CONTROLLED RELEASE FORMULATIONS OF HERBICIDES PENDIMETHALIN BASED ON MICRO-ENCAPSULATION IN APPLE ORCHARDS

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Abstract

The aim of this study was to determine the floristic composition of weeds in apple orchards and to compare the efficacy in controlling annual dicotyledonous and monocotyledonous weed species of an innovative formulation of Pendimethalin 45.5% CS (microcapsules suspension) with two classical formulations: Pendimethalin 33% EC (emulsifiable concentrate) and Pendimethalin 40% SC (concentrated suspension). The research was carried out in 2020 at Research-Development Institute for Plant Protection, Bucharest and Moara Domnească Didactic Farm, Ilfov. These weed species were found in the experimental fields: Echinochloa crus-galli, Digitaria sanguinalis, Setaria spp., *Capsella bursa-pastoris, Erigeron annuus, Galium aparine, Stellaria media, Daucus carota, Euphorbia* spp., *Veronica* spp., *Chenopodium album, Amaranthus* spp., *Polygonum* spp., *Sonchus oleraceus, Galinsoga parviflora, Solanum nigrum* and *Anagalis arvensis. Experimental plots were placed in randomized blocks, in 4 repetitions with a plot area of 20 m^2, each Pendimethalin formulation being tested in 3 different doses. The results obtained showed that Pendimethalin-based herbicides provided good protection of apple orchards against annual weeds. The best results were obtained at higher doses of Pendimethalin as well as in experimental samples in which the active substance is protected in microscopic capsules that prevent the premature dispersion of Pendimethalin.*

Keywords: *microcapsules suspension, weeds, control, apple orchards, pendimethalin*

1. INTRODUCTION

The apple tree (*Malus domestica* Borkh) is widespread all over Romania, especially in the hilly areas, where there are many fruit-growing centres (Argeș, Dâmbovița, Vâlcea, Prahova, Buzău, Suceava, Iași, Maramureș, Bistrița, Sălaj and Mureș). Due to its ecological pliancy, apple ranges about a third of the total orchard surface in Romania, which puts it the second after plum.

Weed management is one of the most important technological practices in orchards, and the concept of integrated control is also reasonable in fruit growing, because the method of soil maintenance together with the other technological links impact on the quantity and quality of the obtained yields (Perianu, 2004). Weeds contend with trees for water, light and nutrients, cause allelopathy as well as conditions that favour the proliferation of rodents, harmful fungi and viral diseases, can stimulate blossom freezing in spring, obstruct the economical use of fertilizers and make it difficult or impossible to use a fruit harvester (Zimdahl, 1980; Byers, 1984; Cianciara, 1987; Berca, 1996, 2004; Jones and Sutton 1996; Ștefan, 2022; Atland et al., 2003; Lipecki, 2006; Hanson and Schneider, 2008; Rankova, 2006; Prodanova-Marinova and Koňova, 2015; Kyselová et al., 2019; Rankova and Zhivondov, 2010; Futch, 2000). The great diversity of ecological areas in which apple is grown and the perpetual adjustement of weed associations according to soil and climatic conditions, tillage technologies and fertilisation regimes require detailed research on floristic composition, dominant weeds and control methods.

In Romanian orchards, according to the literature, there are around 30 species of weeds that usually occur year after year and that, when they find optimal conditions for growth and development, endanger the quantity and quality of the obtained productions. The most common annual weeds are : *Amaranthus retroflexus* (L.), *Capsella bursa-pastoris* (L.) Med., *Cardaria draba* (L.) Desv., *Chenopodium album* (L.), *Conyza canadensis* (L.) Cronq., *Digitaria sanguinalis* (L.) Scop., *Echinochloa crus-galli* (L.) P. Beauv., *Erigeron annuus* (L.) Pers., *Fallopia convolvulus* (L.) A. Löve., *Galinsoga parviflora* Cav., *Galium aparine* (L.), *Lamium purpureum* (L.), *Matricaria maritima* ssp. *inodora* (L.), *Poa annua* (L.), *Polygonum aviculare* (L.), *Polygonum persicaria* (L.), *Senecio vulgaris* (L.), *Setaria glauca* (L.) P. Beauv., *Setaria pumila* (Poir.) Roem et Schult., *Solanum nigrum* (L.), *Stellaria media* (L.) Vill., *Veronica persica* (Poir.). Among the most common perennials are: *Agropyron repens* (L.) P. Beauv., *Cirsium arvense* (L.) Scop., *Convolvulus arvensis* (L.), *Cynodon dacylon* (L.) Pers., *Equisetum arvense* (L.), *Rumex acetosella* (L.), *Sonchus arvensis* (L.), *Sorghum halepense* (L.) Pers. and *Taraxacum officinale* (L.) Weber ex F.H. Wigg., (Coman, 1968; Coman et al., 1987; Șarpe, 1987; Dihoru and Donița, 1970; Ceapoiu, 1992; Chirilă, 2001; Berca, 2004; Perianu, 2004; Grădilă and Jalobă, 2020).

