EFFICACY AND SELECTIVITY OF DIFFERENT FORMULATIONS OF PENDIMETHALIN ON WEED CONTROL IN MAIZE

Marga Grădilă[1]*, Daniel Jalobă[1,2], Valentin-Marius Ciontu[1,2], Raluca-Monica Cristea[1,2]

[1]Research – Development Institute for Plant Protection, 8 Ion Ionescu de la Brad Blvd, 013813, Bucharest, Romania

[2]University of Agronomic Sciences and Veterinary Medicine of Bucharest, 59 Marasti Blvd, 011464, Bucharest, Romania

Abstract

Due to its use in human food, livestock feed and as a raw material in industry, maize is one of the most important crops, both globally and nationally. Romania is one of the European leaders in corn cultivation, being ranked second in EU in 2020. The high degree of weed infestation of croplands requires the use of herbicides applied in an integrated weed control management. Due to the slow growth in the first 4-6 weeks, maize is very sensitive to weed infestation, and due to the low density per square meter, a strong competition in favor of weeds is created from the beginning. In this context, the paper presents data on the efficacy and selectivity of 3 different pendimethalin formulations (EC, SC, CS) applied in pre-emergence and in early post-emergence stage, when maize was at BBCH 13 (3 leaves unfolded). Trials were carried out in 2019 in Romania at Didactic Farm Moara Domnească, Ilfov county. Experimental plots were placed in randomized complete blocks design, in four repetitions on a brown reddish soil with a clay loam texture. The herbicide Pendimethalin 33% EC was applied at 3.0, 4.0 and 5.0 l/ha, Pendimethalin 40% SC at 2.0, 3.0 and 4.0 l/ha and Pendimethaline 45.5% CS at 2.0, 2.5 and 3.5 l/ha. In experimental field the predominant weeds were annual monocotyledonous and dicotyledonous: Echinochloa crus-galli (L.) *Beauv., Digitaria sanguinalis* (L.) *Scop., Setaria sp*. (L.) *Beauv., Chenopodium album* (L.)*, Amaranthus retroflexus* (L.)*, Ambrosia artemisiifolia* (L.) *and Xanthium orientale subsp. italicum* (Moretti) *Greuter. Assessments made at 10, 28 and 42 days after treatments demonstrated a good efficacy of the different formulations of herbicide Pendimethalin in control of annual weeds in maize, the best results were obtained at the higher rates. No phytotoxicity symptoms have been shown in the trial.*

Keywords: *weeds, maize, pendimethalin, effectiveness*

1. INTRODUCTION

Romania is one of the biggest maize producers in the European Union, with an annual average for the last 10 years, of approximately 2.5 million ha cultivated. The average annual maize production ranges from one year to another, between 3. 400 and 7. 800 kg/ha, with a continuous and consistent increase until 2019 (Alda, 2011; Dogaru et al., 2012; Ion et al., 2013; National Institute of Statistics, 2019). Weed control in maize crop is the most important technological work because the weeds compete with the crop plants for space, light, moisture, nutrients and carbon dioxide, which reduces not only the yield, grain quality and hinder harvest operations but also increases the cost of production (Șarpe, 1987; Rutta et al., 1991; Budoi & Penescu, 1996; Chirilă, 2001; Berca, 2004; Bogdan et al., 2006; Gîdea et al., 2010; Głowacka, 2011; Petcu et al., 2015; Simić et al., 2016). One of the reasons concerning this situation is represented by the substantial weed infestation degree of this crop and the high sensitivity of maize to weeds, especially in the first 5-6 weeks after emergence. Generally, the lands cultivated with maize are strongly infested by mono and dicotyledonous weeds, annual and perennial and they are very different related to climatic and soil conditions, and also to the performed agrotechnics. Concerning weed control, the priority objective is to limit the weed competition during the whole vegetation period by reducing the weed infestation degree under the level of the economic damage limit. Excessive growth of weeds in maize field leads to 66% to 80% reduction in crop yield (Adigun, 2001; Ford & Pleasant, 1994; Rusu et al., 2010). To minimize losses caused by weeds, several methods are available such as mechanical, cultural, biological and chemical control methods.

