Control of *Echinochloa crus-galli* in Rice with Different POST Herbicide Treatments

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SUMMARY

The field trials were conducted at two localities during 2013 and 2014 to evaluate different POST herbicide programs for effective *E. crus-galli* control in rice production regions in the Republic of Macedonia. Herbicide selectivity and influence on grain yield were evaluated, as well. Herbicides were applied in 3 POST herbicide programs: early-postemergence (EPOST), mid-postemergence (MPOST) and late-postemergence (LPOST). *E. crus-galli* control differed among POST herbicides, herbicide programs, and DAT. In Kočani locality *E. crus-galli* control across POST herbicide programs was 95 to 92% at EPOST and MPOST treatments at 14 DAT, and 99 to 98% at 28 DAT, respectively. Significantly lower efficacy was provided in LPOST treatment (87% and 83%) at both estimation periods. *E. crus-galli* control across POST herbicide programs in Vinica locality was similar as in Kočani locality. 14 DAT efficacy was ranged between 97 and 93% at EPOST and MPOST treatments, and 28 DAT efficacy was ranged between 99 and 97% at same POST treatments, respectively. Significantly lower efficacy was provided in LPOST treatment (82% and 81%, 14 and 28 DAT, respectively). In both localities all EPOST and MPOST applied herbicides resulted in rice yield which was not statistically different from rice yield in the weed-free control. Because each LPOST herbicide provided lower *E. crus-galli* control, and caused rice injury, there was significant yield reduction in all plots treated with LPOST herbicides.

Key words: *Echinochloa crus-galli*, rice POST treatments, injury, yield

INTRODUCTION

Echinochloa crus-galli (L.) P. Beauv. (barnyardgrass) occurs with great frequency and distribution in lowland flooded rice system in all rice-growing areas (Dowler, 1997; Andres et al., 2007), including rice production regions in the Republic of Macedonia (Pacanoski and Glatkova, 2009). *E. crus-galli* is reported to be among the three most serious weeds of rice in many countries in Asia, and is a major weed in a wide range of crops throughout the tropical and subtropical world (Holm et al., 1991). This weed is highly competitive with rice due to its adaptation to flooded environments, high seed production, rapid growth and C4-photosynthetic pathway (Marambe and Amarasinghe, 2002). This weed is a very aggressive invader, difficult to control, and causes major losses in rice production (Lopez-Martinez et al., 1999). In particular, season-long competition from *E. crus-galli* has been reported to reduce rice yield by 28 to 65% (Smith, 1988) and by 21 to 40% (Stauber et al., 1991), depending largely on rice cultivar as well as density and spatial distribution of its population. It competes with crops for nutrients, water and light. Some infestations of *E. crus-galli* have been shown to remove 60 to 80% of available nitrogen (N) from soil (Holm et al., 1977; cit. by Ottis and Talbert, 2007). In India, Varghese and Nair (1986) concluded that it competed with transplanted rice for N and K during 11-50 days after planting (DAP) and for P during 21-40 DAP.

Several POST herbicides are currently registered in the Republic of Macedonia to control *E. crus-galli*. Cyhalofop and profoxydim are aryloxyphenoxy propionate and cyclohexanedione, respectively, POST herbicides that inhibit acetyl-CoA carboxylase. Cyhalofop has been reported to control barnyardgrass at least 88% when applied early POST (EPOST) as well as late POST (LPOST) at 200 g ai/ha (Ntanos et al., 2000). Vidotto et al., (2007) and Kaloumenos et al., (2013) reported for high level of control (95–100%) of the two *E. crus-galli* accessions with profoxydim applied at 200 g/ha. Profoxydim and cyhalofop-butyl were effective alternatives for the management of *E. crus-galli* resistant biotypes to ALS-inhibiting herbicides, as well (Matzenbacher et al., 2013). Penoxsulam is a triazolopyrimidine sulfonamide herbicide and acts by inhibiting the acetolactate synthase (ALS) enzyme (Lassiter et al., 2004). It is broad-spectrum herbicides registered for weed control in rice. Penoxsulam provides control of *Echinochloa* spp. (Lassiter et al., 2006). Azimsulfuron is sulfonylurea applicable during post emergence of *E. crus-galli* and rice. Same as penoxulam, this herbicide restrains ALS action on susceptible weeds (Ferrero et al., 2002). Applied at 20 g/ha a.i., with a nonionic surfactant at 0.1% v/v, it gives good control of *E. crus-galli* (Massasso et al., 1996). Azimsulfuron has been reported to control *E. crus-galli* at least 92% when applied at 0.025 and 0.030 g/ha with NIS Trend-90 at 0.2 L/ha (Pacanoski and Glatkova, 2009).

