertentu pada petak yang menggunakan bensulfuron berulang kali. Amnya, semua penggunaan racun herba menunjukkan pertambahan populasi yang ketara bagi spesies rumput saka, *Paspalum vaginatum*. Selanjutnya, populasi *Bacopa rotundifolia* meningkat pada musim ke-9 dan ke-10 dengan penggunaan bensulfuron.

Keputusan jangka panjang daripada penggunaan berulang kali sesuatu racun herba menunjukkan peningkatan populasi sesuatu spesies rumpai. Bagaimanapun, kebanyakan petak yang disembur dengan racun herba mengeluarkan hasil padi yang lebih tinggi daripada petak tanpa semburan sepanjang 10 musim kajian. Perbezaan hasil yang diperoleh daripada penggunaan racun herba alternatif adalah kecil sepanjang musim kajian. Keputusan ini menunjukkan penggunaan berulang kali sesuatu racun herba dalam keadaan tertentu sepatutnya dihadkan kepada dua atau tiga musim berturutan sahaja. Untuk penggunaan seterusnya, kaedah lain bagi mengawal rumpai haruslah diguna pakai.

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Abstract
A long term study on the effect of repeated use of the same herbicide on the changes in weed population was carried out at MARDI Station, Seberang Perai. Eight herbicide treatments were repeatedly applied for ten consecutive seasons commencing in off-season 1996 to off-season 2001. Only a single application of herbicide at the recommended crop stage was carried out in each season. Residual weeds were sampled for counting and dry weight determination at 60 days after sowing. Summed dominance ratio (SDR) for each treatment was calculated by comparing weed species dominance and composition between seasons.

The repeated used of a particular herbicide greatly influenced weed species dominance and composition. A noxious weed, *Echinochloa crus-galli* was dominant in plots repeatedly applied with 2,4-D amine. Whilst, a broad-leaved weed, *Monochoria vaginalis* became dominant when molinate/propanil, benthiocarb/propanil, pretilachlor, quinclorac, propanil and fenoxaprop-ethyl were used repeatedly. A perennial sedge, *Scirpus grossus* was among the dominant weed in plots repeatedly applied with quinclorac, propanil, pretilachlor, benthiocarb/propanil, fenoxaprop-ethyl and bensulfuron. However, this weed has become the most dominant weed in certain seasons in plots repeatedly applied with bensulfuron. Generally, all herbicide applications significantly showed an increase in a perennial grass, *Paspalum vaginatum* population. Furthermore, *Bacopa rotundifolia* was observed to increase in its population during season 9 and 10 in plots repeatedly applied with bensulfuron.

The long-term result from continuous use of a particular herbicide showed an increase in certain weed species population. However, the majority of herbicide treated plots produced higher grain yields than untreated plots for ten consecutive seasons. The differences in yields arising from the use of alternative herbicides were recorded in most seasons. These results suggested that successive applications of the same herbicides in some cases should be limited to only two or three seasons. In the case of further successive applications, other methods should be used to control the prevalent weed species.

Introduction

Ecological studies of weed-crop interactions are of fundamental importance to enhance the success of weed control operations. A knowledge of the community patterns and effect of edaphic, climatic and biotic factors on growth and reproduction, may help to gain insight in the mechanism of specialization and distribution of the species. Such studies may reveal the interactions between species and their environment, and thus offer an opportunity to locate vulnerable points at which the weed control operations can be undertaken. Even minor changes in the eco-climatic, edaphic and agro-biotic factors or tillage treatments may cause important changes in species association. Therefore, a knowledge of the life history of weeds and their interrelations with soil, climate, associated crop and agronomic practices is indispensable for evolving suitable methods of weed control (Moody 1983).

Weed management practices can be viewed either to limit weed population density to acceptable levels or to eradicate weed species totally from the cropping environment (Cousens and Mortimer 1995). In the former case, the goal is to halt population growth so that weed populations do not increase, whilst in the latter case the aim is to cause continuous population decline. In addition, ecological shift of weed species from broad-leaved weeds and sedges in transplanted rice culture to competitive grassy weeds in direct-seeded rice has been observed in tropical Asian countries where herbicides have been used continuously in weed control operations (Azmi and Baki 1995). The build-up of a certain weed species populations after the continuous use of a particular herbicide can be viewed in two possible ways; firstly the weed species is inherently very resistant to the herbicide and the elimination of its competitors favours its predominance; secondly, the weed species has gradually acquired resistant to the herbicide through continued absorption of the herbicide at sub-lethal concentrations.

