The Use of Herbicides for Weed Control in Direct Wet-Seeded Rice (*Oryza sativa* L.) in Rice Production Regions in the Republic of Macedonia

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Abstract

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Field trials were conducted in the Agricultural Research Institute for Rice, at two localities during 2005 and 2006. The objective of the study was to establish an appropriate weed management strategy for the effective control of weed flora in direct wet-seeded rice. Herbicide selectivity and influence on grain yield were also evaluated. The weed population in the trials was composed of 8 and 5 weed species in Kočani and Probištip locality, respectively. The most prevailing weeds in both localities were: *Cyperus rotundus, Echinochloa crus-galli* and *Heteranthea limosa*. The average weediness for both years was 456.8 weed stems per m^2 in Kočani locality and 589.0 weed stems per m^2 in Probištip locality. In both localities all herbicides controlled *Cyperus rotundus, Echinochloa crus-galli* and *Heteranthera limosa* excellently except Mefenacet 53 WP. All applied herbicides showed high selectivity to rice, no visual injuries were determined at any rates in any year and locality. Herbicidal treatments in both localities significantly increased rice grain yield in comparison with untreated control.

Keywords: rice; herbicides; weed control; yield

Rice (*Oryza sativa* L.) is one of the world's most important food crops (Singh & Khush 2000). Currently, more than one third of the human population relies on rice for their daily sustenance. Worldwide, 530 millions tones of paddy rice at an average yield of 3.5 t/ha are harvested from 150 millions hectares annually, providing 21% of the world's food calorie supply. Almost 90% of the total crop is produced in Asia, where China and India are the major producers; only a small proportion of the world's rice is grown in temperate regions (Zimdahl 1988; McDonald 1994). In the Republic of Macedonia the total area under rice crop in 2005 and 2006 was about 2500 ha with average yield of 4030 kg/ha (Anonymous 2005). In the Republic of Macedonia the average rice yield is still low compared with many other countries, particularly the European ones. There are some abiotic and biotic factors contributing to the low yield. Weeds are the most serious biotic constraint to higher yields (De Datta & Bernasor 1973; Subhas & Jitendra 2001; Mandal *et al*. 2002). They are a major problem in all rice-production countries, including Macedonia, mainly because rice is grown mostly as a continuous crop. In rice crops worldwide, losses due to competitive effects of weeds are estimated at 10% to 15% of potential production (Smith 1983; Zoschke 1990; Baltazar & DeDatta 1992). On average in Europe, the potential reduction in rice yields due to uncontrolled weeds has been estimated at 55–60% (Oerke *et al*. 1994). Madrid *et al*. (1972) reported that losses in rice yields due to weeds ranged from 41% to 100%.

It has been estimated that without weed control, at a yield level of 7 t/ha to 8 t/ha, yield loss can be as high as about 90% (Ferrero 2003).

Weed management in rice is a combination of cultural and chemical tools (Baltazar & DeData 1992). Chemical control is the most commonly used and reliable method for controlling weeds in rice. The importance of their control was emphasised in the past by various authors (DeData & Baltazar 1996; Labrada 1996; Ze-Pu Zhang 1996). Chemical weed control has increased significantly over the last ten years. This is due to labour shortages, leading to an increased shift from transplanted rice to direct seeding, with a subsequent increase in herbicide use.

Taking into consideration the necessity of chemical weed control for stable rice production, the objective of this study was to investigate the effectiveness of some herbicides for controlling weeds in rice crop, and, at the same time, to estimate the influence of herbicides on rice yield.

MATERIAL AND METHODS

Field trails were conducted during 2005 and 2006 in Kočani and Probištip locality on alluvial soil and Vertisol, respectively. The trial was laid out in randomised complete block with four replications and harvest plot size of 25 m^2. The field trails were carried out with the rice variety Prima riska, which was drill-seeded into a well-prepared seedbed at a seeding rate of 200 kg/ha on May 10th, 2005 and May 15th, 2006 in Kočani locality, and May 22nd, 2005, and May 25th, 2006, in Probištip locality. Standard agronomic practices were used during both years of trials. The following treatments were included in the study (Table 1).

