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Research Article

Different POST-em Herbicide Programs for Weed Management in Lowland Flooded Rice System in North Macedonia

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Abstract: The field experiments were carried out during 2017 and 2018 on commercial rice field in Kochani region to assess different POST-em herbicide programs for weed management in lowland flooded rice system in North Macedonia. In addition, herbicide selectivity and impact on rice grain yield were estimated. POST-em herbicide treatments were used in early-(EPOST-em), mid-(MPOST-em) and late-(LPOST-em) rice growth stages (BBCH 26; 29 and 32-34, respectively). Weed control varied among herbicide treatments, herbicide programs, and weeks after treatments (WAT). All herbicides applied EPOST-em controlled *Echinochloa crus-galli* (ECHCG) and *Scirpus maritumus* (SCMA) 91-100%. At MPOST-em treatment, herbicides showed control of ECHCG between 93 and 97%. However, all herbicides applied LPOST-em controlled ECHCG 79-88%. SCMA control was less than 88 and 85% with MPOST-em and LPOST-em treatments, respectively, perhaps as a consequence of progressive growth stage of SCMA (BBCH 40). Control level of *Cyperus rotundus* (CYPRO) and *Heteranthera reniformis* (HETRE) was high in all POST-em treatments (between 90-100%, and 95-100%, respectively). EPOST-em and MPOST-em application of any herbicide resulted no phytotoxicity to rice plants. LPOST-em treatments caused rice phytotoxicity by cyhalofop-butyl + penoxsulam, cyhalofop-buthyl + bentazon, and profoxidim + bentazon which were ranged from 8-20%. Unlike rice yield at LPOST-em treatments was 6235 kg ha^{-1}, all EPOST-em and MPOST-em used herbicides has impact in rice yield 6685 and 6610 kg ha^{-1}, respectively which, but there were no statistically significant differences with the weed free control 6710 kg ha^{-1}.

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1. Introduction

Rice is considered as one of the greatest cereal crops and the staple food for the majority of the world's population (Jiang et al., 2013). However, worldwide, rice is challenging with several problems and beside harmful biological agents and the environmental damage the climate is the main factor as stressor that can cause failure in rice production (Heriansyah et al., 2022). The favourable environment in rice-production countries, including Macedonia, not only provides valuable conditions for the cultivation of rice but also furthermore offers a suitable climate for many weed species. In some countries, such as in Turkey, researches have been carried out to establish the land suitability classes of rice lands (Dengiz et al., 2022). The weed species in rice are frequently composed of species that are not found as weeds of terrestrial crops, and therefore, rice weed communities are highly different and composed mainly of aquatic plants (McConnell and Barrett, 1985; Pinke et al., 2014). Grasses, like barnyard grass, broadleaf weeds, like mud plantains, and sedges, nutsedges, and bulrushes are dominant weeds in lowland flooded rice systems in North Macedonia (Pacanoski and Glatkova, 2009; Pacanoski, 2015).

Echinochloa crus-galli (L.) P. Beauv. (ECHCG) occurs with high frequency and distribution in all rice-growing areas and is one of the dominant weeds infesting paddy fields in the world (Dowler, 1997; Andres et al., 2007). ECHCG is a strong competitor with rice as a consequence of its adjustment to submerged conditions, high reproductive capacity, quick increment, and C4-photosynthetic mechanism (Marambe and Amarasingle, 2002). Globally troublesome weeds, *Heteranthera limosa* (Sw.) Willd. (HETLI) and *Heteranthera reniformis* Ruiz & Pav. (HETRE), C3 species are the most frequently reported aquatic weeds and a serious problem in lowland flooded rice (Chandler, 1981; Ferrero 1996; Vescovi et al., 1996; Vasconcelos et al., 1999). *Cyperus difformis* L. (CYPDI), *Scirpus maritimus* L. (SCPMA), and *Scirpus mucronatus* L. (SCPMU) are some of the most frequently encountered sedges in rice fields. *Cyperus rotundus* L. (CYPRO) is considered one of the worst weeds in the world (Holm et al., 1991). It is widely spread throughout the tropics and subtropics, and well adapted to lowland flooded environments (Rao, 2000; Pena-Fronteras et al., 2009). CYPRO lately has been reported that occurs in 21 countries where rice is cultivated (Rao et al., 2007). SCPMA, perennial sedge is a serious problem in lowland rice fields in several countries (Caton et al., 2010). The weed is more competitive than other lowlands weeds because its top growth elongates rapidly and nutrient uptake is rapid during its early growth stages (Bernasor and De Datta, 1986).