Farmers have frequently reported seasonal variation in the abundance of weeds including perennial species, where rice is cropped twice a year in the main season (October–February) and in the off-season (April–August). However, an alternative response of the weed flora to serial herbicide use of the same herbicide may be weed succession towards a community of species naturally resilient to the means of control (Mortimer and Hill 1999). This experiment was conducted to determine the effect of repeated application of a particular herbicide on weed dominance and succession, and crop yield across seasons.

Materials and methods

The experiment was conducted at MARDI Station, Seberang Perai, Pulau Pinang over 10 cropping seasons from October 1996 to July 2001. Land previously intensively cropped with direct-seeded rice was unweeded in the off-season of 1995 and an area exhibiting a homogeneous weed flora identified. This was surveyed 60 days after seeding (DAS) and destructive biomass samples (twenty 1 m x 1 m random quadrats) quadrats of weed samples were randomly taken.

In September 1996, at the start of the experiment, 40 permanent 8 m x 8 m plots individually separated by 50-cm levees on a completely randomized block design were constructed. Eight herbicide treatments were assorted for each weeded and unweeded checks and also included per replicate *(Table 1).* A total of four replicates were used in this study. The levees prohibited movement of irrigation water from one plot to another. A 1.0-m gap in between the plots was used for irrigation purpose. Land was tilled twice to an average depth of 10 cm using a 2-wheel hand tractor. The first tillage (dry) was carried out 15 days after harvest and followed by the last tillage (wet) 10 days later. Levelling was done manually according to conventional farmer’s practice using a hand tool leaving a puddled soil devoid of weeds. Plots were tilled individually to prevent mixing of soil from different plots. After land preparation, pre-germinated rice seed [MR 84, (115–120 days to harvest) at a seeding rate of 60 kg/ha] was broadcast onto saturated soil, which remained drained to provide a conducive environment for crop establishment. Plots were inundated at 12 DAS and the water level maintained thereafter at 5–10 cm. In total, 100 kg of N/ha and 40 kg each of P_2O_5 and K_20 were applied to each crop. Two-thirds of N sources together with all of the P_2O_5 and K_2O were applied at 15 days after sowing (DAS). The remaining N was applied at the rice panicle initiation stage. Trebon (ethfenprox 10%) and sumicidin (fenvalerate 3%) were used for insect control. Drat (chlorophacinone) mixed with rice grains as rat bait was placed at 3 m intervals on the bund along the perimeter of the experimental plot 1–2 days before sowing.

Herbicides were applied manually with a lever-operated knapsack sprayer in 250 litres/ha at a spray pressure of 20–25 p.s.i. Eight herbicide treatments were chosen on the basis of common usage by Malaysian

Table 1. Weed management treatments. Soil condition at application time and target weed species are commercial recommendations for herbicide use

Treatment	Application		Soil condition at time of herbicide application	Target weed species
	Rate (kg a.i./ha)	Time (DAS)		
2,4-D amine	1.0	20	Standing water	*Monochoria vaginalis, Fimbristylis miliacea, Scirpus grossus, Sagittaria guyanensis, Limnocharis flava, Cyperus iria, Scirpus juncoides, Ludwigia hyssopifolia, Bacopa rotundifolia*
Bensulfuron	0.05	10	Standing water	*M. vaginalis, F. miliacea, C. iria, S. juncoides, S. guyanensis, B. rotundifolia*
Benthiocarb/propanil*	3.0	5	Saturated or drained	*Echinochloa crus-galli, Leptochloa chinensis* and some broad-leaved weeds and sedge weeds
Fenoxaprop-ethyl	0.1	30	Standing water	*E. crus-galli, L. chinensis*
Molinate/propanil*	3.3	10	Saturated, drained or standing water	*E. crus-galli, L. chinensis* and some broad-leaved weeds and sedge weeds
Pretilachlor	0.1	3	Saturated or drained	*E. crus-galli, L. chinensis* and some broad-leaved weeds and sedge weeds
Propanil	3.0	10	Saturated or drained	*E. crus-galli, L. chinensis*
Quinclorac	0.25	10	Saturated to standing water	*E. crus-galli*
2 x manual weeding	(15 & 30 DAS)			
Unweeded checks				

*Combined a.i.'s for mixtures only available
DAS = Days after sowing

farmers *(Table 1)*, in addition to manually weeded and unweeded checks.

