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HERBICIDES IN CULTIVATION OF MILK THISTLE

Katarzyna Sadowska, Jadwiga Andrzejewska✉

Department of Agronomy, UTP University of Science and Technology in Bydgoszcz
prof. S. Kaliskiego 7, 85-796 Bydgoszcz, **Poland**

ABSTRACT

Background. Milk thistle is a species that can be used not only for medical and nutritional purposes, but also in other branches of the economy. Under field conditions this plant is easily infested with weeds. The aim of the study was to test the effectiveness of selected herbicides during milk thistle cultivation, with particular emphasis on foliar preparations for control of dicotyledonous weeds.

Material and methods. In a two-year field study (2016, 2017) conducted at the Mochełek Research Station, under favourable humidity conditions, the following were tested: (1) Stomp Aqua 400 SC + Fusilade Forte 150 EC, (2) Reglone 200 SL + Fusilade Forte 150 EC and the foliar herbicides; (3) Lentagran 45 WP + Fusilade Forte 150 EC, (4) Betanal Elite 274 EC + Fusilade Forte 150 EC and (5) Boxer 800 SC.

Results. The lowest number and weight of weeds occurred after the applications of (1) Stomp Aqua 400 SC + Fusilade Forte 150 EC and (2) Reglone 200 SL + Fusilade Forte 150 EC. When using these herbicides the thistle was also the tallest (150 cm), had the highest plant density (25 pcs·m^{-2}) as well as the highest yields (1.2 Mg·ha^{-1}). After application of the other herbicides the number and weight of weeds were 3–5 times higher, while the density and height of the thistle plants were on average 55% lower and yields were almost 70% lower, additionally, after spraying with Lentagram 45 WP the 1000 fruit weight of milk thistle was significantly reduced.

Conclusion. Due to the growing international interest in the multidirectional use of milk thistle it is justified to continue the search for appropriate herbicides for the post-emergence control of dicotyledonous weeds.

Key words: dicotyledonous weeds, foliar herbicides, *Silybum marianum*, Stomp Aqua

INTRODUCTION

Milk thistle (*Silybum marianum* (L.) Gaertn.) is an annual or biannual species belonging to the Asteraceae family. The species is native to southern Europe, Asia Minor and northern Africa and it is naturalised in North and South America, Australia and New Zealand (Groves and Kaye, 1989; Morazzoni and Bombardelli, 1995; Martin *et al.*, 2000; Carrier *et al.*, 2002). Milk thistle fruits contain the biologically active flavonolignan complex called silymarin, which is mainly used for the treatment of liver diseases and, therefore, it is one of the most widely grown and economically viable medicinal plant (Andrzejewska *et al*., 2015).

Although milk thistle is now present in many regions of the world as an aggressive weed (Chambreau and MacLaren, 2007; Haban *et al*., 2009; Khan *et al*., 2009; Vereš and Týr, 2012; Tyr, 2015; James and Tozer, 2018) it is susceptible to weeds as a field crop. The greatest threat in milk thistle cultivation occurs immediately after sowing, because its emergence appears after about 2–3 weeks and a further 2–3 weeks elapse before the soil in the interrows is covered by the thistle plants. The effectiveness of mechanical treatments is therefore

✉jadwiga@utp.edu.pl, sadowskir@op.pl

limited, because they can be performed only in the interrows and for a short period of time, i.e. about 2 weeks starting from the emergence of milk thistle plants (Czarnecki and Załęcki, 1990; Andrzejewska *et al*., 2011).

Several active substances have been tested on milk thistle crops, and these studies have shown that milk thistle is a plant very sensitive to the majority of herbicides used in agriculture. The most safe and effective herbicides for the secure control of dicotyledonous weeds in milk thistle are pendimethalin and metribuzin, and for monocots, fluazifop-P-butyl and trifluralin (Zheljazkov *et al*., 2006; Drapalova and Pluhackova, 2014). A recent study conducted in Bulgaria showed that even better efficacy can be achieved using Kalin flo (linuron), Raft 400 S.C. (oxidiarges) in a mixture with Tiger platinium 5 EC (quizalofop-P-ethyl) (Delchev, 2016).