In our country, pre- and post-emergence herbicides can be applied in order to control the full range of weeds in apple orchards. The choice of herbicide depends on the soil cultivation technique (with or without intercropping), the way of applying the treatments (in rows, between rows, in strips or over the whole area) and of course on the segetal flora emerged in the orchard, the optimal timing of application and the attention paid to preventing possible phytotoxicity of the herbicide. Pre-emergent herbicides, commonly mentioned as residual herbicides because of their persistence in the soil, can control weeds for a longer time, requiring a certain amount of water after application for proper dispersal in the soil (Helling, 2005).

One such herbicide is Pendimethalin, from the dinitroaniline class (N-[1-ethylpropyl]-3,4-dimethyl-2,6-dinitrobenzenamine) used for over 30 years in agricultural practice to control most monocotyledonous annual weeds and some broadleaved weeds, and which is used both in pre-emergence, i.e., before weed seeds have sprouted, and in early post-emergence (Ashton and Craft 1981; Travlos et al., 2020). Due to the perenniality of orchards, the continued use of herbicides results in the emergence and evolution of resistant weed biotypes and environmental pollution (Friesen et al., 2000).

An important element inducing efficacy and environmental pollution is the type of pesticide formulation (emulsifiable concentrates, wettable powders, concentrated suspensions, water-dispersible granules, water emulsions, etc.). Today, farmers and consumers increasingly need safer and more convenient pesticide formulations and it is therefore important to be developed new herbicide formulations that are highly more effective, safer (for the worker and the environment) and cost-effective. In this regard, controlled release herbicide formulations based on micro-encapsulation have become necessary in recent years as they increase, under certain conditions, the efficacy of herbicides at low rates (Sopeña et al., 2005; Liang et al., 2017; Singh et al., 2020).

While the advent of biodegradable polymers, microencapsulation has enabled the development of controlled release systems. These revolutionary technologies allow control of the rate, duration and distribution of herbicide active substance. With these technologies, biologically sensitive microparticles are designed to deliver an active herbicide to a specific area of interest, for example, the weed germination zone. Micro-encapsulation is a technological process in which small solid, liquid or gaseous active substances are completely surrounded by individual polymeric coatings (polymeric membranes), which allow the incorporated active substances to be released at a certain rate and/or under certain conditions.

The membrane controls the rate at which the active ingredient spreads throughout the system, including how it should become permeable, i.e., by hydration or by solubilisation of the active ingredient in some components of that membrane. In its turn, the polymer must remain intact during the release period, without swelling or erosion (Collet and Moreton, 2004). The products resulting from this technological process are called microparticles, microcapsules or microspheres according to the system's peculiarities with respect to morphology and internal structure, all of which being < 1 mm, while particles that are smaller than 1 µn are called nanocapsules or nanospheres. The structure of microcapsules is extremely diverse and depends, in most cases, on the technology used. In recent years, in addition to classical formulations of Pendimethalin, microcapsule suspension formulations have also appeared, which justifies the chosen topic and the research conducted.

In this regard, the paper provides data on the floristic composition of weeds in apple orchards and on the efficacy and selectivity in weed control of an innovative formulation of Pendimethalin 45.5% CS (microcapsule suspension) compared to two classical formulations: Pendimethalin 33% EC (emulsifiable concentrate) and Pendimethalin 40% SC (concentrated suspension).