Dates of planting varied seasonally *(Table 2)* and in seasons 5, 6 and 7, uncontrolled flooding due to excessive rainfall *(Figure 1)* affected crop stands and potentially the efficacy of all herbicides, except fenoxaprop and 2,4-D in seasons 5 and 6.

Weed biomass and number were assessed at 60 (± 1 day) DAS from four 1 m x 1 m quadrats per plot placed outside a central 5 m x 5 m reserved for yield determinations. Weeds were washed, sorted by species, dried at 80 °C to constant weight, then weighed. The summed dominance ratio (SDR) of the weed species was computed using the following equations (Janiya and Moody 1989):

$$\text{SDR} = \frac{\text{relative density (RD)} + \text{relative dry weight (RDW)}}{2}$$

where

$$\text{RD} = \frac{\text{density of a given species}}{\text{total density}} \times 100$$

$$\text{RDW} = \frac{\text{dry weight of a given species}}{\text{total dry weight}} \times 100$$

Table 2. Stand establishment in relation to seasonal practice

Season	Year	Date of planting	Uncontrolled flooding	Mean tiller density 30 DAS/25 cm x 25 cm
1. Main	1996/97	14 Oct. 1996	–	25.4
2. Off	1997	16 April 1997	–	27.8
3. Main	1997/98	30 Sept. 1997	–	26.3
4. Off	1998	2 May 1998	–	15.5 – rice thrips attack during seedling stage
5. Main	1998/99	27 Oct. 1998	15–24 Nov. 1998	7.0
6. Off	1999	23 April 1999	19–23 April 1999	26.1
7. Main	1999/2000	12 Oct. 1999	24–29 Oct. 1999	25.4
8. Off	2000	12 April 2000	–	26.7
9. Main	2000/01	12 Oct. 2000	–	18.9
10. Off	2001	28 April 2001	–	23.9

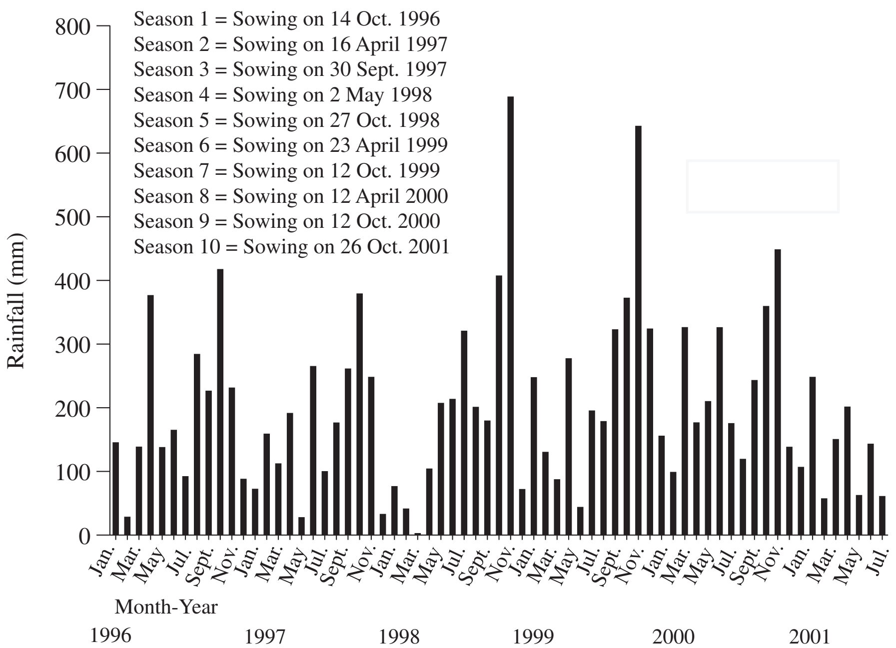

Figure 1. Rainfall distributions from January 1996 to July 2001, MARDI Rice Research Station, Pulau Pinang, Malaysia

Rice yields (in kg/ha at 14% moisture) was taken from a 5 m^2 harvest area in the centre of each plot.