In Poland, Betanal Compact 163 EC and Stomp 330 EC were used to control weeds in milk thistle in the past (Czarnecki and Załęcki, 1990; Załęcki *et. al*., 1995, 1996). Currently, one herbicide is registered for monocot and dicotyledonous weeds – Stomp Aqua 400 SC (pendimethalin) and two herbicides for monocot weeds – Fusilade Forte 150 EC (fluazifop-P-butyl) and Trivko (luazifop-P-butyl) (IOR-PIB, 2018). Stomp Aqua 400 SC is a preparation that is used not later than 3 days after sowing. The effect of this herbicide depends on the level of soil moisture and in dry conditions the effectiveness can be unsatisfactory (the present author's observations). Fusilade Forte 150 EC and Trivko are used on leaves. Many years of observation allow us to highly evaluate the effectiveness of Fusilade Forte 150 EC in the control of monocotyledonous weeds in thistle. In milk thistle cultivation for medicinal and food purposes, according to the Principles of Good Agricultural Practice in the cultivation of herbal plants (Buchwald *et al.*, 2016), it is only possible to use the three herbicides mentioned above. However, a review of recent studies indicates that milk thistle can have many non-medical and non-food applications, e.g. as animal feed, as an energy or phytoremediation plant (Sulas *et al*., 2008; Ledda *et al*., 2013; Andrzejewska *et al*., 2015; Hunce *et al*., 2019). Thus, in these types of crops it is possible to use other herbicides than those used in crops for medicinal purposes. The research hypothesis assumes that preparations containing active substances present in previously used herbicides (Betanal Compact 163 EC5) or those recommended in other herbal plants (Lentagran 45 WP, Boxer 800 SC) may be effective. In addition, it was recognized that it may be effective to apply Reglone 200 SL immediately prior to emergence of milk thistle.

The aim of the study was to test the effectiveness of selected herbicides in milk thistle cultivation, with particular consideration given to foliar preparations against dicotyledonous weeds.

MATERIAL AND METHODS

The field experiment was conducted in 2016 and 2017 at the Research Station Mochełek (53°13' N; 17°52' E), Poland. Soil at Mochełek is a fine-sandy loam, mixed mesic, Ustic, typic hapludalf with pH 6.0. The soil has a high abundance of potassium and phosphorus and is moderate in magnesium. A field with a rich weed seed bank was selected for the experiment, which was established based on previous observations.

The experiment using the Polish cultivar 'Silma' was established as a one-factorial design, with 4 replications; the area of a plot was 15 m^2, and the yield was collected from 10.0 m^2. Sowing was done on 20 April in the first year, on 12 April in the second year. Seeding rate was 12 $kg \cdot ha^{-1}$, and the row spacing 20 cm. Prior to sowing, 50 $kg \cdot ha^{-1}$ N was applied as ammonium nitrate.

After sowing and/or emergence the follow herbicides were applied:

1. Stomp Aqua 400 SC (pendimethalin) + Fusilade Forte 150 EC (fluazifop-P-butyl),
2. Reglone 200 SL (diquat) + Fusilade Forte 150 EC (fluazifop-P-butyl),
3. Lentagran 45 WP (pyridate) + Fusilade Forte 150 EC (fluazifop-P-butyl),
4. Betanal Elite 274 EC (phenmediphan + desmedipham + ethofumesate) + Fusilade Forte 150 EC (fluazifop-P-butyl),
5. Boxer 800 SC (prosulfocarb),
6. Control – no herbicides or other methods.