Taking into consideration that only POST herbicides are registered for *E. crus-galli* control in rice crop in the Republic of Macedonia, and that timing of its germination and growth in rice paddy fields is under considerable variations, particularly environmental conditions, consistency of POST weed-control strategies is variable and highly influenced by weed growth stage and environment. Therefore, the objective of this study was to evaluate different POST herbicide programs for effective *E. crus-galli* control and optimal rice yield in rice production regions in the Republic of Macedonia.

MATERIAL AND METHODS

The field trials were conducted during 2013 and 2014 on commercial rice fields in Kočani and Vinica localities in eastern Macedonia. The soil at Kočani locality was a fluvisol sandy loam with 2.8% coarse, 7.7% coarse sand, 63.1% sand, 26.4% silt+clay, 2.66% organic matter and pH of 6.7. The soil at Vinica locality was vertisol with 3.5% coarse, 9.1% coarse sand, 30.0% sand, 60.3% silt+clay, 2.4% organic matter and pH of 7.2 (Filipovski, 2006). The seedbed was prepared by moldboard plowing in the autumn followed by two passes with a field cultivator in the spring. Phosphorus and potassium fertilizers were added before sowing at a rate of 50 and 80 kg/ha as super phosphate (15.5 % P_2O_5) and potassium sulphate (48% K_2O), respectively. Nitrogen fertilizer was added at a rate of 150 kg N/ha as ammonium nitrate (33.5% N) in two equal doses in the tillering stage and in the panicle initiation stage. Standard water management practices were used, so the plots were flooded 2 days before rice sowing. The field trials were carried out with Italian rice varieties "Gloria" and "Opale" which were drill-seeded in a well-prepared seedbed at a seeding rate of 230 and 200 kg/ha, respectively on May 1st, 2013 and May 5th, 2014 in Kočani locality, and May 12th, 2013, and May 15th, 2014, in Vinica locality, respectively.

The experimental design was a randomized complete block with four replications consisting of 3 POST herbicide programs. POST herbicide treatments were applied in early-postemergence (EPOST), mid-postemergence (MPOST) and late-postemergence (LPOST) periods, which were applied on June 10th, 17th and 24th in 2013, and June 12th, 20th and 27th in 2014, respectively in Kočani locality, and on June 15th, 22nd and 29th in 2013, and June 17th, 25th and July 1 in 2014, in Vinica locality respectively. In POST weed control study were included four herbicide treatments: penoxulam (Rainbow 26.7 g a.i./L, Dow AgroSciences, Indianapolis, Indiana US) at 1.5 L/ha, cyhalofop-buthyl (Clincher duo 200 g a.i./L, Dow AgroSciences, Indianapolis, Indiana US) at 1.5 L/ha azimsulfuron (Gulliver 500 g a.i./L, E.I. du Pont de Nemours and Company, Wilmington, Delaware, US) at 0.04 kg/ha, and proflodim (Aura 200 g a.i./L, BASF Agro B.V.,

Arnhem, NL, Switzerland) at 1.0 L/ha. All herbicides were applied with a CO₂-pressurized backpack sprayer calibrated to deliver 300 L/ha aqueous solution at 220 kPa in drained plots, which were reflooded 2 days after treatment (DAT). Untreated and weed-free controls were included in the studies, as well. The control plots were left untreated during the entire experimental period. Weed-free control was maintained by hand weeding. Hand-weeding was initiated at weeds emergence and continued as needed to maintain weed-free plots. Both sites were naturally infested with a high population of *Echinochloa crus-galli*. Weed densities in non treated control plots was 87 and 112 plants/m² in 2013 and 2014, respectively, in Kočani locality, and 69 and 93 plants/m² in 2013 and 2014, respectively, in Vinica locality. When EPOST treatments were applied, rice was at the tillering stage (BBCH 26), and *E. crus-galli* was at the beginning of tillering stage (BBCH 21-23). During MPOST treatments were applied, rice and *E. crus-galli* were at the end of tillering stage (BBCH 29), while at LPOST treatments, rice and *E. crus-galli* were at the stem elongation stage (BBCH 32-34).