Herbicidal treatments were applied to rice at the tillering stage with a CO_2-pressurized backpack sprayer with 400 l/ha water. Weeds at the time of treatment were at the initial growth stages. Densities of the most prevailing weed species before herbicide applications were: *Cyperus rotundus* (268.5 stems/m^2) and *Echinochloa crus-galli* (119.4 stems/m^2) in Kočani locality, and *Cyperus rotundus* (216.3 stems/m^2), *Echinochloa crus-galli* (150.0 stems/m^2) and *Heteranthea limosa* (135.8 stems/m^2) in Probištip locality (Table 2).

Rice injury and weed control were estimated visually using a 0% to 100% scale, where 0% = no rice injury or no weed control and 100% = all rice plants dead or complete weed control (Frans *et al.* 1986). Rice injury was estimated 14 and 28 days after treatment (DAT). Weed control was estimated at 28 and 56 DAT.

Yield was determined after harvest based on the weight of grain containing 13% moisture. The data were finally subjected to statistical analysis applying LSD-test (Steel & Torrie 1980).

RESULTS AND DISCUSSION

Weed control

Cyperus rotundus, Echinochloa crus-galli and *Heteranthera limosa* infestations were heavy, while *Echinochloa macrocarpa, Scirpus mucronatus, Ammania coccinea, Rotala ramosior*, and *Leersia oryzoides* infestations were light throughout the experimental area in both years (Table 2).

The criterion for weed control was taken as the percentage of weeds that are controlled by any particular treatment in comparison with untreated control. According to data regarding the herbicide

Table 1. Trade names, active ingredients and rates of application of herbicides

Treatment	Active ingredient (a.i.)	Name of active ingredient	Rate (l/ha)
Untreated control	–	–	–
Stam F-34 + Bentazon	350 + 480 g/l	propanil + bentazon	14.0 + 4
Mefenacet 53 WP	490 + 40 g/kg	mefenacet + bensulfuron-methyl	1.5
Rainbow	26.7 g/l	penoxulam	1.0
Rainbow	26.7 g/l	penoxulam	1.2
Rainbow	26.7 g/l	penoxulam	1.5
Gulliver + Trend	500 g/kg	azimsulfuron + adjuvant	0.025 + 0.2
Gulliver + Trend	500 g/kg	azimsulfuron + adjuvant	0.030 + 0.2

Table 2. Weed population in the trials before herbicide application (average of both years)

Weed species	Kočani locality	Probištip locality
Cyperus rotundus	268.5	216.3
Echinochloa crus-galli	119.4	150.0
Heteranthera limosa	25.3	135.8
Echinochloa macrocarpa	14.8	–
Scirpus mucronatus	11.0	–
Ammania coccinea	9.8	56.6
Rotala ramosior	4.4	30.3
Leersia oryzoides	3.6	–
Total weed species	8	5
Total (weed stems/m^2)	456.8	589.0

efficacy presented in Table 3 and 4, we can see that all investigated herbicides had a significant ($P < 0.01$) effect on the reduction of weed stem number per m^2. The herbicide efficacy in control of prevailing weeds in both localities at 28 DAT ranged from 74% to 100% (Table 3). All herbicides controlled *Cyperus rotundus, Echinochloa crus-galli* and *Heteranthera limosa* excellently except Mefenacet 53 WP. Mefenacet 53 WP provided 78% and 84% control of *Echinochloa crus-galli* and *Heteranthera limosa*, respectively, in Kočani locality. Similar results in the control of *Echinochloa crus-galli* and *Heteranthera limosa* were obtained in Probištip locality (74% and 86%, respectively). Weed control at 56 DAT in both localities (Table 4) was similar to the previous assessment (78% to 100%). The efficacy of Mefenacet 53 WP in the control of *Echinochloa crus-galli* and *Heteranthera limosa* was in the range of 82% to 86% in Kočani locality and 78% to 89% in Probištip locality. A mixture of mefenacet and bensulfuron-methyl (Mefenacet 53 WP) showed the reduced control of *Echinochloa crus-galli* and *Heteranthera limosa* in both localities although mefenacet is mainly active against grass weeds (Hess *et al*. 1990) and bensulfuron-methyl is mainly active against sedges and broadleaf weeds (Vidotto *et al*. 2007; Osuna *et al*. 2002). Kim and In (2002) reported that the mixture of mefenacet