Stomp Aqua 400 SC was applied immediately after sowing at a dose of 2.0 $dm^3 \cdot ha^{-1}$. Reglone 200

SL as a desiccant was applied just before *S. marianum* emergence. To predict the date of milk thistle emergence, soil on each plot with an area of 1 m^2 was covered with white nonwoven fabric. The spraying was carried out when the emergence of milk thistle occurred under the fabric. The dose of the preparation was 2.0 $dm^3 \cdot ha^{-1}$. Lentagran 45 WP is recommended for some medicinal plants in Poland (IOR-PIB, 2018). The spraying was performed when the weeds were in the 2–4 leaf phase and the dose of the preparation was 1.5 $kg \cdot ha^{-1}$. Betanal Compact 163 EC5 was recommended for use in thistle in the 1980s (Załęcki *et al*., 1995). Currently available is Betanal Elite 274 EC and this herbicide was applied post-emergence when the weeds had developed one – two proper leaves [11-12 according to the BBCH scale (Martinelli *et al*., 2015)], in a dose of 1.5 $dm^3 \cdot ha^{-1}$. Fusilade Forte 150 EC in a dose of 0.8 $dm^3 \cdot ha^{-1}$ was applied when 3-5 leaves of *S. marianum* were visible [13 according to the BBCH scale (Martinelli *et al*., 2015)]. Boxer 800SC has been recommended for use in some medicinal plants against mono and dicotyledons weeds (IOR-PIB, 2018). In the experiment, this preparation was applied immediately after thistle sowing in a dose of 3.0 $dm^3 \cdot ha^{-1}$.

Approximately 5 weeks after the sowing of milk thistle, i.e. on 24/05/2016 and 17/05/2017, the number and dry weight of weeds were determined. Measurements were made on an area of 1 m^2 on each plot. Weed species were determined, and after their cutting and drying at 60°C, their dry weight was determined. At the same time, the plant density of the milk thistle plants was counted. Plant height was determined immediately before harvest, by measuring five plants on each plot.

The single-stage harvest was performed using a Wintersteiger plot combine harvester on 29 July in 2016, and on 01 August in 2017. The harvested yield was dried in an airy room and cleaned on a K-293 Petkus stream separator. Afterwards, 1000 seed weight (TSW) and the fruit yield were measured.

The results were exposed to the analysis of variance and the differences were verified with the Tukey test at the significance level of $P < 0.05$. The calculations were performed using the package of statistical programs FR – ANALWAR 5.2.

RESULTS

The thermal and humidity conditions were similar in the years of the study, and at the same time similar to the long-term conditions (Table 1). In April and May there were no long periods of moisture deficiency, which had a beneficial effect on germination, emergence and initial plant development. What is more, there was heavy rainfall in June 2016 as well as in July 2016 and 2017. The weather conditions in both growing seasons were, therefore, beneficial for both the growth and development of milk thistle and weeds.

Table 1. Weather conditions during milk thistle growth at the Research Station Mochełek

Month	Temperature, °C			Precipitation, mm		
	2016	2017	long term	2016	2017	long term
April	8.3	6.8	7.9	28.7	40.8	27.0
May	14.7	13.4	13.3	51.4	56.3	49.3
June	17.7	16.8	16.1	98.1	54.3	52.8
July	18.3	17.7	18.6	133.8	118.9	69.8

The weed infestation determined after herbicidal spraying was abundant (Table 2). The most frequent species were *Chenopodium album* and *Geranium pusillum*. Moreover, the species *Viola arvensis* (on plots where Reglone, Lentagram and Betanal were used) was quite numerous, as well as *Fallopia convolvulus* (on plots where Lentagram, Betanal and Boxer were used). Monocot weeds practically did not occur after the control treatment. The highest total number of weeds was determined on the control plots, but was also high after the application of herbicides Lentagran 45 WP, Betanal Elite 274 EC and Boxer 800 SC. Relatively, the smallest number of weeds were on plots where Stomp Aqua SC and Reglone 200 SL were used and they were also small in size because their emergence occurred after the application of herbicides (the present author's observations). The tested herbicides had a significant effect on the dry weight yield of weeds. The lowest

dry weight was accumulated by weeds from plots where Stomp Aqua SC was used, followed by Reglone 200 SL, and then by Boxer 800 SC and Betanal Elite 274 EC (without statistical differentiation). Lentagran 45 WP turned out to be the least effective, although even here the weight of the weeds was still about half as much as that from the control plots.