Rice injury and percent weed control were visually evaluated based on a 0% - 100% rating scale, where 0 is no injury to rice plants or no weed control, and 100 is complete death of rice plants or complete control of weeds (FRANS et al., 1986). Rice injury was estimated 28 days after treatments (DAT), while *E. crus-galli* control efficacy was estimated 14 and 28 DAT from 1m² area within each plot at both localities during two-year experimental period. Yield was determined after harvest based on weights of grain containing 13% moisture.

The data were tested for homogeneity of variance and normality of distribution (Ramsey and Schafer, 1997) and were log-transformed as needed to obtain roughly equal variances and better symmetry before ANOVA were performed. Data were transformed back to their original scale for presentation. Means were separated by using LSD test at 5% of probability.

RESULTS AND DISCUSSION

***Echinochloa crus-galli* control.** *Kočani locality.* *E. crus-galli* control differed among POST herbicides, herbicide programs, and DAT. All EPOST applied herbicides controlled *E. crus-galli* 89 to 92% 14 DAT (Table 1). Because of prolonged affecting of all investigated herbicides (ALS and ACCase inhibitors) (Whitcomb, 1999; Böger et al., 2002), control of *E. crus-galli* was significantly improved 28 days after EPOST treatment. Penoxulam and profoxidim provided 100% control, while cyhalofop-butyl and azimsulfuron provided identical 98% control of *E. crus-galli* (Table 2). Efficacy of herbicides in control of *E. crus-galli* 14 days after MPOST treatment was insignificantly lower than the same period during EPOST treatment. All herbicides provided

control of *E. crus-galli* between 85 and 91% (Table 1). Significant increasing (8-11%) in control of *E. crus-galli* was recorded during second estimation, 28 days after MPOST treatment. Penoxulam showed excellent (99%) control of *E. crus-galli*; similar, other herbicides controlled *E. crus-galli* between 96 and 97% (Table 2). During LPOST treatment, efficacy of herbicides in control of *E. crus-galli* was significantly lower in compare to EPOST and MPOST treatments, respectively probably due to advanced weed growth stage (stem elongation stage - BBCH 32-34). 14 DAT profoxidim and cyhalofop-buthyl provided efficacy of 83 and 85%, respectively, while azimsulfuron and penoxulam reduced the amount of *E. crus-galli* in the rice crop by 79 and 80% (Table 1). Further decreasing in *E. crus-galli* control was noted 28 DAT. All herbicides controlled *E. crus-galli* between 75 and 81% (Table 2). *E. crus-galli* control averaged across POST herbicide programs was 95 to 92% at EPOST and MPOST treatments at 14 DAT, and 99 to 98% at 28 DAT, respectively. Significantly lower efficacy was provided in LPOST treatment (87% and 83%) at both estimation periods (Table 3).

Table 1. *E. crus-galli* control 14 days after EPOST, MPOST and LPOST herbicide treatments, respectively in flooded rice in Kočani and Vinica localities (average for both years)^a

Treatment	Rate (L;kg/ha)	Kočani locality			Vinica locality		
		EPOST ^b	MPOST ^c	LPOST ^d	EPOST	MPOST	LPOST
		% ^e					
Non-treated control	-	0	0	0	0	0	0
penoxulam	1.5	91 ^a	90 ^{ab}	80 ^{ab}	90 ^a	88 ^a	81 ^a
cyhalofop-buthyl	1.5	91 ^a	90 ^{ab}	83 ^{ab}	91 ^a	90 ^a	84 ^a
azimsulfuron	0.04	89 ^a	85 ^b	79 ^b	87 ^a	82 ^b	80 ^a
profoxidim	1.0	92 ^a	91 ^a	85 ^a	91 ^a	89 ^a	85 ^a
LSD (0.05)		4.02	5.25	5.24	4.40	5.50	5.54

^a Abbreviations: EPOST-early-postemergence; MPOST-mid-postemergence; LPOST-late-postemergence

^b EPOST treatments were applied at rice BBCH 26, *E. crus-galli* BBCH 21-23

^c MPOST treatments were applied at rice BBCH 29, *E. crus-galli* BBCH 29.