Results and discussion

Prior to a proper trial, in the off-season 1995, weed diversity status was determined using quadrat method. There were 12 weed species observed under unweeded situations. Weed species ranked by relative dry weight were *Monochoria vaginalis* (62.5% RDW), *Ludwigia hyssopifolia* (18.6%), *Scirpus grossus* (5.14%) and *Echinochloa crus-galli* (4.36%) accounted for 90.6% of weed composition. Other weed species included *Limnocharis flava* (3.86% RDW), *Cyperus iria* (2.15%), *Fimbrystylis miliacea* (1.96%), *Scirpus juncoides* (1.19%), *sagittaria guyanensis* (0.09%), *Cyperus difformis*

(0.06%), *Najus graminea* (0.03%) and *Bacopa rotundifolia* (0.02%).

Weed species incidences varied among herbicide treated plots because of differences in weed control spectrum among the herbicides. The presence of some species was not particularly associated with a specific herbicide treatment except for a few species. Generally, bensulfuron, 2,4-D amine and benthiocarb/propanil gave better weed control than other herbicide treatments as shown by a lower summed dominance ratio of weeds across seasons *(Figure 2)*. An important broad-leaved weed, *M. vaginalis* was dominant when the plots were repeatedly applied with herbicide such as propanil, quinclorac, pretilachlor, molinate/propanil, benthiocarb/propanil, and fenoxaprop-ethyl. *(Figure 3)*. This weed was effectively controlled by bensulfuron, 2,4-D amine and benthiocarb/propanil as depicted by a lower percentage of SDR. Most herbicide treatments except bensulfuron and 2,4-D amine effectively reduced infestation of *E. crus-galli*, an annual grassy weed *(Figure 3)*. Evidently, high incidence of *E. crus-galli* populations was associated with plots subjected to 2,4-D amine and bensulfuron applications. Both 2,4-D amine and bensulfuron showed similar weed control spectrum on broad-leaved weeds and sedges except that repeated application of bensulfuron showed a drastic increased in abundance of *S. grossus* population *(Figure 4)*. Furthermore, *S. grossus* was dominant in plots repeatedly applied with most herbicides except molinate/propanil and 2,4-D amine. Repeated treatments with