Table 2. Species composition, number and dry weight of weeds per 1 m^2 (mean of 2016 and 2017)

Species	Stomp Aqua 400 SC	Reglone 200 SL	Lenta-gram 45 WP	Betanal Elite 274 EC	Boxer 800 SC	Control (without herbicides)
	Fusilade Forte 150 EC					
Centaurea cyanus L.	3	0	2	0	0	1
Thlaspi arvense L.	3	0	1	0	0	0
Capsella bursa-pastoris (L.) Medik.	20	4	3	0	0	0
Chenopodium album L.	14	0	22	48	85	168
Convolvulus arvensis L.	12	17	0	0	0	0
Viola arvensis Murr.	2	33	34	12	5	10
Fallopia convolvulus (L.) Á. Löve	2	7	15	24	13	10
Geranium pusillum L.	0	3	86	69	123	66
Other dicotyledones	0	2	4	0	3	8
Monocotyledones	0	3	1	2	1	32
Sum	56	69	168	155	230	295
Dry weight ($g \cdot m^{-2}$)*	8.7	17.5	55.6	44.5	39.5	109.6

* LSD for dry weight of weeds – 7.75

The highest density of milk thistle plants was obtained after the application of herbicides Stomp Aqua 400 SC and Reglone 200 SL (Table 3). The absence of herbicide protection or the use of Boxer 800 SC resulted in a decrease in plant density by 30%, The application of Betanal Elite 274 EC resulted in a reduction in density by 50% and application of Lentagran 45 WP by as much as 80% as compared with the density obtained after using Stomp Aqua 400 SC or Reglone 200 SL. The greatest height was also achieved by the thistle plants treated with herbicides Stomp Aqua 400 SC and Reglone 200 SL. After spraying with Betanal Elite 274 EC and Boxer 800 SC the plants were about 45% smaller, while the lack of protection or the use of Lentagran 45 WP caused the plants to be 66% smaller compared with the plants protected with Stomp Aqua 400 SC or Reglone 200 SL. As a result, the highest yields of milk thistle fruits were also harvested after using Stomp Aqua 400 SC and Reglone 200 SL. After the use of Betanal Elite 274 EC the yields were 58% lower, and after the use of Boxer 800 SC they were 66% lower. Only symbolic crops were harvested from plots without chemical protection and from plots after the application of herbicide Lentagran 45 WP. Plants treated with this preparation also produced fruits with a lower weight, which was significantly lower than after using Reglone 200 SL and Betanal Elite 274 EC, as well as in comparison with plants for which no herbicide had been used.

Table 3. Milk thistle response to the use of herbicides (mean of 2016 and 2017)

Herbicides	Plant density ($pcs \cdot m^{-2}$)	Plant height before harvest (cm)	Fruit yield ($Mg \cdot ha^{-1}$)	1000 fruit weight (g)
Stomp Aqua 400 SC + Fusilade Forte 150 EC	26	148	1.27	29.3
Reglone 200 SL + Fusilade Forte 150 EC	24	151	1.16	30.5
Lentagran 45 WP + Fusilade Forte 150 EC	5	56	0.24	27.2
Betanal Elite 274 EC + Fusilade Forte 150 EC	12	88	0.53	31.4
Boxer 800 SC	19	82	0.40	29.9
Control (without herbicides)	18	45	0.18	30.4
$LSD_{0.05}$	6.56	15.5	0.258	2.92

DISCUSSION

The study confirmed the usefulness of Stomp Aqua 400 SC in combination with Fusilade Forte 150 EC for weed control in milk thistle cultivation. However, it should be emphasized that the moisture conditions when using Stomp Aqua 400 SC (immediately after sowing the milk thistle) were very favourable, which was reflected in its effectiveness. In the fifth week after sowing, there were only very young weeds that were no longer competition for the milk thistle. Similar results were obtained by Drapalova and Pluhackova (2014), who additionally showed a very low level of phytotoxicity from both of these preparations on the leaves of milk thistle.

A similar efficacy to Stomp Aqua 400 SC in combination with Fusilade Forte 150 EC was achieved using Reglone 200 SL and Fusilade Forte 150 EC. This option may now have a very limited application, e.g. in the cultivation of milk thistle around arable fields on wild game protection strips. Unfortunately, Reglone 200 SL will be withdrawn from the market at the beginning of 2020, as the European Commission has not renewed the approval of diquat (European Commission, 2018).