In North Macedonia, some POST-em herbicides are few herbicides for ECHCG control, and they may be useful in controlling broadleaf weeds and sedges, as well. Cyhalofop and profoxydim are POST-em herbicides, and inhibitors of acetyl-CoA carboxylase (Monadjemi et al., 2012; Kanatas, 2020). Cyhalofop at 200 g ai ha^{-1} controlled ECHCG at least 88% when applied EPOST as well as LPOST (Ntanos et al., 2000). Profoxydim applied at 200 g/ha provided 95-100% control of two ECHCG accessions (Vidotto et al., 2007; Kaloumenos et al., 2013). Similarly, Matzenbacher et al., (2013) reported that ALS-resistant biotypes of ECHCG were successfully controlled by profoxydim and cyhalofop-butyl. Penoxsulam as a triazolopyrimidine sulfonamide inhibits the acetolactate synthase (ALS) enzyme (Lassiter et al., 2004). It is a broad-spectrum herbicide registered for weed control in rice. It provides effective control of *Echinochloa* spp., sedges *Cyperus* spp. and *Scirpus* spp., and numerous broadleaf weeds, including, mud plantain *Heteranthera* spp. (Walton et al., 2005; Lassiter et al. 2006). Bentazon is a benzothiadiazole herbicide, an inhibitor of a photosystem II (Fleming et al. 1988; Bradshaw et al. 1992; Han and Wang, 2002). It is a POST-em herbicide commonly used to control broadleaf weeds and sedges in rice (Nyarko and De Datta, 1991). Bentazon effectively controlled SCPMA (Bernasor and De Datta, 1986) and CYPRO (Pathak et al., 1989), when applied at the six-eight leaf stage, respectively.

Taking into account that for weed management in lowland flooded rice in North Macedonia only POST-em herbicides are registered, and that period of weed germination and growth in rice crops is under substantial alterations, especially in environmental conditions, the reliability of POST-em weed-control programs is fluctuating and greatly determined by the floristic composition of weed population and environmental condition. Hence, the aim of this investigation was to estimate different POST-em herbicide programs for successful weed management and optimal rice yield in lowland flooded rice systems in North Macedonia.

2. Material and Methods

The field experiments were carried out in 2017 and 2018 on commercial rice fields in the Kochani region in North Macedonia. The type of soil was a vertisol with 3.5% coarse, 9.1% coarse sand, 30.0% sand, 60.3% silt + clay, 2.4% organic matter, and pH 7.2. The rice seedbed was arranged by moldboard plowing in the autumn. Two passes with a field cultivator were done in the spring. The fertilizers with the content of potassium and phosphorus were added before rice sowing at a rate of 80 and 60 kg ha^{-1} as potassium sulphate (48% K_2O) and superphosphate (15.5% P_2O_5), respectively. Additionally, the supplementary fertilizer, 150 kg nitrogen fertilizer/ha^{-1} as ammonium nitrate (33.5% N) was applied at 2/3 and 1/3 doses at the beginning of tillering stage (BBCH 21) and the panicle initiation (green ring) stage (BBCH 30), respectively. Usual water management applications were utilized, so the plots were flooded 2 days before the sowing of rice. Italian rice variety "Gloria" was used in the field trials, which was drill-seeded in a well-prepared seedbed at a seeding rate of 200 kg ha^{-1} on May 1st, 2017, and May 5th, 2018.