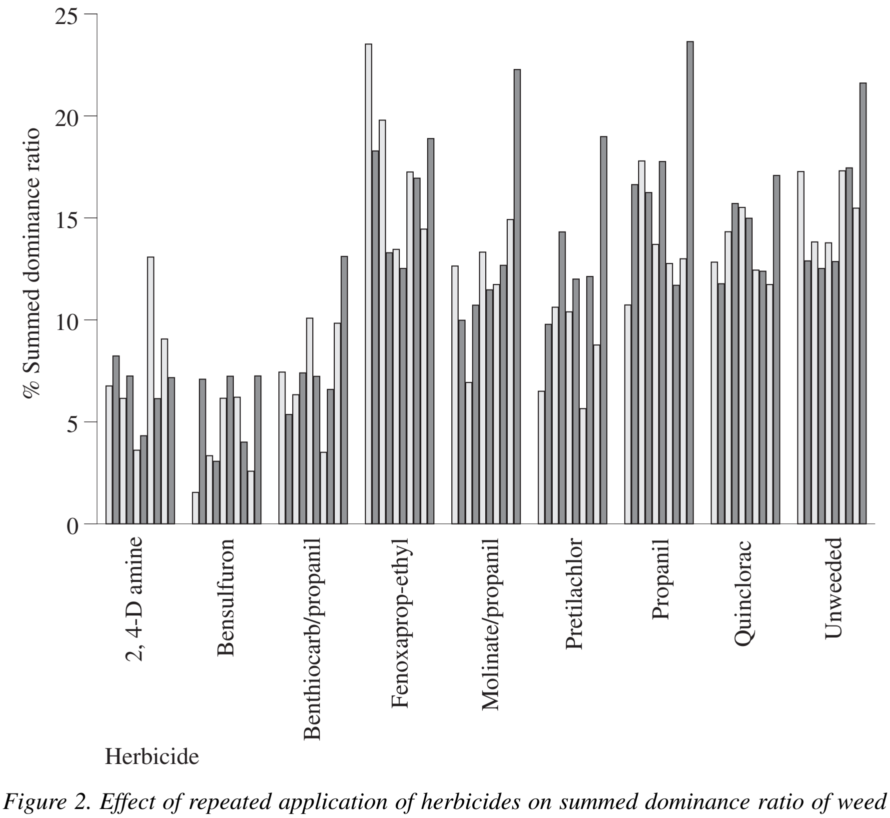

Figure 2. Effect of repeated application of herbicides on summed dominance ratio of weed species in direct-seeded rice across seasons. [Note: For every herbicide, the columns start with season 1 to season 10 (from left to right)]