^d LPOST treatments were applied at rice BBCH 32-34, *E. crus-galli* BBCH 32-34.

^e Means followed by the same letter within a column are not significantly different according to Fisher's Protected LSD at P<0.05

Table 2. *E. crus-galli* control 28 days after EPOST, MPOST and LPOST herbicide treatments, respectively in flooded rice in Kočani and Vinica localities (average for both years)^a

Treatment	Rate (L;kg/ha)	Kočani locality			Vinica locality		
		EPOST ^b	MPOST ^c	LPOST ^d	EPOST	MPOST	LPOST
		% ^e					
Non-treated control	-	0	0	0	0	0	0
penoxulam	1.5	100 ^a	99 ^a	78 ^a	98 ^a	98 ^a	78 ^a
cyhalofop-buthyl	1.5	98 ^a	97 ^{ab}	80 ^a	100 ^a	100 ^a	82 ^a
azimsulfuron	0.04	98 ^a	96 ^b	75 ^a	98 ^a	95 ^b	76 ^a
profoxidim	1.0	100 ^a	97 ^{ab}	81 ^a	100 ^a	98 ^a	81 ^a
LSD (0.05)		2.06	2.49	6.59	2.01	2.86	7.11

^a Abbreviations: EPOST-early-postemergence; MPOST-mid-postemergence; LPOST-late-postemergence

^b EPOST treatments were applied at rice BBCH 26, *E. crus-galli* BBCH 21-23

^c MPOST treatments were applied at rice BBCH 29, *E. crus-galli* BBCH 29.

^d LPOST treatments were applied at rice BBCH 32-34, *E. crus-galli* BBCH 32-34.

^e Means followed by the same letter within a column are not significantly different according to Fisher's Protected LSD at P<0.05

Table 3. Control of *E. crus-galli* by different POST herbicide treatments at different DAT in flooded rice in Kočani and Vinica localities in 2013 and 2014, averaged over herbicide program.^{a-c}

POST Treatments	<i>E. crus-galli</i> control			
	Kočani locality		Vinica locality	
	%			
	14 DAT	28 DAT	14 DAT	28 DAT
EPOST	95 ^a	99 ^a	97 ^a	99 ^a
MPOST	92 ^a	98 ^a	93 ^a	97 ^a
LPOST	87 ^b	83 ^b	82 ^b	81 ^b
LSD (0.05)	4.16	5.67	5.05	6.14

^a Herbicide treatments included penoxulam (Rainbow 26.7 g a.i./L, Dow AgroSciences, Indianapolis, Indiana US) at 1.5 L/ha, cyhalofop-buthyl (Clincher duo 200 g a.i./L, Dow AgroSciences, Indianapolis, Indiana US) at 1.5 L/ha, azimsulfuron (Gulliver 500 g a.i./L, E.I. du Pont de Nemours and Company, Wilmington, Delaware, US) at 0.04 kg/ha, and profoxidim (Aura 200 g a.i./L, BASF Agro B.V., Arnhem, NL, Switzerland) at 1.0 L/ha applied EPOST, MPOST and LPOST

^b Means followed by the same letter within a column are not significantly different according to Fisher's Protected LSD at P<0.05

^c Abbreviations: EPOST-early-postemergence; MPOST-mid-postemergence; LPOST-late-postemergence.

