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Evaluating the effects of application modes and soil types on the herbicide efficacy and crop yield of pendimethalin and clomazone on transplanted pepper (*Capsicum annuum* L.)

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Abstract. Field experiment was carried out in 2014 and 2015 in two locations Kochani and Drachevo in Republic of Macedonia to evaluate the efficacy and crop safety of pendimethalin and clomazone on transplanted pepper according to mode of application, (pretransplant -PRE-T and pretransplant incorporated -PTI) and soil types (alluvial soil and vertisol). The weed population in both years and locations mainly consisted annual spring and summer grasses and broadleaf weeds. Weed competition significantly reduced pepper yield. There was no recorded difference between the efficacy of pendimethalin PRE-T and pendimethalin PTI. However, the efficacy of clomazone PTI was higher than that of clomazone PRE-T in both experimental years and locations, indicating incorporation into soil if critical for clamazone. Both pendimethalin and clomazone had low efficacy on *Solanum nigrum L*. Pepper plants were not visibly injured by any herbicides treatments. In summary, locations and soil types did not affect herbicide efficacy and pepper selectivity. Pepper yield was markedly affected by herbicide efficacy in both years and locations.

Key words: pepper, weeds, herbicides, pretransplant, pretransplant incorporated, soil type, effectiveness, injury.

INTRODUCTION

Pepper *(Capsicum annuum L.)* is an economically important vegetable crop in Republic of Macedonia, which is currently grown in about 8,522 ha, with total pepper production of 175,867 t and average pepper production in about 20.6 t ha^{-1} (Anonymous, 2015). Pepper is grown, in areas with a warm climate and a long growing season, which are also favorable to the growth of weeds, which results in increased weed pressure (Granberry & Colditz, 1990). Pepper is not a very competitive crop and weeds can significantly reduce pepper yield (Eshel et al., 1973; Frank et al., 1988). The weed infestation may reduce pepper yield by 60–80% (Sharma et al., 1988; Narayana, 1990, Khan et al., 2012). Weed management in pepper is required to minimize decrease of yield and quality of the fruit. Subhra & Pabirta (2014) noticed that the decrease in the pepper fruits/plant was proportional to the duration of weeds competition.

In Republic of Macedonia weed control in pepper are a combination of inter-row cultivation, hand weeding and herbicide application. For Macedonian farmers the use of soil applied herbicides before transplanting is most acceptable. This time of application leaves the soil surface without weeds at the beginning of the growing season. According to Isik et al. (2009) immediately after transplanting, chilli pepper seedlings grow slowly whereas weeds emerge fast, grow rapidly and compete with the crop for nutrients, moisture, sunlight and growing space during all growing season.

Some soil applied herbicides can be used pre-transplanting (PRE-T) or pre-transplanting incorporated (PTI) depending on the soil and weather conditions. Soil incorporation can increase the efficacy of the herbicide, but on the other hand, it can cause phytotoxicity on crops. Also, soil incorporation increases farmers' costs. The choice of any weed control measures therefore, depends largely on its effectiveness and costs (Subhra & Pabitra, 2014).

Pendimethalin is a herbicide of the dinitroaniline class used in premergence and early postemergence applications to control annual grasses and certain broadleaf weeds. Pendimethalin inhibits root and shoot growth. It controls the weed population and prevents weeds from emerging, particularly during the crucial development phase of the crop. Its primary mode of action is to preventing plant cell division and elongation in susceptible species. Pendimethalin is used in major crops such as corn, potatoes, sunflower, wheat, rice, vegetables like pepper, carrot, parsley, etc. Incorporation of pendimethalin into the soil by cultivation or irrigation is recommended (Janic, 1985 and 2005).