2. MATERIALS AND METHODES

Research was carried out in apple orchards of Didactic Station Moara Domnească, Ilfov county (N: 42°94'87''; E: 026°15'269'') and of Research - Development Institute for Plant Protection Bucharest (N: 44°30'173''; E: 026°03'934''). Trials were conducted in 2020, using Randomized Complete Blocks as study design for Jonagold variety (Moara Domnească trial) and Jonathan variety (Bucharest). Apple trees as uniform as possible in size and vigour were selected for the trials which were placed in 4 replicates with a plot area of 20 m². Herbicides, dosages, active substance concentrations and formulation type are shown in Table 1. Each experimental block included a control and 2 reference product variants. The maintenance of apple orchards was identical in the 2 locations and is shown in Table 2. No other herbicides were applied in the experimental plots.

Herbicides were applied pre-emergence, in spring, when apple orchards wereat the phenological stage of leaf emergence, respectively at BBCH 15 (five leaves unfolded), at RDIPP- Bucharest and at BBCH majority 11 (first leaf unfolded), at Moara Domnească. Treatments were applied by nozzle spray pump at an air temperature of 14°C and a soil temperature of 9°C on 15 April at Moara Domnească and at an air temperature of 17°C and a soil temperature of 11°C on 22 April at RDIPP- Bucharest. At Moara Domnească, drip irrigation was applied in April, May and June with a volume of water of 250 l/h for 4-5 hours per day. At RDIPP- Bucharest no irrigation was applied. The soil in the 2 orchards was fertilized in mid-March with Mono Ammonium Phosphate (MAP) type 12-61-0, containing 12% nitrogen ($NH4+$) and 61% phosphorus as $P2O5$, at a dose of 7 kg/ha and Urea type 46-0-0, containing 2 urease enzyme inhibitors (mixture of NBPT + NPPT in a 3:1 ratio), thus ensuring superior performance against urea evaporation, at a dose of 150 kg/ha.

Table 1. Herbicides applied in apple orchards

No.	Experimental sample	Concen. g.s.a./l	Rate l/ha	Other rate g.s.a./ha
1.	Untreated	-	-	-
2.	Pendimethalin 33% EC (Emulsifiable concentrate)	330	3.0	990
3.			4.0	1320
4.			5.0	1650
5.	Pendimethalin 40% SC (Suspension concentrate)	400	2.0	800
6.			3.0	1200
7.			4.0	1600
8.	Pendimethaline 45.5% CS (Capsule suspension)	455	2.0	910
9.			2.5	1140
10.			3.5	1600
11.	Sharpen 40 EC	400	3.0	1200
12.			4.0	1600
13.	Activus 400 SC	400	4.0	1600

Table 2. Maintenance of apple orchards

Date	Type	Comercial Product	Rate kg/l/ha
7-11-19	Fung	Bouillie bordelaise	5.0 kg/ha
20-1-20	Inse	Ovipron Top EC	25.0 l/ha
15-3-20	Fung	Alcupral 50 PU	4.5 kg/ha
20-3-20	Fert	Mono Amoniu Fosfat	7.0 kg/ha
20-3-20	Fert	Uree tip 46-0-0	150 kg/ha
20-3-20	Fung	Chorus 50 WG	0.75 kg/ha
2-4-20	Fung	Score 250 EC	0.20 l/ha
12-4-20	Fung	Orius 25 EW	1.0 l/ha
12-4-20	Inse	Fastac 10 EC	0.15 l/ha
10-5-20	Inse	Calypso 480 SC	0.2 l/ha
10-6-20	Fung	Merpan 80 WDG	2.0 kg/ha
24-6-20	Fung	Shavit F72 WDG	2.0 kg/ha
24-6-20	Inse	Mospilan 20 SP	0.300 kg/ha

Weeds density was assessed as couple of plants on square meter and as percentage of groundcover. The number of weeds per square meter was determined by weed mapping with a metric frame of 1 m side in 4 repetitions on the diagonal of the plot. The percentage of weed cover was revealed visually, according to species, density and phenological aspects of each weed (sprouting, budding, flowering, flowering, fruiting, ripening, seed dispersal, height, etc.). Weed control (efficacy) was assessed one month after application of treatments in % compared to the untreated control according to the EWRS scale. Phytotoxicity on trees was assessed visually on a scale from 0% to 100% (0 - no tree injury and 100 - complete drying of trees). Statistical calculation of results was performed using ARM-9 software (P = .05, Student-Newman-Keuls).