Vinica locality. Herbicides efficacy in control of *E. crus-galli* in Vinica locality was similar as in the previous locality. 14 days after EPOST treatment investigated herbicides controlled *E. crus-galli* between 87 and 91% (Table 1). The continued affecting of herbicides increased their efficacy in *E. crus-galli* control for 9 to 11% during the second estimation (28 day after EPOST treatment). Cyhalofop-buthyl and profoxidim, as well as penoxsulam and azimsulfuron provided identical *E. crus-galli* control, 100 and 98%, respectively (Table 2). At MPOST treatment, efficacy of herbicides in control of *E. crus-galli* 14 DAT was negligible lower than the same period during EPOST treatment. Penoxulam, profoxidim and cyhalofop-buthyl provided control of *E. crus-galli* between 88 and 90%, while azimsulfuron provided 82% control of the same weed (Table 1). Considerable improving of efficacy was noted during the second estimation, 28 days after MPOST treatment. All herbicides provided control of *E. crus-galli* in the rice crop more than 95% (Table 2). During LPOST treatment, efficacy of herbicides in control of *E. crus-galli* 14 days after LPOST treatment was significantly lower than the same period during EPOST and MPOST treatments. Control of this weed in the rice crop was ranged between 80 and 85% (Table 1). Because of regeneration (recovered) of some *E. crus-galli* plants, decreasing of herbicides efficacy was noted 28 days after LPOST application. Profoxidim and cyhalofop-buthyl controlled *E. crus-galli* 81 and 82%, respectively while azimsulfuron and penoxulam provided 76 and 78% control of this weed (Table 2). *E. crus-galli* control averaged across POST herbicide programs was similar as in Kočani locality. 14 DAT efficacy was ranged between 97 and 93% at EPOST and MPOST treatments, and 28 DAT efficacy was ranged between 99 and 97% at same POST treatments, respectively. Significantly lower efficacy was provided in LPOST treatment (82% and 81%) at both estimation periods (Table 3).

Similar results were reported by other authors. Ntanos et al., (2000) reported 85 to 95% *E. crus-galli* control in drained plots 30 DAT with cyhalofop-butyl applied EPOST at 150 g ai/ha. Barnyardgrass control with cyhalofop-butyl applied LPOST at same rate was 75%. Barnyardgrass control with penoxsulam applied alone early postemergence (EPOST) and mid-postemergence (MPOST) was greater than 99% (Ottis et al., 2003). Two of the resistant barnyardgrass biotypes in Greece were effectively controlled by azimsulfuron (0,02 kg ai/ha) applied at 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 x, 1 x, and 2 x field rate, respectively. But, linear contrast pointed out that *E. crus-galli* was significantly more sensitive to azimsulfuron than *Echinochloa erecta* and *Echinochloa phyllopogon*. Excellent control of *E. crus-galli* with

penoxulam applied at three-to four leaf growth stage has been reported by Ottis et al., (2003). Barnyardgrass control with penoxsulam has been reported to be at least 99% at 21 days after application applied alone and following a PRE application of clomazone (Ottis et al., 2004). Penoxulam applied in rates of 20 to 40 g ai/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).

Grain rice yield

E. crus-galli competition caused large reductions in the rice yield. Hill et al., (1985) cit. by Moon et al., (2010) reported that *E. crus-galli* cause more than 50% of rice yield with dense infestation without proper control. In Greece, season-long *E. crus-galli* competition at densities of 10 plants/ m² reduced yield by 30% (Ntanos et al., 1992). In Korea, according Kwon et al., (2007), the yield of rice was reduced by 51-60%. with densities of 96 *E. crus-galli* plants/m². In China, densities of only 25 plants/m² reduced rice yield by 50% (Chin, 2001), while VanDevender et al., (1997) reported that 20 *E. crus-galli* plants/m² can reduce the rice yield by 80%. Comparison of untreated and weed-free control indicated that *E. crus-galli* reduced average rice yield by 42% and 40% in Kočani and Vinica locality, respectively. Rice yields in all POST herbicide treatments, except LPOST, were nearly twice greater than the nontreated control in both localities (Table 4). Herbicide treatments for control of *E. crus-galli* doubled rice yields in Italian experiments (Tabacchi and Romani, 2002), while in experiments in Greece, control of *E. crus-galli* led to a four-fold increase in rice yields (Ntanos, et al., 2000). Chin et al., (2000) have reported a significant increase in rice yield with application of herbicides in compare with untreated controls, as well.