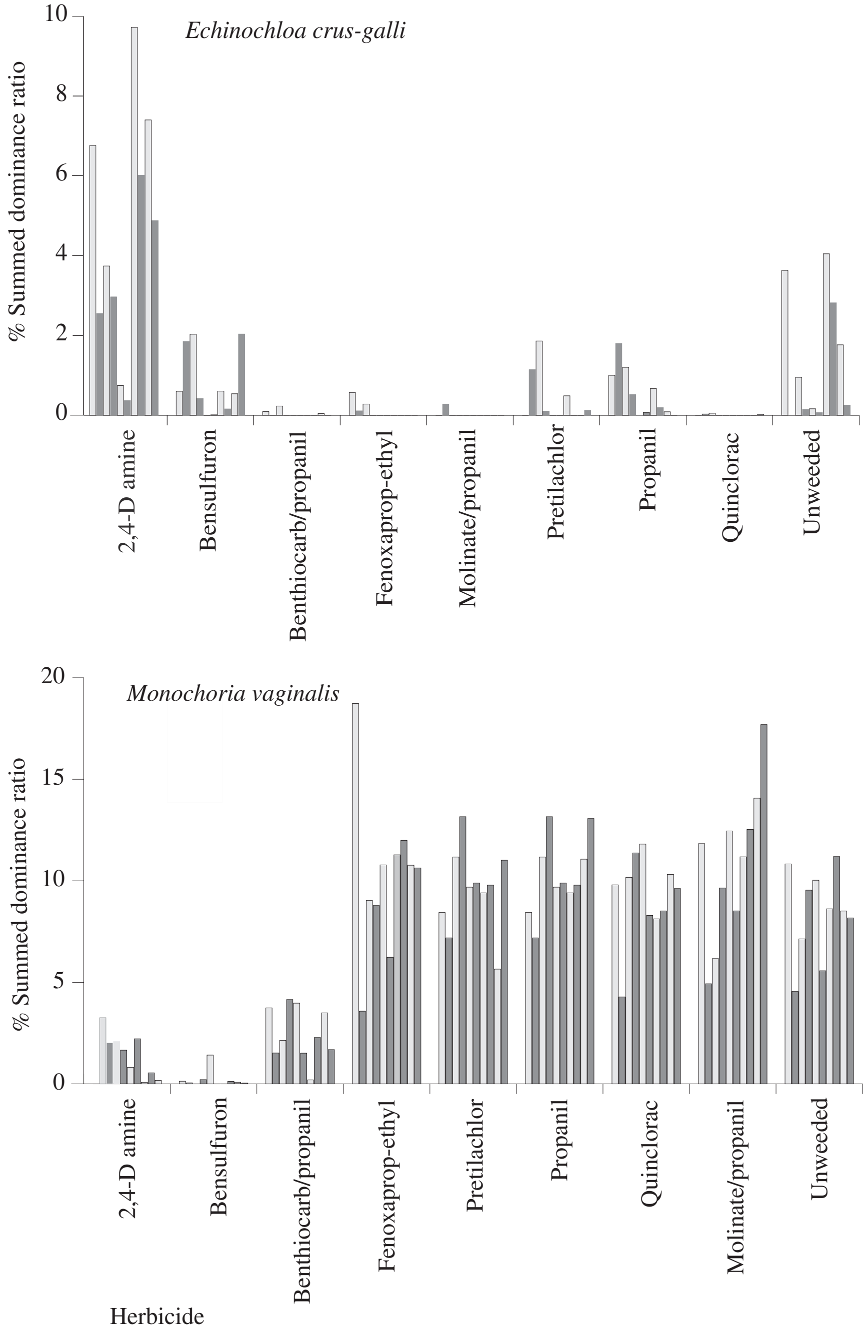

Figure 3. Effect of repeated application of herbicides on ***E. crus-galli*** *and* ***M. vaginalis*** *in direct-seeded rice across seasons. [Note: For every herbicide, the columns start with season 1 to season 10 (from left to right)]*