3. RESULTS AND DISCUSSIONS

The spring of 2020 was low in rainfall but quite warm in April, when most weed seeds usually emerge, with rainfall amount of only 18.8 mm at RDIPP- Bucharest and 13.4 mm at Moara Domnească (National Meteorological Administration, 2020). Although these conditions were not favourable for weed growth and development, due to irrigation at Moara Domnească, the degree of weed infestation exceeded 130 plants/m^2 (Table 3). The floristic composition of the experimental plots was dominated by annual weeds, with the following species present in the experimental plots of the apple orchard of the Moara Domnească Didactical Farm: *E. crus-galli*, *D. sanguinalis*, *Setaria* spp., *E. annuus*, *Veronica* spp., *C. bursa-pastoris*, *G. aparine* and *S. media*. There have been identified *A. retroflexus*, *C. canadensis*, *P. oleracea* and *C. dactylon*, too, but of low density on meter square. *E. crus-galli*, *Setaria viridis*, *P. annua*, *C. album*, *Daucus carota*, *C. bursa-pastoris*, *Euphorbia* spp., *Sonchus oleraceus* and *Anagalis arvensis* (L.) were took into account in Bucharest orchard. Other species were also counted in small numbers: *C. draba*, *C. arvense*, *L. purpureum*, *M. inodora*, *Ranunculus repens* (L.), *T. officinale*, *A. repens* and *Ambrosia artemisiifolia*. Even though these species had a low density, they must be watched carefully because some are perennial weeds, difficult to control, and others are allergenic invasive species.

Of the monocotyledonous class, in the apple orchard at Moara Domnească, the weed with the highest density/m^2 was *E. crus-galli* popularly named cockspur or barnyard grass and of the dicotyledonous *E. annuus*, popularly known as daisy fleabane or white top.

Table 3. The efficacy of herbicides in apple after 1 month of treatment, Moara Domnească

Experimental sample	**Rate l/ha**	**Efficacy (% control compared to untreated check)**							
		Apple: majority BBCH 51 (buds swelled)							
		Weeds BBCH							
		51[1]	**51[1]**	**47[2]-51**	**49[3]**	**65[4]**	**65[4]**	**49[3]**	**61[5]**
		E.crus-galli	***D. sanguina.***	***Setaria* spp.**	***E. annuus***	***Veronica* spp.**	***C.b.-pastoris***	***G. aparine***	***S. media***
Untreated (plants/m^2)		30.7 a	12.7a	11.0a	22.4a	15.2a	15.5a	8.5a	14.2a
% soil coverage		32.2 a	12.0a	8.5 a	20.2a	6.0a	8.8a	5.0a	3.8a
Untreated		0.0c	0.0c	0.0d	0.00d	0.00d	0.0b	0.00e	0.0b
Pendimethalin 33% EC	3.0	65.4b	98.5ab	87.7c	53.6c	70.1c	97.4a	74.0d	94.6a
	4.0	70.5b	98.6ab	91.6bc	59.2abc	75.1bc	99.7a	77.5bcd	96.4a
	5.0	78.0a	100.0a	98.1a	66.4ab	82.4ab	100.0a	83.0abc	97.8a
Pendimethalin 40% SC	2.0	65.5b	94.3b	86.7c	53.8c	70.1c	98.1a	70.7d	93.6a
	3.0	70.2b	100.0a	96.9ab	57.4bc	74.6bc	100.0a	76.1cd	95.9a
	4.0	77.4a	100.0a	99.4a	66.5ab	80.5ab	100.0a	82.8abc	98.9a
Pendimethalin 5.5% CS	2.0	69.2a	98.0ab	86.7c	58.0bc	74.2bc	99.4a	70.8d	93.1a
	2.5	71.3b	100.0a	99.0a	63.4ab	80.0ab	100.0a	75.6cd	97.3a
	3.5	80.5 a	100.0a	100.0a	70.6a	85.8a	100.0a	85.3a	100a
Sharpen 40 EC	3.0	65.0b	100.0a	99.4a	53.3c	70.8c	100.0a	83.6ab	98.2a
	4.0	76.8a	100.0a	100.0a	58.2bc	74.8bc	100.0a	84.0ab	100a
Activus 400	4.0	77.2b	100.0a	99.7a	63.4ab	80.0ab	100.0a	82.8abc	100a
LSD P =.05		4.0-4.5	1.1-3.9	1.4-7.0	6.0- 6.3	6.0-6.3	1.3-2.3	4.6-5.4	2.8-5.9
Standard Deviation		1.92t	4.34t	4.78t	2.549t	2.549t	4.69t	2.481t	5.74t