Overwhelmed by cultural method, farmers are moving towards other alternative methods of weeds control. In this scenario, chemical weed control is the best option. Chemical control method is quick, more effective, time and labour saving method than others. Chemical weeds control method is suggested by many researchers (Johnson et al., 1986; Khan & Haq, 2004; Juhl, 2004; Grădilă et al., 2020; Toloraya et al., 2001). Chemical control of weeds in maize crops provided significant production increases and reduced weed density (Chikoye et al., 2002; Manea et al., 2010; Tesfay et al., 2014). Treatments are applied upon soil before or after sowing during the vegetation period. Most herbicides applied in pre-emergence are pellicular herbicides, their effectiveness being influenced by the humidity in the soil. Results of weeds chemical control depend upon several factors: the weed emergence pattern, application timing and stage of crop (Hoverstad et al., 2004; Vandini et al., 2005; Tahir et al., 2009). Also, one important factor influencing the efficacy and pollution is the type of formulation of the pesticides (Emulsifiable concentrates, Wettable powders, Suspension concentrates, Water-dispersible granules, Emulsions in water, etc.). Nowadays, the farmers and consumers increasingly require safer and more convenient pesticide formulations. Emulsifiable concentrates and wettable powders are nowadays viewed less favorable by farmers and registration authorities. Suspension concentrates are now common and water-dispersible granules and emulsions in water are receiving increasing attention. The heavy use of herbicides has given rise to serious environmental and public health problems. It is therefore important to develop new herbicide formulations that are highly effective, that are safer (for the worker and for the environment), and that involve a low cost/production ratio. In this sense, controlled release formulations of herbicides have become necessary in recent years, since they often increase herbicide efficacy at reduced doses (Seaman, 1990; Sopena, 2005; Knowles, 2007; Hazra & Purkait, 2019). In this context, the paper delivers data on the efficacy and selectivity of 3 different pendimethalin formulations (EC, SC, CS) in maize crop applied in pre-emergence and in early post-emergence.

2. MATERIALS AND METHODS

The trials were carried out at Didactic Farm Moara Domnească in Ilfov County, within University of Agronomic Sciences and Veterinary Medicine of Bucharest, in the south-east zone of Romania (Figure 1 and 2). The experiments were conducted in 2019, in randomized complete blocks design, with plot area of 30 m ^{2}, in four repetitions on a brown reddish soil with a clay loam texture and a good fertility. Each experimental block included an untreated plot. The planting density was 60.000 plants per hectare. DKC 54670 was the variety sown in the experimental field. The previous crop was wheat. Sowing was performed on 12th April 2019 with planting rate of 15 kg/ha. The following agro-technical measures have been applied: systematic crop rotation, the adequate previous crop, deep plowing up to 30 cm depth in summer, seedbed tillage by 2 passes with disc harrow followed by milling and high quality hybrids. In the same time 200 kg/ha of complex fertilizer was applied. The herbicide Pendimethalin 33% EC was applied at 3.0, 4.0 and 5.0 l/ha, Pendimethalin 40% SC at 2.0, 3.0 and 4.0 l/ha and Pendimethaline 45.5% CS at 2.0, 2.5 and 3.5 l/ha.



Figure 1. Maize location



Figure 2. Images of experimental field

The herbicides were applied in pre-emergence and in early post-emergence stage, when maize was at BBCH 13 (3 leaves unfolded). The herbicide treatment was done with pump with nozzles for plot trails. The amount of spray solution was 300 L/ha. The pre-emergent treatments were applied on 22 April (15°C air temperature; 13°C soil temperature) and the early post-emergent treatments on 5 May (24°C air temperature; 20°C soil temperature). The herbicide efficacy was recorded on the 10th, 28th and 42th day after treatments by the 10 scores scale for efficacy of EWRS (European Weed Research Society), in % control compared to untreated plots. Also, observations were done on the weeds found in the experimental plots before treatment, and on selectivity - at each date of the efficacy assessments. In each trial, herbicide phytotoxicity was rated visually - at each date of the efficacy assessments on a 0-10 scale (0: no visible injury; 10: plant death). Weed density was assessed in ground % and in number of plants per square meter. Determination of segetal flora was performed on one square meter using a metric frame. Statistical data - processing of the assessments was based on the analysis of ARM-9 software (P = .05, Student - Newman - Keuls).