Clomazone, whose active ingredient is isoxazolane, is a selective herbicide with both contact and residual activity. Clomazone systemically enters through the roots and shoots and translocates via the xylem. This herbicide is used for the control of annual broadleaf weeds and grasses. It inhibits the biosynthesis of photosynthetic pigments of both chlorophyll and carotenoids. Susceptible plants sprayed with the herbicide typicallyshow signs of whitening or bleaching, followed by necrosis. Clomazone is used on major crops such as oilseed rape, cotton, tobacco, soybeans, rice and sugar cane and vegetables like peas, beans, carrots, pepper and potatoes. Incorporation of clomazone into the soil is not mandatory but is recommended (Dan, et al., 1989; Cabral, 2017).

To identify the best application method and the effects of soil types for pendimethalin and clomazone on Pepper, the study aimed at evaluating the efficacy and phytotoxicity of the two herbicides. Results from this study will provide guidance for farmers in Republic of Macedonia to adopt the right weed control programs to achieve better weed control in pepper.

MATERIALAS AND METODS

Field experiment was carried out in 2014 and 2015 at two locations Kochani and Drachevo, in eastern and northern Macedonia on alluvial soil and vertisol, respectively (Filipovski, 2006).

The experiment was laid out in a randomized block design having four replications and harvest plot size of 20 m^2. The field studies was carried with local pepper variety 'Kurtovska kapija' which was transplanted in a well-prepared seedbeds on June 13^{th}, 2014 and June 16^{th}, 2015 in Kochani location and June 16^{th}, 2014 and June 18^{th}, 2015 in

Drachevo location. The inter-row spacing was 60 cm and intra-row spacing was 30 cm. Standard agronomic practices were used in both locations and both experimental years. Tested treatments are described in Table 1.

Table 1. Trade names, active ingridients, rates and time of aplications of herbicides

Treatments	Concentration of active ingredient (a.i) in herbicide	Trade name of herbicide	Rate L ha^{-1}
Untreated Control	/	/	/
Weed-free control	/	/	/
Pendimethalin PTI	330 g L^{-1}	Stomp 330 E	5.00
Pendimethalin PRE-T	330 g L^{-1}	Stomp 330 E	5.00
Clomazone PTI	480 g L^{-1}	Gamit 4 EC	0.75
Clomazone PRE-T	480 g L^{-1}	Gamit 4 EC	0.75

PTI (pretransplant incorporated); PRE-T (pretransplant).

Application of the herbicides were with a CO_2 – pressurized backpack sprayer with 350 L ha^{-1} water. Both herbicides were applied in two method (PTI and PRE-T). Time of application were one day before pepper transplanting. Incorporation was performed with two parallel passes of a field cultivator with 25 cm sweeps operation to a depth of 8 cm. Untreated and weed free control were included in the studies. Weed free control was maintained with two runs of hoeing. Weed control efficacy was estimated 30 days after treatment (DAT) by weed plants counting and herbicides efficacy was calculated using the following equation (Mani et al., 1968).

$$\mathrm{Wce} = \frac{\mathrm{Wup} - \mathrm{Wtp}}{\mathrm{Wup}} \cdot 100 \tag{1}$$

where Wce – weed control efficiency; Wup – number of weeds in the untreated plots; Wtp – number of weeds in the treated plots.

Pepper plant injury including bleaching, chlorosis, necrosis, stunting and minor leaf malformation were recorded 30 days after treatments (DAT). Injury was based on a scale of 0 to 100% where 0% = no pepper injury and 100% = all pepper plants death (Frans et al., 1986). Peppers in all plots (variants) were harvested two times based on the visual maturity of the pepper in weed free plots. The average yield for each variant is calculated. Pepper fruits were classified into marketable and non-marketable categories, based on factors such as size and colour Non-marketable materials were removed. The data were subjected to statistical analysis applying LSD- test (Steel & Torrie, 1980).

RESULTS AND DISCUSSION

Weed population: The weed population in both years and locations mainly consisted annual spring and summer grasses and broadleaf weeds. In both years Kochani weed population consisted 9 species, and total number of weeds was 223.7 plant m^{-2} in 2014 and 173.5 plant m^{-2} in 2015, respectively. In Drachevo region weed population in both years was consisted of 8 species, and total number of weeds was 126.2 plant m^{-2} in 2014 and 122.4 plant m^{-2} in 2015, respectively. (Table 2).