[1]Beginning of heading: tip of inflorescence emerged from sheath, first spikelet just visible;

[2]Flag leaf sheath opening; [3]First awns visible (in awned forms only)

[4]Full flowering: 50% of anthers mature; [5]Beginning of flowering: first anthers visible

E. crus-galli had a density >30 plants/m^2 and a percentage of groundcover over 32% in the control sample, one month after treatments. Barnyard grass (*Poaceae*) occurs on a wide variety of soils and crops all over the country, but at higher density was remarked in warmer areas. The development of this plant is ensured by the fact that seed germination occurs only one year after seed formation and can retain germination capacity for up to 10-16 years, germinates rollingly, and after flowering, the plant grows very fast if light, moisture and nutrient conditions are provided. It has a quick flowering capacity over a wide range of photoperiods (Păunescu, 1997; Rusu et al., 2010). The number of seeds per plant ranges from 200 to 10.000 and the number of seeds per hectare can reach 1-2.5 billion seeds (Anghel et al., 1972; Berca, 1996). It is worth noting that plants that have reached the bud stage may retain their seeds even after the stems have been cut (Staicu, 1969).

E. annuus (*Asteraceae*) is an annual or biennial species native to eastern North America that was originally introduced to Europe in the 17th century as an ornamental. It is now one of the 150 most widespread invasive plant species in Europe, where it is particularly plentiful in forests and disturbed and ruderal habitats such as roadsides, railway lines and waste areas (Edwards et al., 2006; Trtikova et al., 2011).

It is listed as one of the 50 most frequently found invasive species in Germany (Kowarik, 2002). Together with the invasive *Ailanthus altissima* it is the most frequently found invasive plant in both semi-natural and artificial habitats in Romania (Anastasiu and Negrean, 2005). In the experimental plots at Moara Domnească, the bunghorus had an average density >22 plants/m^2 and a percentage of ground cover >20%, as it is a difficult species to fight against (Table 3).

Of the data analysis shown in Table 3, it can be concluded that at Moara Domnească, 30 days after the application of the treatments, the Pendimethalin-based herbicides had a good efficacy in control of annual weeds, the best results being obtained at the highest doses and in the experimental variants in which the active substance is protected in microcapsules that prevent the dispersion of Pendimethalin (CS formulation). Thus, for the rate of 2.0 l/ha (910 g.s.a/ha), the lowest rate tested for Pendimethalin herbicide formulated as a microcapsule suspension, the efficacy was: 69.2% for *Echinochloa*, 98.0% for *Digitaria*, 86.7% for *Setaria*, 58.2% for *Erigeron*, 74.2% for *Veronica*, 99.4% for *Capsella*, 70.8% for *Galium* and 93.1% for *Stellaria*. Among the species of the genus *Veronica*, *V. hederifolia*, *V. arvensis* and *V. persica*, an invasive species in Romania, have been recognized.

In Bucharest orchard, the degree of weed infestation was lower than the one of Moara Domneasca where irrigation was applied. There have been found 85 plants/m^2 while the dominant ones were the annual monocotyledonous as foxtail, barnyard grass and crabgrass whose density was 36 plants/m^2. Among the dicotyledons, the species *C. album*, popularly known as pigweed or wild spinach, was observed with a density of more than 20 plants/m^2 and a percentage of ground cover more than 25% (Table 4).