3. RESULTS AND DISCUSSION

Maize, *Zea mays* (L.) is the most important crop in Romanian agriculture because it has a production capacity about 50% higher than other cereals, a wide area of distribution, being less influenced by climate change. Maize has a high resistance to drought, heavy rains, but also to diseases and pests, and agricultural and harvesting works can be fully mechanized (Băşa et al., 2016; Schils et al., 2018). However, maize crops are strongly infested, year after year, by a numerous and various segetal flora, both in terms of the number of species present and especially the many possible combinations between the various biological groups (Anghel et al., 1972; Budoi & Penescu, 1996; Bîlteanu, 2001; Chirilă, 2001; Berca, 1996; Ene & Grădilă, 2017; Grădilă & Jalobă, 2017; Grădilă & Jalobă, 2018). In this context, in experimental field the predominant weeds were annual monocotyledonous and dicotyledonous: ECHCG - *Echinochloa crus-galli* (L.) Beauv., DIGSA - *Digitaria sanguinalis* (L.) Scop., SETSS - *Setaria* sp. (L.) Beauv., CHEAL - *Chenopodium album* (L)., AMARE - *Amaranthus retroflexus* (L.), AMBEL - *Ambrosia artemisiifolia* (L.) and XANSI - *Xanthium orientale* subsp. *italicum* (Moretti) Greuter. There were also present *Datura stramonium* (L.), *Fallopia convolvulus* (L.) Löve., *Sinapis arvensis* (L.), *Solanum nigrum* (L.), *Convolvulus arvensis* (L.), *Cirsium arvense* (L.) Scop. and S*orghum halepense* (L.) Pers., but they had a low density on square meter. In such conditions of weeds infestation, the herbicides Pendimethalin 33% EC, Pendimethalin 40% SC and Pendimethalin 45.5% CS provided good results in control of annual weeds species in maize crop (Tables 1 and 2). The best results were obtained in pre-emergent applications and at higher rates.

Table 1. The efficacy of herbicides in maize after 42 days of treatment in pre-emergence

Treatment name	**Dose L/ha**	**Efficacy (% control compared with the untreated plots)**						
		Weeds stage majority (BBCH)						
		48	50	47	47	45	48	51
		ECHCG	**DIGSA**	**AMARE**	**CHEAL**	**AMBEL**	**XANSI**	**SETSS**
Untreated (ground %)		18.5	13.5	9.3	18.0	12.0	7.5	20.0
Untreated		0.0c	0.0d	0.0e	00c	0.0f	0.0d	0.0c
Pendimethalin 33% EC	3.0	65.0 b	68.9c	69.3cd	58.9b	70.6de	77.5c	70.5b
	4.0	70.5b	70.8c	74.9abc	66.6b	78.4c	81.9bc	73.1b
	5.0	71.3b	74.8 bc	79.6a	76.4a	83.8b	90.2a	77.2ab
Pendimethalin 40% SC	2.0	65.5b	69.0c	70.8cd	61.5b	74.1d	75.7c	71.9b
	3.0	70.2b	75.0bc	71.4bcd	64.7b	74.6d	79.4c	73.2b

	4.0	77.2a	76.6abc	80.1a	77.0a	83.1b	90.0a	82.7a
Pendimethalin 45.5% CS	2.0	70.3b	75.3bc	65.3d	59.9b	69.4de	78.1c	72.2b
	2.5	77.4a	80.3ab	74.9abc	66.4b	73.4d	79.3c	82.8a
	3.5	78.0a	81.5ab	80.1a	75.7a	79.9bc	86.0ab	84.3a
LSD P=Various		3.0-3.3	5.0-5.7	4.7-5.5	5.5- 6.4	2.9-3.8	3.6-4.7	5.4 - 6.2
Standard Deviation		1.4t	2.5t	2.3t	2.6t	1.6t	2.2t	2.8t