The experiment was set in a randomized block design with four replications comprising three POST-em herbicide programs. POST-em herbicides were applied in early-(EPOST-em), mid-(MPOST-em), and late-(LPOST-em) rice growth stages, i.e. on June 10th, 17th and 24th in 2017, and June 12th, 20th and 27th in 2018, respectively. In the POST-em weed control investigation were included four herbicide treatments: penoxsulam at 1.5 L ha^{-1} + bentazon at 4.0 L ha^{-1}, cyhalofop-buthyl at 1.5 L ha^{-1} + bentazon at 4.0 L ha^{-1}, cyhalofop-buthyl at 1.5 L ha^{-1} + penoxsulam at 1.5 L ha^{-1} and profoxidim at 1.0 L ha^{-1} + bentazon at 4.0 L ha^{-1}. The used herbicides were applied with a CO_2-pressurized backpack sprayer calibrated to distribute 300 L ha^{-1} aqueous solution at 220 kPa in drained plots, which were re-flooded two days after treatment (DAT). Untreated and weed-free controls were included in the studies, as well. The control plots were not treated with herbicides during the entire experimental period. In weed-free control, weeds were removed by hand. Hand-weeding was started at weeds emergence and continued as required to maintain weed-free plots. Weed and rice growth stages during different POST-em herbicide applications are presented in table 1.

Table 1. Weeds and rice growth stages during POST-em herbicide applications

		Growth stages (BBCH)		
		EPOST-em	MPOST-em	LPOST-em
Weeds	**ECHCG**	BBCH 21-23	BBCH 29	BBCH 32-34
	SCPMA	BBCH 30-32	BBCH 37-39	BBCH 40
	CYPRO	(BBCH 11-12)	BBCH 13-15	BBCH 17-19
	HETRE	BBCH 12-14	BBCH 14-16	BBCH 16-18
Crop	**Rice**	BBCH 26	BBCH 29	BBCH 32-34

The efficacy of weed control was estimated 2 and 4 Weeks After Treatment (WAT) by the weed plants for 1m^2 within each plot, at both localities during a two-year experimental period, while the herbicide efficacy was calculated by equitation (Chinnusamy et al., 2013):

$$WCE = \frac{Wup - Wtp}{Wup} \times 100 \quad (1)$$

Where:
WCE - weed control efficiency
Wup- number of weeds in the untreated plots
Wtp- number of weeds in the treated plots

Rice phytotoxicity was visually assessed based on a ranking scale of 0-100%, where 0 is not any phytotoxicity to rice plants, and 100 is complete death of rice plants (Frans et al., 1986). Visual assessments of percent rice phytotoxicity were assessed one and 3 WAT, based on leaf chlorosis and necrosis for each replication.

A cutting survey was conducted to measure the grain yield of rice in the October harvest season, for both years. The yield of rice grain was assessed from 1m^2 for each repetition t ha^{-1}, and yield was measured after the harvest of grain that contained 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 was performed. Years, replication (nested within years), and all interactions containing either of those effects were considered random effects; herbicide program and DAT were considered fixed effects. Based on the mixed procedure used, all data were pooled over years. Finally, data were transformed back to their original scale for presentation. Means were separated by using the LSD test at 5% of probability.

3. Results and Discussions

3.1. Weed control

The site was naturally infested with a high population of ECHCG, SCPMA, CYPRO, and HETRE. Weeds number in the non-treated control plot was 191 and 232 plants/m^2 in 2017 and 2018, respectively. POST-em herbicide program and WAT main effects were identified, hence, data are presented individually by POST-em herbicide program averaged over years and WAT (Table 2), and by WAT averaged over years and herbicide program (Table 3).