The green foxtail (*S. viridis*) is an invasive species in Europe and North America, as well as in Canada, where it first came out in 1882 brought by ship ballast tanks. It is highly pliant and versatile and it can be found in many crops, both cereal and hoeing crops. In our country it is common in meadow crops, vineyards, vegetable gardens, in ruderal places, stubble fields and can cover 50-95% of the soil surface, reducing the quantity and quality of crops. In the experimental plots at RDIPP-Bucharest, it had a density of more than 15 plants/m^2, and a percentage of soil cover of 18% (Table 4).

C. album (Amaranthaceae) is an ordinary weed in about 40 crops in 47 countries, most commonly found in sugar beet, potatoes, maize and cereals. It is one of the main weeds in Canada and Europe, and in India, Mexico, New Zealand, Pakistan and South Africa it is ranked among the six most noxious weeds. In Europe and America, it is a problem weed in corn, soybeans, wheat, barley, potatoes, horticultural crops and orchards. It also grows in wastelands, pastures, uncultivated land, along roadsides and riverbanks. It is tolerant of a wide range of crop conditions, climates, soil types, fertility and pH, reflected in Coquillat (1951) suggestion that it is one of the five most widespread plants in the world. It grows vigorously on fertile, heavy, well-watered soils (reaching up to 2 m height), often remaining dwarfed in drier, less fertile soils.

Biotypes of this weed resistant to atrazine, chloridazone and pyridate have been reported (Solymosi and Lehoczki, 1989; Parks et al, 1995). Under these weed conditions the efficacy of Pendimethalin in controlling this species was lower: 58.9% for Pendimethalin 33% EC applied at 3.0 l/ha (990 g. s.a./ha), 61.5% for Pendimethalin 40% SC applied at 2.0 l/ha (800 g. s.a./ha), and 75.7% for Pendimethalin 45.5% CS applied at 2.0 l/ha (900 g. s.a./ha). We also noted the presence of the species *D. carota* (Apiaceae) popularly called wild carrot which generates up to 4000 seeds/plant, retaining germination capacity for 5-7 years. Due to the lower weed density/m^2 the Pendimethalin formulations provided good protection of apple orchards at RDIPP-Bucharest against annual weeds with the best results being recorded by microcapsules in suspension at the 3.5 l/ha dose, namely: 66.1% at *S. viridis*, 83.1% at *E. crus-galli*, 82.4% at *P. annua*, 79.5% at *C. album*, 86.9% at *D. carota*, 90.1% at *C. bursa-pastoris*, 84.3% at *Euphorbia* and 100% at *S. oleraceus* and *A. arvensis*.

Table 4. The efficacy of herbicides in apple after 1 month of treatment, RDIPP-Bucharest

Experimental sample	**Rate l/ha**	**Efficacy (% control compared to untreated check)**								
		Apple: majority BBCH 51 (buds swelled)								
		Weeds BBCH								
		61[5]-65[4]	65[4]	61[5]	60[6]	61[5]	69[7]	61[5]	61[5]	69[7]
		S. viridis	*E.crus-galli*	*P. annua*	*C. album*	*D. carota*	C.*b.-pastoris*	*Euph.* spp.	*S. olerac.*	*A. arvensis*
Untreated (plants/m²)		15.5 a	13.5a	7.7a	20.5a	8.8a	7.5a	4.5a	3.5a	3.5a
% soil coverage		18.0 a	14.0a	8.5 a	25.5a	14.4a	8.8a	8.2 a	5.0a	4.4a
Untreated		0.0c	0.0d	0.0e	0.0c	0.0f	0.0d	0.0c	0.0c	0.0b
Pendimethalin 33% EC	3.0	49.5d	69.0c	69.3cd	58.9b	70.6de	77.5c	73,1b	98.1ab	96.8a
	4.0	53.7cd	75.0bc	74.9abc	66.6b	78.4c	81.9bc	77.2ab	99.6ab	100a
	5.0	63.3ab	80.3ab	80.1a	76.4a	83.8b	90.2a	82.8a	100.0a	100a
Pendimethalin 40% SC	2.0	49.5d	68.9c	65.3d	61.5b	74.1d	75.7c	71.9b	95.1b	97.4a
	3.0	53.7cd	74.8bc	71.4bcd	64.7b	74.6d	79.4c	72.2b	98.7ab	100a
	4.0	59.0bc	81.5ab	79.6a	77.0a	83.1b	89.9a	82.7a	100.0a	100a
Pendimethalin 5.5% CS	2.0	59.0bc	70.8c	70.8cd	75.7a	73.4d	78.1c	70.5b	95.3b	97.4a
	2.5	64.0ab	75.3bc	74.9abc	66.4b	82.2bc	86.0ab	77.2ab	100.0a	100a
	3.5	66.1a	83.1a	82.4a	79.5a	86.9a	90.1a	84.3a	100.0a	100a
Sharpen 40 EC	3.0	52.0cd	68.4c	75.0abc	60.4b	68.1e	76.9c	74.1b	95.4b	100a
	4.0	53.2cd	71.9c	78.4ab	65.5b	82.2bc	79.3c	76.5ab	99.7ab	100a
Activus 400	4.0	54.8cd	76.6abc	80.1a	75.7a	79.9bc	86.0ab	77.5ab	100.0a	100a
LSD P=.05		4.7-4.9	5.0-5.7	4.7-5.5	5.5-6.4	2.9-3.8	3.6-4.7	5.4-6.2	1.4-3.8	1.6-2.9
Standard Deviation		1.98t	2.56t	2.37t	2.64t	1.66t	2.29t	2.82t	4.80t	5.21t