Table 3. Control of prevalent weeds in both localities at 28 DAT (average of both years)

Treatments	Rate (l/ha)	Weed control (%)					
		Kočani locality			Probištip locality		
		CYPRO	ECHCG	HETLI	CYPRO	ECHCG	HETLI
Untreated control	–	0	0	0	0	0	0
Stam F-34 + Bentazon	14,0 + 4	96**	95**	91**	97**	97**	94**
Mefenacet 53 WP	1.5	98**	78**	84**	97**	74**	86**
Rainbow	1.0	98**	99**	96**	98**	97**	100**
Rainbow	1.2	97**	100**	99**	99**	99**	100**
Rainbow	1.5	99**	100**	100**	99**	100**	100**
Gulliver + Trend	0.025 + 0.2	100**	93**	99**	99**	92**	100**
Gulliver + Trend	0.030 + 0.2	100**	96**	100**	100**	94**	100**
$LSD_{0.05}$		2.1	3.6	*2.3*	*1.8*	*2.9*	*2.6*
$LSD_{0.01}$		*2.9*	*4.9*	*3.1*	*2.5*	*3.9*	*3.6*

Significant level *$P < 0.05$, **$P < 0.01$, NS – non significant; CYPRO – *Cyperus rotundus*; ECHCG – *Echinochloa crus-galli*; HETLI – *Heteranthera limosa*

Table 4. Control of prevalent weeds in both localities at 56 DAT (average of both years)

Treatments	Rate (l/ha)	Weed control (%)					
		Kočani locality			Probištip locality		
		CYPRO	ECHCG	HETLI	CYPRO	ECHCG	HETLI
Untreated control	–	0	0	0	0	0	0
Stam F-34 + Bentazon	14.0 + 4	98**	98**	94**	99**	97**	95**
Mefenacet 53 WP	1.5	99**	82**	88**	98**	78**	89**
Rainbow	1.0	98**	100**	99**	99**	99**	100**
Rainbow	1.2	99**	100**	100**	99**	100**	100**
Rainbow	1.5	100**	100**	100**	99**	100**	100**
Gulliver + Trend	0.025 + 0.2	100**	95**	100**	100**	94**	100**
Gulliver + Trend	0.030 + 0.2	100**	99**	100**	100**	97**	100**
$LSD_{0.05}$		*1.4*	*2.6*	*2.1*	*1.3*	*2.5*	*2.9*
$LSD_{0.01}$		*1.8*	*3.5*	*2.8*	*1.8*	*3.4*	*4.0*

Significant level *$P < 0.05$, **$P < 0.01$, NS – non significant; CYPRO – *Cyperus rotundus*; ECHCG – *Echinochloa crus-galli*; HETLI – *Heteranthera limosa*

and bensulfuron-methyl controlled annual and perennial weeds at a level of 90%. Particularly high efficacy was shown by Rainbow (applied at 1.2 and 1.5 l/ha, respectively), followed by Gulliver + Trend (applied at both doses) which excellently controlled weeds in both localities. Similar findings were reported by many other authors. Shiracura *et al.* (1995) stated that azimsulfuron at a rate as low as 6 g a.i./ha afforded the excellent control of sedge and perennial weeds, especially of *Cyperus serotinus*. Only two of the resistant barnyardgrass biotypes in Greece were effectively controlled by azimsulfuron (0.02 kg a.i./ha) applied at the two-to-three leaf stage, but all biotypes were effectively controlled with addition of propanil (3.5 kg/ha) at the three-to-five leaf stage (Vasilakoglu *et al.* 2000). On the contrary, Vidotto *et al.* (2007) found that the fresh weight reduction of all *Echinochloa* population in Italian rice field sprayed with azimsulfuron averaged 55.1%, 70.9% and 76.9% at 0.5×, 1×, and 2× field rate, respectively. But, the linear contrast pointed out that *Echinochloa crus-galli* was significantly