The other three herbicides are not suitable for the protection of milk thistle plantations under conditions of high weed pressure. Although in comparison with the control plots (without weed control) the number, and especially the weed weight, were significantly smaller, there were losses in the plant density of the milk thistle, the plants were small and the fruit yields below the profitability level (Sadowska and Andrzejewska, 2010). The losses of milk thistle plants and their low level of growth is the result of two factors – competition from weeds and damage to tissues caused by these herbicides. The latter effect was observed especially on plots where Lentagran 45 WP was used (unpublished data). It should be noted that in the latest recommendations, Boxer 800 S.C. was no longer included in the group of herbicides intended for use in herbal crops (IOR-PIB, 2018).

The study did not enable the indication of an effective foliar herbicide against dicot weeds in milk thistle cultivation. However, this search should be continued as such preparations are needed in the case of inefficacy of soil herbicides (dry spring) and to combat secondary weed infestation. Considering the large prospective and multidirectional use of milk thistle (Sulas *et al*., 2008; Ledda *et al*., 2013; Andrzejewska *et al*., 2015; Hunce *et al*., 2019) it will be worth testing in our temperate climate mixtures of herbicides that have proved effective in the warmer conditions of southern Europe (Delchev, 2016).

CONCLUSIONS

In temperate climate conditions, with sufficient soil moisture in the spring season and high weed pressure, Stomp Aqua 400 SC and Fusilade Forte 150 EC remain effective against dicotyledonous and monocotyledonous weeds. Reglone 200 SL is also

effective in pre-emergence use with subsequent foliar spraying with Fusilade Forte 150 EC. Lentagran 45 WP, Betanal Elite 274 EC and Boxer 800 SC proved ineffective. Due to the promising future role for milk thistle, further research for foliar herbicides to control dicotyledonous weeds is justified.

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HERBICYDY W UPRAWIE OSTROPESTU PLAMISTEGO

Streszczenie

Ostropest plamisty jest gatunkiem, który w perspektywie może być wykorzystany nie tylko do celów medycznych i żywieniowych, ale także w innych gałęziach gospodarki. W uprawach polowych roślina ta łatwo ulega zachwaszczeniu. Celem badań było przetestowanie skuteczności wybranych herbicydów w uprawie ostropestu plamistego, ze szczególnym uwzględnieniem preparatów nalistnych do zwalczania chwastów dwuliściennych. W dwuletnich badaniach polowych (2016, 2017) prowadzonych w Stacji Badawczej Mochełek, w korzystnych warunkach wilgotnościowych testowano: (1) Stomp Aqua 400 SC + Fusilade Forte 150 EC, (2) Reglone 200 SL + Fusilade Forte 150 EC oraz herbicydy nalistne: (3) Lentagran 45 WP + Fusilade Forte 150 EC, (4) Betanal Elite 274 EC + Fusilade Forte 150 EC i (5) Boxer 800 SC. Najmniejsza liczba i masa chwastów występowała po zastosowaniu Stomp Aqua 400 SC + Fusilade Forte 150 EC i Reglone 200 SL + Fusilade Forte 150 EC. Także przy stosowaniu tych herbicydów ostropest był najwyższy (150 cm), uzyskano najwyższą obsadę roślin (25 szt.·m^{-2}) i najwyższe plony (1.2 Mg·ha^{-1}). Po zastosowaniu pozostałych herbicydów liczebność i masa chwastów były 3–5-krotnie większe, natomiast obsada i wysokość roślin ostropestu były średnio o 55%, a plony o prawie 70% niższe, a dodatkowo po oprysku Lentagramem 45 WP znacząco zmniejszyła się masa 1000 owoców ostropestu. Ze względu na rosnące na świecie zainteresowanie wielokierunkowym wykorzystaniem ostropestu plamistego uzasadnione jest dalsze poszukiwanie herbicydów do powschodowego zwalczania chwastów dwuliściennych.

Słowa kluczowe: chwasty dwuliścienne, herbicydy nalistne, *Silybum marianum*, Stomp Aqua