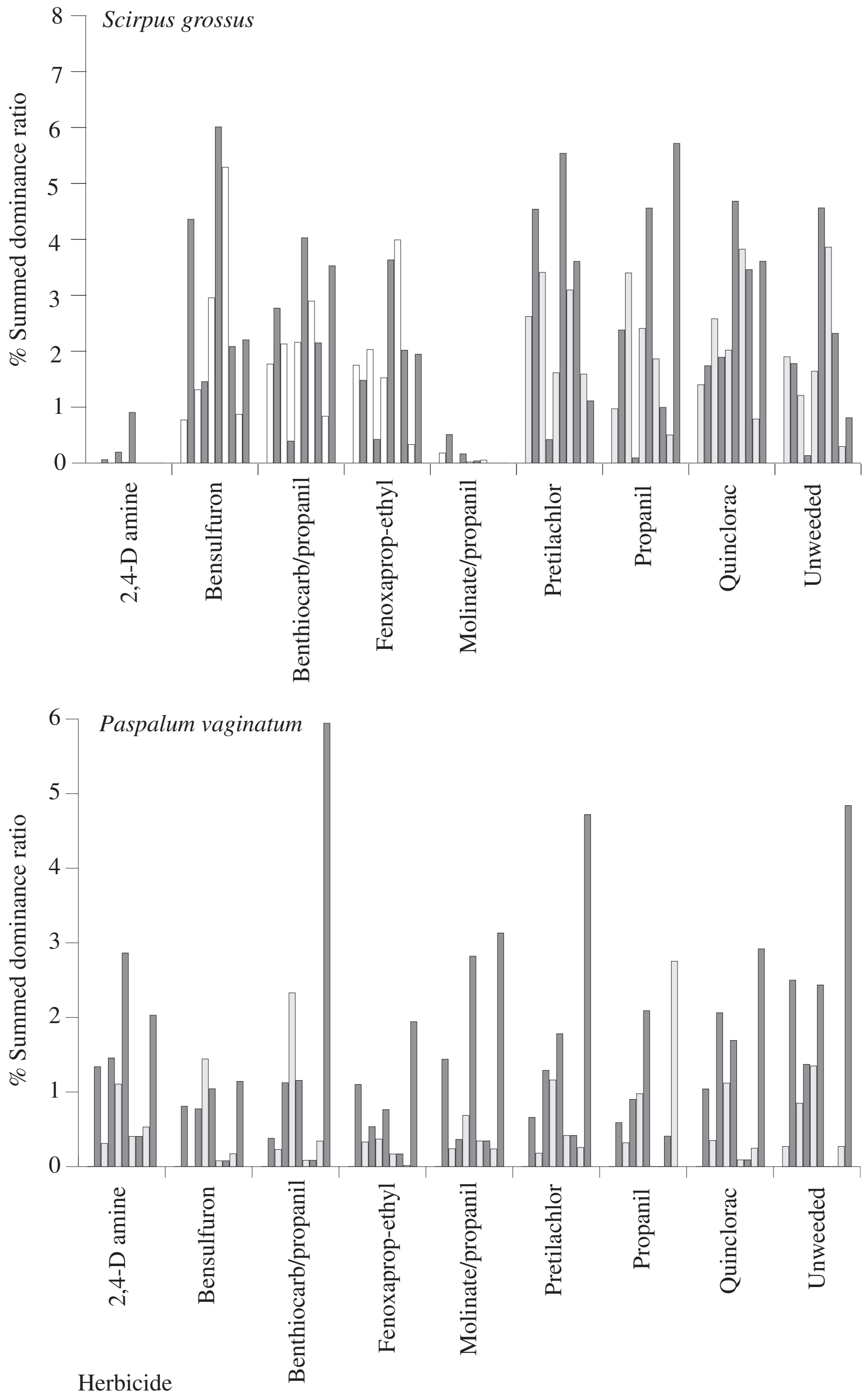

*Figure 4. Effect of repeated application of herbicides on **S. grossus** and **P. vaginatum** in direct-seeded rice across seasons. [Note: For every herbicide, the columns start with season 1 to season 10 (from left to right)]*

2,4-D amine and molinate/propanil for ten consecutive seasons were effective in suppressing *S. grossus* infestations.

Weed control practices applied to one crop can affect weed populations in the subsequent crop. Continued use of the herbicides on the same piece of land leads to an inevitable increase in tolerant weeds particularly perennials that are difficult to control (Moody 1991). In this study, perennial grassy weed i.e. *P. vaginatum* seems to be unaffected (independent) to any herbicide treatments *(Figure 4)*. Mahn and Helmecke (1979) noted that reliance on a single herbicide could result in quantitative changes in the structure of the weed population in as few as 5 years. As population stresses are shifted by herbicides, weeds of formerly secondary importance emerge as primary weed problems. In this case, *S. grossus* showed a drastic increase in population in most of the herbicide treatments except 2,4-D amine-treated plots.

In this study, it is very difficult to observe the resistant weed species in the first seven consecutive seasons. The same herbicides were used again in the following seasons in order to observe development of resistant biotype to a particular herbicide. The rise in population of *Bacopa rotundifolia* was observed in the ninth and tenth seasons in plots treated with bensulfuron methyl *(Plate 1)*. However, *B. rotundifolia*, an annual weed, could not be sampled at 60 DAS because it completed its life cycle at above 40 to below 55 DAS.

Grain yields were increased by herbicide treatments or hand weeding in Season 1 (main season 1996/97) *(Figure 5)*. The lowest yield was recorded in unweeded plots (3 963 kg/ha). Generally, rice yields in Season 2 to Season 10 were lower than that of Season 1. All herbicide treated plots and hand weeding gave higher yields than unweeded plots except for the fenoxaprop-ethyl treated plots. Season 5 recorded

Plate 1. High population of ***Bacopa rotundifolia*** *in plot repeatedly applied with bensulfuron for 9 consecutive seasons*