Table 5. Grain yield and crop injury (average of both years)

Treatments	Rate (l/ha)	Grain yield (kg/ha)		Rice injury (%)	
		Kočani locality	Probištip locality	Kočani locality	Probištip locality
Untreated control	–	3260	2990	–	–
Stam F-34 + Bentazon	14.0 + 4	6620**	6185**	0	0
Mefenacet 53 WP	1.5	5980**	5500**	0	0
Rainbow	1.0	6755**	6290**	0	0
Rainbow	1.2	6780**	6430**	0	0
Rainbow	1.5	6830**	6560**	0	0
Gulliver + Trend	0.025 + 0.2	6750**	6480**	0	0
Gulliver + Trend	0.030 + 0.2	6795**	6580**	0	0
$LSD_{0.05}$		*319.07*	*388.53*		
$LSD_{0.01}$		*434.27*	*528.81*		

Significant level *$P < 0.05$, **$P < 0.01$, NS – non significant

more sensitive to azimsulfuron than *Echinochloa erecta* and *Echinochloa phyllopogon*.

Excellent control of *Echinochloa crus-galli* with penoxulam applied at the three-to-four leaf growth stage was reported by Ottis *et al.* (2003). Barnyardgrass control with penoxsulam was reported to be at least 99% at 21 days after application if applied alone and following the PRE application of clomazone (Ottis *et al.* 2004). Penoxulam applied in rates of 20 to 40 g a.i./ha provided 94% to 100% control of *Echinochloa oryzoides* and *Echinochloa phyllopogon* at the three-to-four leaf stage. However, mixtures of penoxulam at 20 or 30 g/ha with bentazon, azimsulfuron or MCPA resulted in reduced control of *Echinochloa phyllopogon* compared with a single application of penoxulam (Damalas *et al.* 2006).

Taking into consideration the fact that all investigated herbicides applied at the particular growth stages of rice possesses high selectivity to rice, no visual injuries were determined at any rates in any year and locality (Table 5).

Grain yield

The removal of the competitive effect of weeds led to an increase in the participation of the yield components of rice crops and as a result the grain production also increased. Herbicidal treatments in both localities had a significant ($P < 0.01$) effect on grain yield (Table 5). In both localities the lowest grain yield was recorded in untreated control plots (3260 and 2990 kg/ha, respectively) while the highest grain yield (6830 and 6580 kg/ha, respectively) was recorded in plots treated with Rainbow (1.5 l/ha) in Kočani locality and plots treated with Gulliver + Trend (0.030 +0.2 l/ha) in Probištip locality. Chin *et al*. (2000) reported a significant increase in rice yield after the application of herbicides in comparison with untreated controls. Herbicide treatments for the control of barnyardgrass doubled rice yields in Italian experiments (Tabacchi & Romani 2002). In experiments in Greece, the control of barnyardgrass led to a fourfold increase in rice yields (Ntanos *et al*. 2001). Talbert and Burgos (2007) found that penoxsulam did not injure rice and improved rice yields compared with standard propanil-based programs. Rice treated with penoxsulam (POST) yielded 3110 and 2730 kg/ha with and without the addition of clomazone PRE, respectively, in comparison with 1140 kg/ha in untreated plots (Griffin 2006).

Weed management is a fundamental practice in rice cultivation. Unsuccessful weed control can result in the almost total loss of rice yield. In view of these encouraging results, the application of herbicides suitable for every floristic situation led to minimization of yield losses, and at the same time, to an increase in the quality and quantity of rice crops.

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