3.2. *Echinochloa crus-galli*

ECHCG control varied among POST-em treatments, herbicide programs, and WAT. At EPOST treatment, all herbicides controlled ECHCG 91-100%. Nevertheless, the greatest control was achieved with penoxsulam + bentazon and cyhalofop-butyl + penoxsulam (98-100%). The efficacy of cyhalofop-butyl in ECHCG control is acceptable if application follows the early phenological phases (2-4 leaves) (Kalsing et al., 2017). At MPOST-em treatment, herbicides assured control of ECHCG between 93-97%. However, all herbicides applied LPOST-em controlled less ECHCG 79-83%, except cyhalofop-butyl + penoxulam which controlled ECG 88% (Table 2). Averaged ECHCG control over different POST-em herbicide programs was 95-92% at EPOST-em and MPOST-em treatments at 2 WAT, and 98-99% at 4 WAT, respectively. Substantially poorer efficacy was achieved in LPOST-em treatment (84% and 80%) at both assessment periods (Table 3). Inadequate ECHCG control in LPOST-em treatment probably is a consequence of the progressive weed growth stage (stem elongation stage - BBCH 32-34). For this reason, herbicides should be applied at early growth stages of ECHCG (maximum tillering stage-BBCH 29) to achieve the most effective control. Regarding the phenology effect on profoxydim effectiveness, the study of Kanatas (2020) revealed a higher ECHCG control at the earlier growth stage (BBCH 13) for 15-50% than at the late growth stages (BBCH 22 and 30). In addition, it is reported by Ntanos et al. (2000) that cyhalofop-butyl applied EPOST at 150 g ai ha^{-1} controlled ECHCG between 85 and 95% in drained plots 30 DAT. Cyhalofop-butyl applied LPOST at the same rate provided only 75% control of ECHCG. Penoxsulam applied alone in EPOST-em and MPOST-em periods controlled ECHCG nearly 100% (Ottis et al., 2003). In the investigation of Pacanoski (2015) ECHCG control across POST-em herbicide programs (penoxulam, cyhalofop-buthyl, azimsulfuron, and profoxidim) was 99-92% at EPOST-em and MPOST-em treatments at 14 DAT, and 99-98% at 28 DAT, respectively. Substantially poorer efficacy was achieved in LPOST-em treatment (87% and 81%) at both assessment periods in investigated localities.

3.3. *Scirpus maritumus*

SCPMA control varied among POST-em treatments, herbicide programs, and WAT. The used EPOST-em herbicides suppressed SCPMA 96-99%. However, SCPMA control was less than 88 and 85% with MPOST-em and LPOST-em treatments, respectively. Between the MPOST-em and LPOST-em, only penoxsulam + bentazon controlled SCPMA was statistically greater in comparison to other assessed herbicides (Table 2). Averaged across POST-em herbicide programs, SCPMA control was 96-99% at EPOST-em treatments at 2 and 4 WAT, respectively. This efficacy was perhaps due to the better activity of the herbicides applied to younger weed growth stages, which was not the case in MPOST-em and LPOST-em herbicide programs. Significantly lower efficacy was provided in these POST-em treatments (between 81% and 76%) at both estimation periods (Table 3). This indicates the regrowth of SCPMA plants affecting weak control as the season evolved. Single penoxsulam treatment was applied at 20, 30, and 40 g a.i. ha^{-1} controlled SCPMA between 50-80%, but the combination of penoxsulam (30 g a.i. ha^{-1}) and bentazon (960 g a.i. ha^{-1}) provided complete (100%) control of SCPMA (Kogan et al., 2011).

3.4. *Cyperus rotundus*

The efficacy of POST-em herbicides for the control of CYPRO varied amongst applied herbicides, herbicide programs, and WAT, as well. EPOST-em treatments provided control of CYPRO >92%, but the highest control was attained with cyhalofop-butyl + penoxsulam and penoxsulam + bentazon (99-100%). Similar efficacy was noted at the MPOST-em program. Although all herbicides provided control of CYPRO higher than 92%, cyhalofop-butyl + penoxsulam and penoxsulam + bentazon showed statistically higher efficacy in their control compared to other herbicides. The high herbicide efficacy was recorded at LPOST-em treatment when herbicides controlled CYPRO between 90-96% (Table 2).

Averaged CYPRO control over different POST-em herbicide programs ranged between 92-95% at 2 WAT. At 4 WAT, control of CYPRO increased to 97 and 95% in EPOST-em and MPOST-em treatments, respectively, but it was the same at LPOST-em applied herbicides (92%) (Table 3). Mahajan and Chauhan, (2013) reported that pendimethalin alone applied PRE-em and penoxsulam applied POST-em poor controlled CYPRO (66%). Similarly as in previous research, in the Philippines, penoxsulam + cyhalofop applied POST-em provided poor control of CYPRO in direct-seeded rice (Chauhan and Opeña 2012).