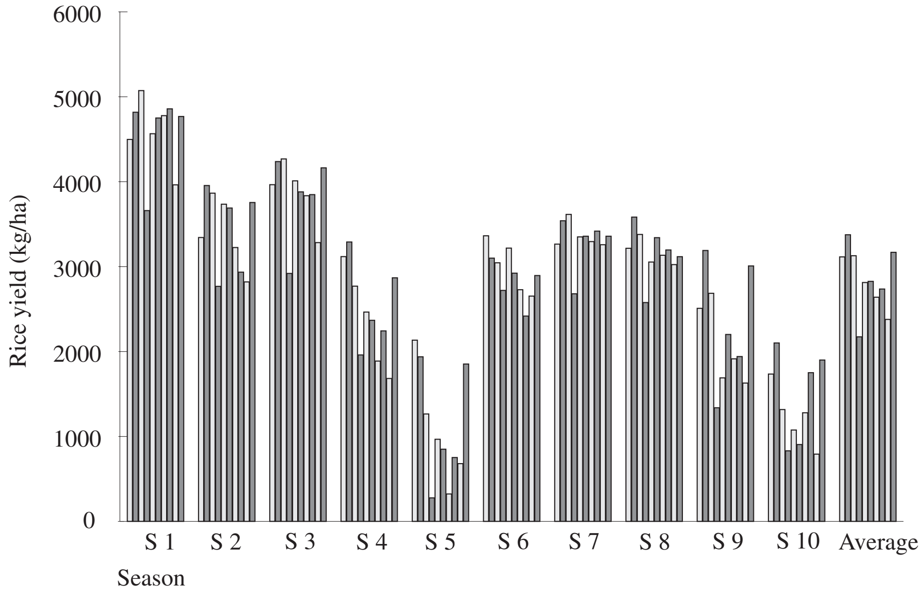

Figure 5. Effect of repeated application of the same herbicides on rice yields across seasons. [Note: For every season, the columns start with no. 1 = 2,4-D amine, 2 = Bensulfuron, 3 = Benthiocarb/propanil, 4 = Fenoxaprop-ethyl, 5 = Molinate/propanil, 6 = Pretilachlor, 7 = Propanil, 8 = Quinclorac, 9 = Unweeded and 10 = Manual weeding (from left to right)]

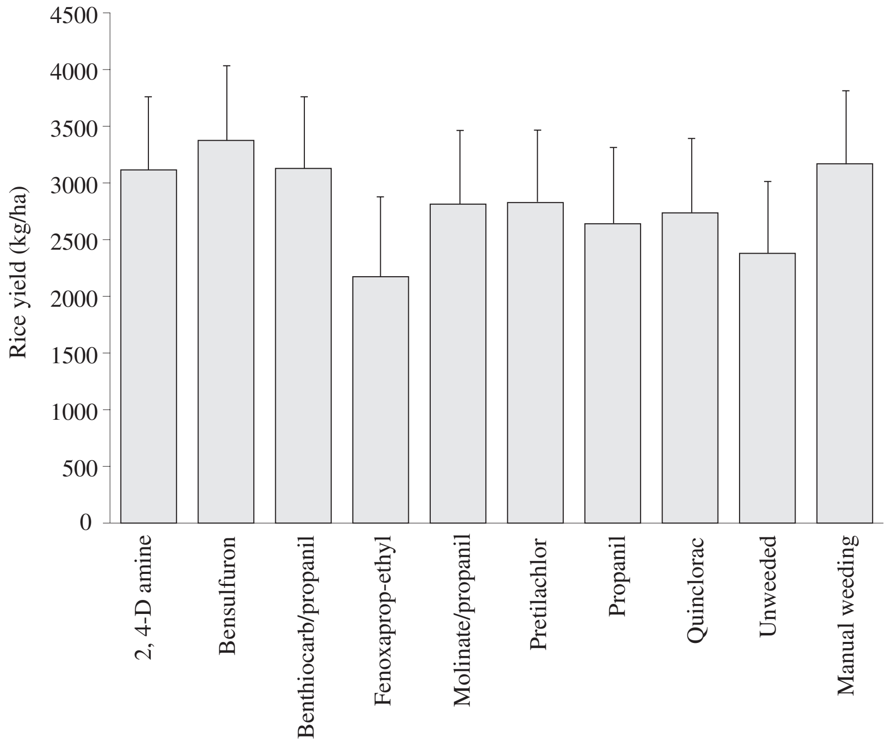

Figure 6. Average of rice yields for 10 consecutive seasons of repeated applications of the same herbicides in direct-seeded rice

inferior grain yields than the earlier seasons and at later seasons due to poor crop stand because of severe flooding during early crop stages *(Table 2)*. Generally, from the overall rice yield productions across seasons, bensulfuron, 2,4-D amine, benthiocarb/ propanil together with manual weeding gave better yields (above 3 000 kg/ha) than other herbicide treatments *(Figure 6).*

Conclusion

This study has confirmed two well established axioms in yield protection from competitive weeds in direct-seeded rice; the need for early weed control and characteristic inter-specific selection within the weed flora through the use of selective herbicides. All herbicides applied prior to the first 20 DAS afforded yield protection in comparison to fenoxaprop applied 30 DAS, while eliminating *E. crus-galli* resulted in the elevated of the other weed species. In the long term, rice yields were highest in bensulfuron-treated plots, although equivalent yield gains from other herbicide applications were achieved in individual seasons. The apparent superiority of bensulfuron for weed control in this study was a reflection of higher yields in season 4 and 5 when initial rice stands were poor. Moreover, manual weeding at 15 and 30 DAS in most seasons was as effective as individual herbicide applications suggesting that the replacement of manual weeding with herbicides may be largely driven by economic criteria.

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