Table 2. Weed infestation in the study (for both years and locations) in the untreated plots

Weed species	Weeds No m^{-2}			
	Kochani		Drachevo	
	2014	2015	2014	2015
1. *Portulaca oleraceae L.*	94.0	70.0	12.0	19.0
2. *Amaranthus retroflxus L.*	38.8	42.0	68.0	51.0
3. *Echinochloa crus gali (L.) P. Beauv*	24.7	12.1	10.9	15.6
4. *Galinsoga parviflora Cav.*	24.3	10.6	1.5	2.8
5. *Chenopodium album L.*	17.0	10.5	15.0	9.8
6. *Solanum nigrum L.*	9.7	17.8	9.0	12.3
7. *Setaria spp. (L.) P. Beauv*	7.1	5.3	8.6	10.0
8. *Polygonum lapathifolium L.*	6.5	3.1	1.2	1.9
9. *Abuthilon theofrasti Medik.*	1.6	2.1	/	/
Total weed species	9	9	8	8
Total weeds No m^{-2}	223.7	173.5	126.2	122.4

Herbicides efficacy: All herbicide treatment showed a highly significant ($P < 0.01$) effect on weed density per m^2 compared to the untreated control. Efficacy of herbicides in 2014 (Table 3.) ranged from 90.5% (clomazone PRE-T) to 98.3% (pendimethalin PTI) in Kochani and from 89.0% (clomazone PRE-T) to 98.0% (pendimethalin PTI) in Drachevo. In 2015 herbicide efficacy ranged from 85.3% (clomazone PRE-T) to 93.5% (clomazone PTI) in Kochani and from 82.8% (clomazone PRE-T) to 92.3% (pendimethalin PTI) in Drachevo. Method of application did not affect the efficacy of pendimethalin. Efficacy of clomazone PTI was significantly higher compared to clomazone PRE-T. (Table 3). John et al. (1998) emphasizes that clomazone must be incorporated to reduce vaporization.

Lower total herbicide efficacy in 2015 in both locations was caused by the lower efficacy of both herbicides on *Solanum nigrum* (Table 5). No effect of location/soil type on efficacy of both tested herbicide was observed. (Table 3).

Table 3. Total herbicides efficacy at 30 days after treatment (DAT) in both experimental locations and years

Treatments	Total herbicide efficacy/Weed control (%)			
	2014		2015	
	Kochani	Drachevo	Kochani	Drachevo
Untreated Control	0.0	0.0	0.0	0.0
Pendimethalin PTI	98.3 **	98.0 **	92.5 **	92.3 **
Pendimethalin PRE-T	97.5 **	97.0 **	91.5 **	91.8 **
Clomazone PTI	97.8 **	97.5 **	93.5 **	91.3 **
Clomazone PRE-T	90.5 **	89.0 **	85.3 **	82.8 **
LSD 0.05	1.2	1.0	1.3	1.0
LSD 0.01	1.7	1.4	1.8	1.4

(*) Significant level $P < 0.05$; (**) Significant level $P < 0.01$.

In 2014, efficacy of herbicides on dominant weeds 30 DAT ranged from 88.0% (ECHCG treated with clomazone PRE-T) to 99.8% (CHEAL treated with clomazone PTI) in Kochani and from 85.0% (SETSP treated with clomazone PRE-T) to 99.5% (POROL treated with clomazone PTI) in Drachevo (Table 4). In 2015, herbicide efficacy on dominant weeds ranged from 70.3% (SOLNI treated with clomazone PRE-T) to 99.5% (GALPA treated with clomazone PTI) in Kochani and from 63.0% (SOLNI treated with clomazone PRE-T) to 99.3% (POROL treated with clomazone PTI) in Drachevo (Table 5).