In general, rice yields followed the variations in *E. crus-galli* control with yields increasing as its control with the various POST treatments increased. In both localities all EPOST and MPOST applied herbicides resulted in rice yield which was not statistically different from rice yield in the weed-free control (Table 4). Opposite, rice yield at LPOST treatments was statistically lower compare with the rice yield in the weed-free control. Because each LPOST herbicide provided lower *E. crus-galli* control, and caused rice injury (Table 5), there was significant yield reduction in all plots treated with LPOST herbicides (Table 4). Ntanos et al. (2000) reported similar results about greater rice yields when cyhalofop-butyl at 0.2 kg/ha was applied EPOST than when it was applied LPOST. 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⁻¹, respectively with and without the addition of clomazone PRE, in compares with 1140 kg/ha⁻¹ in nontreated plots (Griffin, 2006).

Table 4. Rice grain yield as influenced by EPOST, MPOST and LPOST applied herbicides in flooded rice in Kočani and Vinica localities (average for both years)^{a-c}

Treatment	Rate (L;kg/ha)	Kočani locality			Vinica locality		
		EPOST	MPOST	LPOST	EPOST	MPOST	LPOST
		kg/ha					
Non-treated control		3710 ^b	3710 ^b	3710 ^d	3950 ^b	3950 ^b	3950 ^c
Weed-free control	-	6530 ^a	6530 ^a	6530 ^a	6640 ^a	6640 ^a	6640 ^a
penoxulam	1.5	6580 ^a	6510 ^a	6130 ^c	6620 ^a	6590 ^a	6280 ^b
cyhalofop-buthyl	1.5	6520 ^a	6480 ^a	6200 ^{bc}	6600 ^a	6550 ^a	6340 ^b
azimsulfuron	0.04	6470 ^a	6420 ^a	6060 ^c	6680 ^a	6570 ^a	6350 ^b
profoxidim	1.0	6550 ^a	6490 ^a	6280 ^b	6690 ^a	6630 ^a	6330 ^b
LSD (0.05)		118.67	127.00	144.97	153.74	138.82	130.40

^a Abbreviations: EPOST-early-postemergence; MPOST-mid-postemergence; LPOST-late-postemergence

^b Herbicide treatments included penoxulam (Rainbow 26.7 g a.i./L, Dow AgroSciences, Indianapolis, Indiana US) at 1.5 L/ha, cyhalofop-buthyl (Clincher duo 200 g a.i./L, Dow AgroSciences, Indianapolis, Indiana US) at 1.5 L/ha azimsulfuron (Gulliver 500 g a.i./L, E.I. du Pont de Nemours and Company, Wilmington, Delaware, US) at 0.04 kg/ha, and profoxidim (Aura 200 g a.i./L, BASF Agro B.V., Arnhem, NL, Switzerland) at 1.0 L/ha applied EPOST, MPOST and LPOST

^c Means followed by the same letter within a column are not significantly different according to Fisher's Protected LSD at $P < 0.05$

Table 5. Rice plant injury as influenced by EPOST, MPOST and LPOST applied herbicides in flooded rice in Kočani locality in 2013 and 2014, averaged across years

Treatment	Rate (L;kg/ ha)	Kočani locality			Vinica locality		
		EPOST	MPOST	LPOST	EPOST	MPOST	LPOST
		%					
Non-treated control	-	-	-	-			
penoxulam	1.5	0	0	7	0	0	8
cyhalofop-buthyl	1.5	0	0	12	0	0	10
azimsulfuron	0.04	0	0	9	0	0	11
profoxidim	1.0	0	0	18	0	0	13