The dominant weeds in the experimental plots were annual monocotyledonous (*Echinochloa, Setaria* and *Digitaria)*. The barnyard grass had in plots treated in early-post-emergence a density of 20 plants/m^2 in untreated check at 42 days after treatment. The percentage of soil cover was higher than 24%. *E. crus-galli* is among the most noxious weeds in the world due to its superior biology and tremendous ecological adaptations (Michael, 2003; Leeson et al., 2005; Heap, 2014). It causes substantial yield losses in different field crops. It is widespread in different countries, infesting numerous cropping systems due to its invasive nature. (Marambe & Amarsinghe, 2002; Rusu et al., 2010). It has a strong allelopathic potential, which aids resource competition to exert notable yield losses. E. *crus-galli* is included among the most dangerous herbicide resistant weeds of the world (Bajwa et al., 2015; Beckie, 2006). It has evolved both target-site and non-target-site herbicide resistance due to which a quest for alternative herbicides is also in danger (Norsworthy et al., 2014). The foxtails (*Setaria* spp.) are one of the worst weed groups interfering with world agriculture and land management, therefore one of the world's most successful terrestrial plant organisms. The surviving of the foxtails is to a large extent due to their intimate evolutionary relationship with humans, disturbance, agriculture, and land management. The invasive threat of these weeds group continues due to its increasing geographic range of distribution, the appearance of new species and biotypes, and the increase of herbicide resistant varieties. The invasive and colonizing ability of the weedy foxtails is buffered against change by the accumulation of dormant seed in soil seed banks, a trait permitting enduring occupation of a locality. Frequently, more than one *Setaria* species co-exist together in a locality, possibly allowing a more complete exploitation of resources left available by human disturbance and management (Dekker, 2003; Borza et al., 2007). In Romania it is found in all areas, in all crops and in all pedoclimatic conditions. In the experimental plots where treatment was aplied post-emergently, the foxtails had a density of 18 plants/m^2 in untreated check at 42 days after treatment with a percentage of soil cover of 20%. *D. sanguinalis* (large crabgrass) is a troublesome annual weed found in most summer crops around the world (Oreja et al., 2020). The success of this plant as a weed in extensive crops is mainly due to its high seed production (Jonhson & Coble, 1986) and the long period of seedling emergence in the field, distributed from spring to mid-summer (Mohler & Callaway, 1995; Gallart et al., 2010; Cardina et al., 2011). The species *Echinochloa, Setaria* and *Digitaria* belong to the yearly monocotiledonate weeds class with late spring germination very harmful for the maize crop. Growing very fast it asphyxiates the maize crop (Rusu & Bogdan, 2012). The success of these plants is also due to a large number of seeds. Thus ten of barnyard grass plants emerging up to the 3-leaf stage of maize growth produced 14.400 to 34.600 seeds m^2 compared to only and 1.200 to 2.800 seeds m^2 from plants emerging after the 4-leaf corn stage (Bosnic & Swanton, 1997; Kropff et al., 1984). *D. sanguinalis* had in the experimental plots where treatmet was aplied in post-emergence at 42 days after treatment a percentage of soil cover of 12.2% (Table 2).

Table 2. The efficacy of herbicides in maize after 42 days of treatment in early-post-emergence

Treatment name	**Dose L/ha**	**Efficacy (% control compared with the untreated plots)**						
		Weeds stage majority (BBCH)						
		48	50	47	47	45	48	51
		ECHCG	**DIGSA**	**AMARE**	**CHEAL**	**AMBEL**	**XANSI**	**SETSS**
Untreated (ground %)		24.7	12.2	12.0	17.0	11.0	8.25	14.5
Untreated		0.0e	0.0c	0.0d	0.0d	0.0c	0.0d	0.0b
Pendimethalin 33% EC	3.0	47.7d	61.6b	61.1c	53.6c	71.5b	70.1c	66.6a
	4.0	53.7cd	66.8ab	69.1abc	59.2abc	74.6ab	75.1bc	71.9a
	5.0	54.8cd	72.0a	74.0ab	66.0ab	80.6a	82.4ab	73.3a
Pendimethalin 40% SC	2.0	49.5d	62.4b	64.0c	53.8c	69.5b	70.1c	67.8a
	3.0	53.7cd	64.7ab	67.8bc	57.4bc	74.5ab	74.6bc	72.1a
	4.0	59.0bc	72.9a	76.1a	66.5ab	81.2a	83.8a	76.6a
Pendimethalin 45.5% CS	2.0	49.5d	63.0b	63.8c	52.3c	70.5b	70.2c	67.9a
	2.5	63.3ab	66.7ab	69.5abc	58.0bc	75.6ab	74.2bc	75.9a
	3.5	66.1a	71.9a	73.9ab	67.6a	80.5a	80.5ab	77.0a
LSD P=Various		4.7-4.9	5.0-5.3	5.0-5.5	6.0-6.3	4.2-4.7	5.2-5.9	6.1-6.4
Standard Deviation		1.9t	2.2t	2.3t	2.5t	2.1t	2.6t	2.7t