3.5. *Heteranthera reniformis*

The control of HETRE differed among POST-em herbicides, but no differences were observed among herbicide programs and DAT, respectively. Control of HETRE by EPOST-em treatments was above 95%; penoxsulam + bentazon and cyhalofop-butyl + penoxsulam provided excellent control (100%). Cyhalofop-buthyl + bentazon and profoxidim + bentazon increased MPOST-em control of HETRE compared to their EPOST-em application by 3 and 1%, respectively (Table 2). MPOST-em penoxsulam + bentazon and cyhalofop-butyl + penoxsulam provided a similar level of control of HRE as EPOST-em treatment. A negligible decrease in HETRE suppression was recorded at LPOST-em penoxsulam + bentazon and cyhalofop-butyl + penoxsulam application. Opposite, LPOST-em profoxidim + bentazon increased control of HRE by 2% in comparison with their MPOST-em application. LPOST-em cyhalofop-buthyl + bentazon achieved the same level of HETRE control as MPOST-em treatment (Table 2). Nonsignificant differences were observed among herbicide programs and DAT. HETRE efficacy averaged across all POST herbicide programs was 96-100% at 2 and 4 WAT, respectively. Consistent HETRE control was probably due to younger weed growth stages during all POST-em herbicide programs.

Table 2. ECHCG, SCPMA, CYPRO, and HETRE control with EPOST-em, MPOST-em and LPOST-em herbicide trea
rice in Kochani region in 2017 and 2018, averaged over years and WAT

Treatments	Rate (L ha^{-1})	ECHCG			SCPMA			CYPRO		
		EPOST-em (%)	MPOST-em (%)	LPOST-em (%)	EPOST-em (%)	MPOST-em (%)	LPOST-em (%)	EPOST-em (%)	MPOST-em (%)	LP
Non-treated control	-	0	0	0	0	0	0	0	0	
penoxsulam + bentazon	1.5+4.0	98^{ab}±0.65	96^{a}±0.96	79^{b}±1.68	99^{a}±0.29	88^{a}±1.29	85^{a}±1.65	100^{a}±0.00	99^{a}±0.25	96^{a}
cyhalofop-buthyl + bentazon	1.5+4.0	95^{c}±0.95	93^{b}±1.11	83^{ab}±2.21	97^{ab}±0.91	80^{b}±1.85	74^{b}±1.25	94^{b}±1.25	92^{b}±1.49	91^{b}
cyhalofop-butyl + penoxsulam	1.5+1.5	100^{a}±0.00	97^{a}±0.85	88^{a}±1.38	96^{b}±1.11	78^{b}±2.20	75^{b}±1.75	99^{a}±0.25	98^{a}±0.85	94^{a}
profoxidim + bentazon	1.0+4.0	96^{bc}±0.48	95^{ab}±1.11	79^{b}±1.80	98^{ab}±0.48	75^{b}±1.75	72^{b}±1.29	92^{b}±1.68	93^{b}±1.47	90
LSD (0.05)		2.06	2.49	6.59	2.09	5.40	4.83	3.51	3.20	3

Abbreviations: EPOST-em-early-posteemergence; MPOST-em-mid-postemergence; LPOST-em-late-postemergence.
EPOST-em treatments were applied at rice BBCH 26, ECHCG BBCH 21-23, SCPMA BBCH 30-32, CYPRO BBCH 11-12, and HETRE BBCH 12-14.
MPOST-em treatments were applied at rice BBCH 29, ECHCG BBCH 29, SCPMA BBCH 37-39, CYPRO BBCH 13-15 and HETRE BBCH 14-16.
LPOST-em treatments were applied at rice BBCH 32-34, ECHCG BBCH 32-34, SCPMA BBCH 40, CYPRO BBCH 17-19 and HETRE BBCH 16-18.
Weed control efficacy was estimated 2 and 4 WAT.
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 ECHCG, SCPMA, CYPRO, and HETRE with different POST-em herbicide programs at different WAT in lowland flooded rice in Kochani region in 2017 and 2018, averaged over years herbicide program