[6]First flowers opened; [7]End of flowering.

Fig 1. Aspects for experimental plots

Pendimethalin suppresses both roots and shoots growth so that impacted weeds died shortly after germination. In the experimental plots the direct and most visible symptom was the inhibition of lateral root formation. Of the dinitroanaline herbicides, pendimethalin has higher water solubility and lower volatility, allowing it to be applied to the soil surface rather than requiring mechanical incorporation which is an advantage (Savage and Jordan 2020; Devine et al., 1993; Tomlin, 2000). Comparing pendimethalin formulations the results denoted that the capsule suspension consistently reduced weed infestation due to microencapsulation. Microcapsules have many advantages over traditional pesticide formulations, namely reduced toxicity to plants, fish and mammals, improved storage stability, low volatilisation and extended herbicidal activity, while also reducing costs for farmers and companies, too. With all these advantages, the microcapsule suspension also requires moisture in the form of rain or irrigation to release the active substance into the weed germination zone. Therefore, at Moara Domnească, where irrigation was applied, the results in weed control were better, even though the apple orchard was more weed infested. Our results clearly show that all three formulations of Pendimethalin applied pre-emergence proved effectiveness in weed control, but the microcapsule suspension showed excellent activity against annual weeds in apple orchards. No phytotoxicity symptoms were observed in the experimental plots. No symptoms of chlorosis, browning, necrosis, leaf deformities or flowering delays were observed in plots treated with Pendimethalin (EPPO Standards Bulletin, 2014).

4. CONCLUSIONS

The great diversity of ecological zones in which apple is grown and the permanent changing of weed associations according to soil and climatic conditions, tillage technologies and fertilisation regimes require detailed research on floristic composition, dominant weeds and control methods.

In the apple orchards studied, the floristic composition of the experimental plots was dominated by annual weeds.

Of the monocotyledonous class in the Moara Domnească apple orchard, the weed with the highest density/m^2 was *E. crus-galli*, and of the dicotyledons, the invasive species *E. annuus*.

At RDIPP-Bucharest, the dominant weeds were the monocotyledonous annuals, i.e., foxtail, barnyard grass and crabgrass which had a density of 36 plants/m^2, and among the dicotyledons, the species *C. album*, with a density of more than 20 plants/m^2 and a percentage of ground cover > 25%.

Under these weed infestation conditions, the Pendimethalin formulations provided good protection of the apple orchards studied against annual weeds.

The best results were obtained at higher doses of Pendimethalin as well as in experimental samples where the active substance is protected in microscopic capsules that prevent premature dispersion of Pendimethalin.

Microcapsules have many advantages over traditional pesticide formulations, including reduced toxicity to plants, fish and mammals, improved storage stability, low volatilisation and extended herbicidal activity.

No symptoms of phytotoxicity were observed in the cultivars tested.

Controlled release systems are an alternative to conventional herbicide application systems and are more effective and safer for the consumer and the environment.

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