Because the velocity of the effect is influenced by the available reserves of weed seeds in the soil, the effectiveness of this herbicide in control of foxtails, barnyard grass and large crabgrass was lower when the pendimethalin were applied post-emergently and at the lowest doses. In such a way, at 42 days after treatments application, for the erbicide Pendimethalin CS at 2.0 l/ha the effectiveness was: *E. cruss-galli* 49.5%, *Setaria* spp. 67.9 % and *D. sanguinalis* 63.0%. Compared to the herbicide Pendimethalin EC at 3.0 l/ha, the effectiveness was: *E. cruss-galli* 47.7%, *Setaria* spp. 66.6 % and *D. sanguinalis* 61.6%. Pendimethalin [N-(1-ethylpropyl)-3, 4-dimethyl 2,6-dinitro benzenamine], a member of the group 2,6 dinitroaniline herbicides has selective pre-emergence characteristics. Pendimethalin disrupts the mitotic sequence by inhibiting the production of the microtubule protein, tubulin (Tomlin, 2000). Its persistence in the soil is affected by cultivation, soil temperature, and moisture conditions (Gasper et al., 1994; Schleicher et al., 1995; Srivastava et al., 2006; Sondhia, 2012). Pendimethalin is safe for use and does not appear to pose any health hazard to consumers or harm to the environment (Tandon, 2015). The long-term excessive application of pesticides has induced adverse effects on the environment and human health. Controlled release technology in pesticides is an effective way to solve these problems. The microcapsules have many advantages compared to traditional pesticide formulations, which include reduced plant, fish, and mammalian toxicity; improved storage stability; protected pesticides from environmental hazards. Regarding the control of dicotyledonous species, there were no significant differences between the 3 formulating of the herbicide Pendimethalin and for the species of *Ambrosia* and *Xanthium*, the classic formulation EC (Emulsifiable concentrates) proved more effectiveness, probably due to the fact that the CS (Capsule suspensions) formulation releasing more of the active substance, favored the development of these weeds. Thus, for Pendimethalin CS at 3.5 l/ha the effectiveness was: *A. retroflexus* 73.9%, *C. album* 76.6 %, *A. artemisiifolia* 80.5% and *X. italicum* 80.5%. For the herbicide Pendimethalin EC at 5.0 l/ha the effectiveness was: *A. retroflexus* 74.0%, *C. album* 66.4 %, *A. artemisiifolia* 80.6% and *X. italicum* 82.4%. The Pendimethalin 40% SC have a good efficacy in control of dicotyledonous weeds both pre-

emergence and early post-emergence. At higher dose of 4.0 l/ha at pre-emergent application for the Pendimethalin 40% SC, the effectiveness was: *E. cruss-galli* 77.2%, *D. sanguinalis* 76.6%, *A. retroflexus* 80.1%, *C. album* 77.0 %, *X. italicum* 90.0%, *A. artemisiifolia* 83.1 % and *Setaria* spp. 82.7 % at 42 days after treatment pre-emergent. By comparison, at the same dose but applied early post-emergence, the effectiveness was: *E. cruss-galli* 59.0%, *D. sanguinalis* 72.9%, *A. retroflexus* 76.1%, *C. album* 66.5 %, *A. artemisiifolia* 81.2%, *X. italicum* 83.8% and *Setaria* spp. 76.6 % at 42 days after treatment. For *C. album* species, efficacy was lower and at 42 days after treatment did not exceed 67% at any of the tested doses. In fact, *C. album* are the most frequently reported triazine resistant weed species (Bandeen & McLaren, 1976; Murphy et al., 1986; Vaughn KC & Vaughn, 1990; Gasquez, 1991; Holt et al., 1993; Moss & Rubin, 1993; Smeda et al., 1997; Harris et al., 1995; Heap, 1997; Zeng & Baird, 1997; Wang & Darmency, 1997; Bhowmik, 2010; Lowe et al., 2001; Dayan, 2019; Murphy & Tranel, 2019). In recent years, there has been a rapid increase in the number of reported cases of herbicide-resistant weed species (over 100), as well as an increase in the types of herbicides to which resistance has evolved (Warwick & Black, 1994). No phytotoxicity symptoms have been shown in experimental plots. No symptoms of chlorosis, necrosis, leaf deformation, height reduction, distortion and delay at flowering in plots treated with Pendimethalin were seen (OEPP/EPPO Standards Bulletin, 2014). Also, in experimental plots there were present the invasive species *A. artemisiifolia* and *X. italicum* that, when under favourable conditions of growing and development, can cause great damage and pose serious challenges in control (Grădilă & Jalobă, 2018; Grădilă et al., 2020).

4. CONCLUSIONS

In experimental field the predominant weeds were annual monocotyledonous and dicotyledonous. The dominant weeds were *Echinochloa, Setaria* and *Digitaria.* The efficacy and selectivity of 3 different Pendimethalin formulations (EC, SC, CS) applied in pre-emergence and in early post-emergence stage, were evaluated. The Pendimethalin formulations had a good efficacy in controlling weeds in maize crop, the best results being when Pendimethalin was formulated a CS (Capsule suspensions) and applied pre-emergently. Because the monocotyledonous weeds grow faster than maize plants, the efficacy of Pendimethalin was lower where applied in postemergence for these species. Suspension concentrates (SC) formulation provided the highest and most consistent efficacy both in pre-emergence and in early post-emergence. Regarding the control of dicotyledonous species there were no significant differences between the 3 formulating of the herbicide Pendimethalin. Capsule suspensions offer both safer and more effective performance in favorable cases.

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