	Control									
POST-em Programs	ECHCG (%)		SCPMA (%)		CYPRO (%)		HETRE (%)		Total for all Weeds (%)	
	2 WAT	4WAT	2 WAT	4 WAT	2 WAT	4 WAT	2 WAT	4 WAT	2 WAT	4 WAT
EPOST-em	95ᵃ±1.89	99ᵃ±0.58	96ᵃ±0.82	99ᵃ±0.48	95ᵃ±2.38	98ᵃ±1.50	96ᵃ±2.02	100ᵃ±0.50	96ᵃ±0.29	99ᵃ±0.41
MPOST-em	92ᵃ±1.03	98ᵃ±0.85	81ᵇ±1.03	80ᵇ±2.95	94ᵃᵇ±1.93	97ᵃ±1.89	98ᵃ±1.41	100ᵃ±0.50	92ᵃᵇ±2.72	94ᵃᵇ±3.64
LPOST-em	87ᵇ±1.87	80ᵇ±2.86	78ᵇ±2.78	76ᵇ±2.95	92ᵇ±1.03	92ᵇ±2.17	96ᵃ±0.75	99ᵃ±0.48	88ᵇ±3.04	87ᵇ±3.82
LSD (0.05)	4.16	5.67	4.17	5.53	2.90	2.25	4.83	1.50	5.93	8.92

Herbicide programs included penoxsulam at 1.5 L ha^{-1} plus bentazon at 4.0 L ha^{-1}, cyhalofop-buthyl at 1.5 L ha^{-1} plus bentazon at 4.0 L ha^{-1}, cyhalofop-buthyl at 1.5 L ha^{-1} plus penoxsulam at 1.5 L ha^{-1} and profoxidim at 1.0 L ha^{-1} plus bentazon at 4.0 L ha^{-1} applied EPOST-em, MPOST-em and LPOST-em.
Means followed by the same letter within a column are not significantly different according to Fisher’s Protected LSD at P<0.05.

3.6. Rice phytotoxicity

Rice phytotoxicity of cyhalofop-butyl + penoxsulam, cyhalofop-buthyl + bentazon, and profoxidim + bentazon was more serious and ranged from 8-20%. Phytotoxicity caused by cyhalofop-butyl + penoxsulam and cyhalofop-buthyl + bentazon significantly reduced by 1 and 3 WAT (Table 4). However, rice phytotoxicity of profoxidim + bentazon was still evident at 3 DAT. The LPOST-em treatment caused rice phytotoxicity, particularly by treatments that contained cyhalofop-buthyl and profoxidim, probably related to the high temperature and advanced rice growth stage. During LPOST-em application temperature was about 30°C and rice was at the stem elongation stage (BBCH 32-34).

Rice phytotoxicity has been confirmed with ACCase-inhibiting herbicides (Carey et al., 1992; Baltazar and Smith, 1994; Buehring et al., 2006). For example, the 0.4 kg ha^{-1} rate of cyhalofop-butyl caused phytotoxicity in rice and a significant impact on grain yield (Ntanos et al., 2000). Although excellent outcomes in the control of *Echinochloa* spp. were found with profoxidim, it showed phytotoxicity over all tested indica type cultivars (Marchesi, 2012). Opposite, 10 rice cultivars showed tolerance to penoxsulam as proved by plant height, number of days to 50% heading, and rice grain yield (Bond et al., 2007).

3.7. Rice grain yield

Rice grain yields for each treatment in both years mostly revealed overall weed control and crop phytotoxicity (Table 4). Evaluation of non-treated and weed-free controls showed that weeds reduced rice grain yield by 60% averaging across both experimental years (Table 4). Similarly, many authors estimated that average yield losses in rice attributed to weed competition are between 40 and 96% (Johnson et al., 2004; Ekeleme et al., 2009; Mahajan et al., 2009); Chauhan and Johnson, 2011). Particularly large reductions in the rice yield caused ECHCG (Ottis and Talbert, 2007; Wilson et al., 2014; Shabbir et al., 2019), SCPMA (Lieffers and Jennifer, 1982; Mamun et al., 2013), CYPRO (Rabbani et al., 2011; Chauhan and Opeña, 2012; Donayre et al., 2015) and HETRE (Schiele, 1988; Ferrero, 1996).