Table 4. Herbicide efficacy on predominant weeds in both locations 30 DAT in 2014

Treatments	Kochani					Drachevo				
	POROL	AMARE	ECHCG	GALPA	CHEAL	POROL	AMARE	ECHCG	SETSP	CHEAL
Untreated Control	0	0	0	0	0	0	0	0	0	0
Pendimethalin PTI	98.3	95.3	94.8	97.3	99.5	97.8	95.0	96.5	97.8	98.3
Pendimethalin PRE-T	97.5	93.5	93.8	96.3	99.0	96.3	93.5	95.0	97.3	97.5
Clomazone PTI	97.8	95.0	95.0	95.3	99.8	99.5	91.0	96.8	98.0	98.0
Clomazone PRE-T	89.8**	89.5**	88.0**	90.5**	92.0**	88.5**	87.8**	90.0**	85.0**	88.8**
LSD 0.05	0.9	1.3	0.9	1.2	1.0	1.5	1.5	1.2	1.2	1.2
LSD 0.01	1.3	1.8	1.2	1.7	1.4	2.1	2.2	1.7	1.6	1.7

(*) Significant level $P < 0.05$; (**) Significant level $P < 0.01$;

POROL – *Portulaca oleracea*; AMARE – *Amaranthus* retroflexus; ECHCG – *Echinochloa* crus galli; GALPA – *Galinsoga parviflora*; CHEAL – *Chenopodium album*; SETSP – *Setaria spp*.

Table 5. Herbicide efficacy on predominant weeds in both locations 30 DAT in 2015

Treatments	Kochani					Drachevo				
	POROL	AMARE	ECHCG	GALPA	SOLNI	POROL	AMARE	ECHCG	GALPA	SOL NI
Untreated Control	0	0	0	0	0	0	0	0	0	0
Pendimethalin PTI	97.0	93.5	94.3	98.3	75.0	98.8	95.5	95.3	91.8	75.3
Pendimethalin PRE-T	95.8	92.0	92.8	98.3	74.3	98.3	94.8	94.3	91.3	74.3
Clomazone PTI	97.8	93.5	96.8	99.5	75.5	99.3	92.0	95.3	90.8	74.3
Clomazone PRE-T	86.8 **	89.8 **	90.3 **	83.8 **	70.3 **	87.0 **	86.3 **	86.3 **	86.0 **	63.0 **
LSD 0.05	1.2	1.3	1.2	1.4	1.0	0.9	1.2	1.0	1.2	1.7
LSD 0.01	1.7	1.8	1.7	2.0	1.4	1.3	1.7	1.4	1.7	2.4

(*) Significant level $P < 0.05$; (**) Significant level $P < 0.01$;

POROL – *Portulaca oleracea*; AMARE – *Amaranthus* retroflexus; ECHCG – *Echinochloa* crus galli; GALPA – *Galinsoga parviflora*; SOLNI – *Solanum nigrum.*

Most of tested herbicide treatments provided good controll (efficacy above 90%) on *Portulaca oleracea, Amaranthus retroflexus, Echinochloa crus galli, Galinsoga parviflora, Setaria spp*. and *Chenopodium album*, except that the efficacy of clomazone PRE-T was significantly lower. Both herbicides showed very low efficacy on *Solanum nigrum* (63.0–75.5%). According to John, et al. (1998), efficacy of clomazone PTI on *Chenopodium album* and *Datura stramonium* ranged between 77.0% and 95.0% without injury to bell pepper. Efficacy of pendimethalin in Subhra & Pabitra (2014) trials 30 DAT was 74.7%. In Gare et al. (2015) higher weed control efficiency was noted in treatments with pendimethalin, butachlor and fenoxaprop-P-ethyl combinated with two runs of hoeings and one hand weeding than in herbicides used alone without hoeing and hand weeding.

Visual injury of pepper: Pepper plants was not visibly injured by any herbicide treatments except clomazone PTI which caused transient bleaching on 2–3 leaves (0.3–0.7%) (Table 6). The injured plants recovered without affecting the pepper yield.