REFERENCES

- Mougin, C., Cabanne, F., Canivenc, M., Scalla R.:** Hydroxylation and N-demethylation of chlortoluron by wheat microsomal enzymes. *Plant Science*, 66, 195-203, 1990.
- Andres, A., Concenço, G., Melo, P.T.B.S., Schmidt, M. Resende, R.G.:** Detection of Echinochloa sp. Resistance to Quinclorac in Rice Fields in Southern Brazil. *Planta Daninha*, Viçosa-MG, 25, 221-226, 2007.
- Böger, P., Wakabayashi, K., Hirai K.:** Herbicide Classes in development: Mode of action, targets, genetic engineering, chemistry. Springer-Verlag Berlin Heidelberg, 2002.
- Chin, D.V.:** Biology and management of barnyardgrass, red sprangletop and weedy rice. *Weed Biology and Management*, 1, 37-41, 2001.
- Chin, D.V., Hach, C.V., Thanh, N.C., Tai, N.T.:** Weedy rice situation in Vietnam, In: FAO Report of global workshop on red rice control, Information division, Food and Agricultural Organization of UN, Rome, 67-74, 2000
- Damalas, C.A., Dhima, K.V., Eleftherohorinos, I.G.:** Control of early watergrass (*Echinochloa oryzoides*) and late watergrass (*Echinochloa phyllopogon*) with cyhalofop, clefoxidim, and penoxulam applied alone and in mixture with broadleaf herbicides. *Weed Technology*, 20, 992-998, 2006.
- Dowler, C.C.:** Weed survey-southern states. *Proc. South. Weed Sci. Soc.*, 50, 237, 1997.
- Ferrero, A., Tabacchi, M., Vidotto, F.:** Italian rice-field weeds and their control. *Agris records*. <http://agris.fao.org/aos/records/QR2003000161>, 2002.
- Filipovski, G.:** Soil classification of the Republic of Macedonia. *MASA*, 313-323, 2006.
- Frans, R.E., Talbert, R., Marx, D., Crowley H.:** Experimental design and techniques for measuring and analyzing plant responses to weed control practices. In N. D. Camper ed. *Research methods in weed science*. 3rd ed. Champaign, IL: Southern Weed Science Society, pp. 37-38, 1986.
- Griffin, R.M.:** *Echinochloa polystachya* management in Louisiana rice. A dissertation submitted to the graduate faculty of the Louisiana State University, pp 84, 2006.
- Holm, L.G., Pancho, J.V., Herberger, J.P., Plucknett, D.L.:** A geographic atlas of world weeds. Malabar, Florida, USA: Krieger Publishing Company. 1991
- Holm, L., Doll, J., Holm, E., Pancho, J. and Herberger, J.:** World weeds: Natural histories and distribution. Wiley: New York, pp. 722-739, 1997.
- Jiang, S.H., Zhou, H., Lin, D.Z., Dong, Y.J., Ye, S.H. Zhang, X.M.:** Identification and gene mapping of a thermo-sensitive leaf-color mutant at seedling stage in rice. *Chin J.Rice Sci.*, 27, 359-364, 2013.
- Kaloumenos, N.S., Chatzilazaridou, S.L., Mylona, P.V., Polidoros, A.N., Eleftherohorinos, I.G.:** Target-site mutation associated with cross-resistance to ALS-inhibiting herbicides in late watergrass (*Echinochloa oryzicola* Vasing.). *Pest Manag Sci.*, 69, 865-868, 2013.
- Lassiter, R.B., Langston, V.B., Richburg, J.S., Mann, R.K., Simpson, D.M., Wright T.R.:** Penoxsulam: a new herbicide for rice in the southern U.S. *Proc. South. Weed Sci. Soc.* 57, 69, 2004.
- Lassiter, R.B., Haygood, R.A., Mann, R.K., Richburg, J.S., Walton L.C.:** Penoxsulam for postflood weed control in southern U.S. rice. *Proc. South. Weed Sci. Soc.* 59, 13, 2006.