Averaged across both experimental years all EPOST-em and MPOST-em used herbicides resulted in rice yield (6685 and 6610 kg ha^{-1}, respectively) which was statistically in pair with rice yield in the weed-free control (6710 kg ha^{-1}). Contrary, rice yield at LPOST-em treatments (6235 kg ha^{-1}) was significantly weak in comparison with the rice yield in the weed-free control. The LPOST-em herbicides showed lower weed control and affected rice phytotoxicity, and yield was lower in all replications treated with LPOST-em herbicides, particularly in plots treated with profoxidim + bentazon (-690 kg ha^{-1}). However, statistical differences were observed among profoxidim + bentazon and other LPOST herbicides treatments, as well (Table 4).

In the investigation of Sekhar et al. (2020) herbicide combination penoxsulam + cyhalofop butyl resulted in higher grain yield than the sole application of cyhalofop-butyl. The application of this herbicide combination increased the grain yield by 28-60% more than the sole application of cyhalofop-butyl. Similarly, the application of penoxsulam + cyhalofop butyl at its higher dose (130 + 135 g a iha^{-1}) recorded the highest grain yield of 8.46 t/ha (Sheeja and Syriac, 2015). Tagour et al. (2010) reported that the mixture bentazon + penoxsulam has a higher impact in increasing the number of productive tillers, number of panicles m^{-2}, 1000 grain weight, and grain and straw yield. Similarly, plots treated with penoxsulam + bentazon achieved the highest yield 9.17 t/ha (Kogan et al., 2011).

Table 4. Effect EPOST-em, MPOST-em and LPOST-em applied herbicides at different WAT in rice plant phytotoxicity in Kochani region in 2017 and 2018, averaged across years

Treatments	Rate ($L\ ha^{-1}$)	Rice phytotoxicity (%)						
		EPOST-em		MPOST-em		LPOST-em		EPOS
		1 WAT	3 WAT	1 WAT	3 WAT	1 WAT	3 WAT	
Non-treated control*	-	-	-	-	-	-	-	2670±9
Weed-free control	-	-	-	-	-	-	-	6710^{ab}
Penoxsulam + bentazon	1.5+4.0	0	0	0	0	2	0	6740^{a}±
Cyhalofop-buthyl + bentazon	1.5+4.0	0	0	0	0	18	8	6680^{ab}
Cyhalofop-butyl + penoxsulam	1.5+1.5	0	0	0	0	16	5	6700^{ab}
Profoxidim + bentazon	1.0+4.0	0	0	0	0	20	18	6620^{b}±
Average yield of herbicide treatments								66
LSD 0.05								10

*Non-treated control was excluded from the analysis of variance in order to detect the significant differences between the herbicide treatments
Means followed by the same letter within a column are not significantly different according to Fisher's Protected LSD at P<0.05

4. Conclusion

The use of POST-em herbicides in rice, depending on the time, has an effect on the control of weeds, but at the same time also has phytotoxic effects. The weed control level for all herbicides differed among herbicide programs and WAT. EPOST-em application of any herbicide evaluated in this study provided overall weed control of 96-99% at 2 and 4 WAT, respectively. A non-significantly lower efficacy was provided in MPOST-em treatment (92% and 94%) at both assessment periods. The lowest efficacy (88 and 87%, respectively) was recorded in LPOST-em applied herbicides at 14 and 28 DAT.

EPOST-em and MPOST-em application of any herbicide evaluated in this study resulted in no phytotoxicity to rice plants averaged over years at one and 3 WAT, respectively. Phytotoxicity was evident only in LPOST-em treatment. At one WAT phytotoxicity, between 2 and 20% was detected in all LPOST-em herbicides.

In general, rice yields are a result of the differences in weed control; the crop yields increase as control with the different POST-em treatments increased. The reason each LPOST-em herbicide assured weak weed control and some of them caused rice phytotoxicity, in plots where LPOST-em herbicides were applied the results showed significant yield reduction.

Based on the results on the efficacy of herbicides, time of use, their impact on yield, as well and rice plant phytotoxicity it is recommended the use the herbicides penoxsulam + bentazone and cyhalofop-butyl + penoxsulam EPOST-em application in rice crop.

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