Table 6. Efects of herbicide treatments on pepper yield and crop injury

Treatments	Pepper yield kg ha^{-1}				Crop injury %			
	2014		2015		2014		2015	
	Kochani	Drahcevo	Kochani	Drachevo	Kochani	Drachevo	Kochani	Drachevo
Untreated Control	17,347	21,008	21,051	22,391	/	/	/	/
Weed-free control	45,719	44,922	44,193	43,829	/	/	/	/
Pendimethalin PTI	44,788	44,290	43,420	43,033	/	/	/	/
Pendimethalin PRE-T	44,430	44,166	43,368	43,120	/	/	/	/
Clomazone PTI	44,875	44,375	43,480	43,111	0.7	0.3	0.6	0.4
Clomazone PRE-T	39,176 **	38,667 **	38,568 **	36,658 **	/	/	/	/
LSD 0.05	1,134	1,100	637	629				
LSD 0.01	1,569	1,522	880	870				

(*) Significant level $P < 0.05$; (**) Significant level $P < 0.01$.

Weather and soil condition had no impact on the herbicide phytotoxicity. However according to Timothy et al. (2001) clomazone at application rate 1.12 kg ha^{-1} PTI and PRE-T significantly injured (leaf bleaching or chlorosis) 'Sweet Banana' (40% and 20%, respectively) and 'Red Chili' (30% and 18%, respectively) varieties in early season evaluations. However this injury was transient and did not significantly affect total fruit number or yield.

Pepper yield: Weed competition caused large reductions of pepper yield. Comparison of untreated and weed free control indicated that weeds reduced pepper yield from 53% to 63% without herbicide applications. Tested herbicide treatments in both experimental years at both locations had a significant ($P < 0.01$) effect on pepper yield. In both years, the lowest yield was recorded in untreated control (Table 6.). Absence of the weeds led to the increase of the pepper yield. Among herbicide treatments the pepper yield in 2014 ranged from 39,176 kg ha^{-1} (clomazone PRE-T) to

44,875 kg ha^{-1} (clomazone PTI) in Kochani and from 38,667 kg ha^{-1} (clomazone PRE-T) to 44,375 kg ha^{-1} (clomazone PTI) in Drachevo. In 2015 pepper yield ranged from 38,568 kg ha^{-1} (clomazone PRE-T) to 43,480 kg ha^{-1} (clomazone PTI) in Kochani and 36,658 kg ha^{-1} (clomazone PRE-T) to 43,120 kg ha^{-1} (pendimethalin PRE-T) in Drachevo. According to Yadav, R.S. (2001) all weed control treatments including pendimethalin produced significantly higher dry chilli yield compared with weedy check.

In both experimental years and locations, the lowest pepper yields among tested herbicide treatments was recorded on plots treated by clomazone PRE-T (from 36,658 kg ha^{-1} to 39,176 kg ha^{-1}) (Table 6), which correlated with the efficacy of the same herbicide variant. However, in the Mohsen & Douglas (2015) studies clomazone PRE-T did not reduce banana pepper yield.

According to Rodrigo et al. (2016) herbicides clomazone and pendimethalin applied PTI caused slight foliar chlorosis and necrosis but did not affect fruit yield, whereas the same herbicides applied posttransplant reduced fruit yield significantly. Cavero et al. (1996) noted insignificant reductions of seeded peppers yield after postemergence application of clomazone (1.0 and 2.0 kg ha^{-1}) at growth stage 6–8 leaves. Stall et al. (1996) also noted that pepper was tolerant to clomazone and pendimethalin applied PPI. Phillip & Tim (2006) study has shown that pendimethalin and clomazone gave best control when applied PRE-T. Both tested herbicide applied at double rates on soils with very low organic carbon and clay content did not cause any crop injury. Yield and quality of tested pepper cultivars were also not affected by these herbicides.

CONCLUSIONS

In the pepper production, pepper yields was markedly affected by weed competition. Weed management is important for increasing both the yield and quality of the pepper. Weeds reduced pepper yield about 53–63%. Pendimethalin and clomazone showed very good efficacy when they were incorporated into soil. Efficacy of clomazone was lower, if it was not incorporated into soil before transplanting. Pepper plants was not significantly visible injured by any herbicides treatments. Soil and weather conditions had no impact on the herbicides efficacy and crop yield.

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