- Lopez-Martinez, N., Salva, A.P., Finch, R.P., Marshall, G., De Prado, R.:** Molecular markers indicate intraspecific variation in the control of *Echinochloa* spp. with quinclorac. *Weed Sci.*, 47, 310-315, 1999.
- Kwon, O.D., Cho, S.H., Moon, B.C., Kook, Y.I.:** Effect of densities of *Echinochloa crus-galli* and *Cyperus difformis* in transplanting rice cultivation on rice yield and rice quality, and economic threshold levels of the weeds. *Korean Journal of Weed Science*, 27, 102-11, 2007.
- Marambe, B. and Amarasinghe, L.:** Propanil-resistant barnyardgrass (*Echinochloa crus-galli* (L.) Beauv.) in Sri Lanka: Seedling growth under different temperatures and control. *Weed Biol. Manag.*, 2, 194-199, 2002.
- Matzenbacher, F.O., Kalsing, A., Menezes, V.G., Barcelos, J.A.N., Merotto, J.A.:** Rapid diagnosis of resistance to imidazolinone herbicides in barnyardgrass (*Echinochloa crus-galli*) and control of resistant biotypes with alternative herbicides. *Planta Daninha*, 31, 645-656, 2013.
- Massasso, W., Salomone, M.C., Trombini, A.:** Azimsulfuron (DPX A8947) nuova sulfonilurea per la lotta contro *Echinochloa* spp. ed altre infestanti non graminacee nelle risaie italiane. In: *Atti Giornate Fitopatologiche*. 1, 279-286, 1996.
- Moon, B. C. Cho, S.H. Kwon, O.D. Lee, S.G. Lee, B.W. Kim D. S.:** Modelling rice competition with *Echinochloa crus-galli* and *Eleocharis kuroguwai* in transplanted rice cultivation. *Journal of Crop Science and Biotechnology*, 13, 121-126, 2010.
- Ntanos, D.A., Koutroubas, S., Mavrotas, D.C.:** Barnyardgrass (*Echinochloa crus-galli*) control in water-seeded rice (*Oryza sativa*) with cyhalofop-butyl. *Weed Technology*, 14, 383-388, 2000.
- Ottis, B.V., Talbert, R.E., Malik, M.S., Ellis, T.A.:** Rice weed control with penoxulam (Grasp), AAES Res. Ser. 517, 144-150, 2003.
- Ottis, B. V., Lassiter, R. B., Malik, M. S., Talbert, R.E.:** Penoxsulam (XDE-638) for rice weed control. *Proc. South. Weed Sci. Soc.*, 57, 304, 2004.
- Ottis B.V. and Talbert R.E.:** Barnyardgrass (*Echinochloa crus-galli*) control and rice density effects on rice yield components. *Weed Technology*, 21:110-118, 2007.
- Pacanowski Z. and Glatkova G.:** The use of herbicides for weed control in direct wet-seeded rice (*Oryza sativa* L.) in rice production regions in the Republic of Macedonia. *Plant Protect. Sci.*, 45, 113-118, 2009.
- Ramsey, F.L. and Schafer D.W.:** The statistical sleuth: A course in methods of data analysis. Belmont, CA: Duxbury, pp. 91-97. 1997.
- Smith, R.J.Jr.:** Weed thresholds in southern US rice, (*Oryza sativa*). *Weed Technology*, 2, 232-241, 1988.
- Stauber, L.G., Smith, R.J. Jr., Talbert, R.E.:** Density and spatial interference of barnyardgrass (*Echinochloa crus-galli*) with rice (*Oryza sativa*). *Weed Sci.*, 39, 163-168, 1991.
- Tabacchi, M., and Romani, M.:** *Echinochloa* spp. control with new herbicides in water and dry-seeded rice in Italy. Proceedings of the Second Temperate Rice Conference, 13-17 June 1999, Sacramento, California, USA. Los Banos (Philippines): International Rice Research Institute, 2002.
- Talbert, R.E. and Burgos, N.R.:** History and management of herbicide-resistant barnyardgrass (*Echinochloa Crus-galli*) in Arkansas rice, *Weed Technology*, 21, 324-331, 2007.
- VanDevender, K.W., Costello, T.A. and Smith, R.J.Jr.:** Model of rice (*Oryza sativa*) yield reduction as a function of weed interference. *Weed Sci.*, 45, 218-224, 1997.

Varghese, A. and Nair, K.P.M.: Competition for nutrients by rice and weeds. *Agricultural Research Journal of Kerala*, 24, 38-42, 1986.

Vasilakoglu, I.B., Eleftherohorinos, I.G., Dhima, K.V.: Propanil-resistant barnyardgrass (*Echinochloa crus-galli* L.) biotypes found in Greece, *Weed Technology*, 14, 524-529, 2000.

Vidotto, F., Tesio, F., Tabacchi, M., Ferrero, A.: Herbicide sensitivity of *Echinochloa* spp. accessions in Italian rice fields, *Crop Protection*, 26, 285-29, 2007.

Whitcomb, CE.: An introduction to ALS-inhibiting herbicides. *Toxicology and industrial health*. 15, 231-239, 1999.