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THE EFFECT OF FLAMING AND MECHANICAL TREATMENTS ON WEED CONTROL, GROWTH AND YIELD OF CARROT

Summary

Two-year studies (2015-2016) were carried out at the Research Institute of Horticulture in Skierniewice. The aim of these studies was to determine the effect of weed flaming, combined with manual and mechanical treatments on weed infestation, growth and yield of carrot and population of selected groups of soil organisms. The number of weeds was significantly reduced due to methods of weeding. The higher number of weeds was recorded after flame weeding, in comparison to combined methods. The lowest results of weed control were obtained after weed flaming carried out before emergence of carrot and three times after emergence without any additional hand weeding. The hand weeding in the intra-rows of carrot immediately after flaming treatment has increased effectiveness of weed control. Studies showed that the better weed control was noticed after replacing one or two last flaming treatments with mechanical treatments. The mechanical treatments did not damage carrot plants while flaming caused burning the plants and drying the bottom leaves. The rate of these damages depended on execution accuracy, number of flaming treatments and development stage of carrot. The lowest yield of roots were obtained from untreated plots and from the plots with weeds flaming. During the studies changes in population of some groups of soil organisms were observed.
***Key words**: carrot, weed control, thermal weed control, mechanical treatment*

PŁOMIENIOWE I MECHANICZNE ZWALCZANIE CHWASTÓW ORAZ ICH WPŁYW NA ZACHWASZCZENIE ORAZ WZROST I PLONY MARCHWI

Streszczenie

W latach 2015-2016 w Instytucie Ogrodnictwa w Skierniewicach przeprowadzono badania polowe, których celem było określenie wpływu płomieniowego zwalczania chwastów, w połączeniu z zabiegami mechanicznymi i ręcznym pieleniem, na zachwaszczenie, wzrost roślin i plonowanie marchwi, a także liczebność populacji wybranych grup organizmów glebowych. Liczba chwastów została znacznie ograniczona pod wpływem zastosowanych metod ochrony. Po zabiegu wypalania zanotowano większą liczbę chwastów, w porównaniu do metod łączonych. Najsłabsze zniszczenie chwastów otrzymano po zastosowaniu samego pielenia płomieniowego, wykonanego przed wschodami marchwi oraz trzykrotnie po wschodach, bez dodatkowego ręcznego pielenia. Pielenie ręczne w rzędach marchwi, wykonywane bezpośrednio po wypalaniu chwastów, podnosiło skuteczność chwastobójczą tego zabiegu. Lepsze zniszczenie chwastów otrzymano po zastąpieniu jednego lub dwóch ostatnich zabiegów wypalania chwastów, pieleniem mechanicznym. Zabiegi mechaniczne nie uszkadzały roślin marchwi, natomiast po użyciu wypalaczy gazowych obserwowano „przypalenia" i zasychanie dolnych liści. Stopień tych uszkodzeń zależał od ilości zabiegów wypalania, dokładności ich wykonania i fazy rozwojowej marchwi. Najniższe plony korzeni marchwi uzyskano w kontroli oraz po zastosowaniu samego pielenia płomieniowego. Bezpośrednio po wypalaniu obserwowano niewielkie zmiany liczebności niektórych grup organizmów glebowych.
***Słowa kluczowe**: marchew, odchwaszczanie, wypalanie chwastów, zabiegi mechaniczne*

1. Introduction

Carrot (*Daucus carota* L.) is one of the most important vegetables crops in Poland. Its cultivation area is about 22-24 thousand hectares. Weed management is one of the basic elements in technology production of this crop. The methods of weed management used in carrot are aimed at reduction of weeds to the level which does not threaten the crops. Carrot is very sensitive to weeds, due to the long period of emergence (2-3 weeks), slow growth and poor covering the soil surface after emergence. The high weeds infestation, especially in the initial period of the growing season, can significantly reduce yield of carrot roots and their quality. Abandonment of weeds control can lead to yield reduction, even up to 80% [1] or sometimes to complete loss of the yield. The mechanical weed control is widely used in organic production of vegetable crops and increasingly in integrated weed management. This method can form the basis of weed control in organic production of carrot or can be a complement to other methods. The mechanical weed control in the interrows should be performed very shallowly, because the working elements of weeder can damage the roots of carrots and pull out weed seeds located deeper [2].

Another way to reduce the weed infestation consists in thermal weed control. This method is an important part of the weed management in organic farming and mainly used for pre-emergence weed control. Flaming is the most widely used thermal weed control method. It is a method of weed control that utilizes the heat from propane-burners to expose weeds to rapid lethal temperatures. Weeds flaming can be used in the row species, especially having a long period of emergence and poorly competing with weeds. For this purpose the special thermal

weeder are used, whose flames act directly on young weeds. The weed flaming can be done in the period of post-emergence of weeds and pre-emergence of the crops on the whole area of the field or after emergence of the crops in inter-rows [3, 4]. In post-emergence weeds flaming, the special covers should be used to protect the crops from high temperature of the flame [1]. The highest effects of weeds flaming are obtained especially in cotyledons or at a few leaves stage of weeds. Seedlings are more easily controlled than larger plants. Raising the plant temperature to 50°C causes proteins degradation and when the temperature exceeds 90°C and contact with the plant lasts for at least 0.1 second, the cell membranes are destroyed, leading to deflating the parts of plants that have come in contact with the flame [5]. In the contrast to mechanical weeding, weeds burning does not loosen the soil surface, but the effect is short-lived as well. The weed flaming delays the first mechanical or manual treatments by about 2 weeks. [6, 7]. The thermal weed control gives some benefits such as: quick weed control without chemical residues, better weed control than cultivation for small seeded crops, does not bring weed seeds to the soil surface, can be used on wet soils, may kill some insect pests and pathogens on plant residues on soil surface.

The aim of this studies was to determine the effect of weed flaming, combined with manual and mechanical treatments on a weed infestation, growth and yield of carrot and population of selected groups of soil organisms.

2. Methods

The studies were carried out at the Research Institute of Horticulture in Skierniewice on pseudo-podzolic soil over loamy sand (1.3-1.5% of organic matter, pH 6.8) in the years 2015-2016. In experiments the effects of weed flaming, performed several times during carrot vegetation, without or with additional hand weeding in the intra-rows, weed flaming combined with mechanical treatments performed after emergence at various terms and hand weeding of whole the plots, were tested. The field trials were set up in a completely randomized block design with 4 replications. The plot size was 12,2 m^2. The carrot seeds cv. Nerac F_1 were sown on May 10th in 2015 and May 16th in 2016 at 55 seeds per 1 meter of row and 45 cm width of inter-rows. Mechanical treatments were carried out using a weeder P430/2, equipped with traditional elements such as: ploughshare, angled blades and basket elements. These treatments were carried out 4-5 and 6-7 weeks after carrot emegence.

The weed flaming treatments were carried out in the period of pre-emergence in the inter-rows of carrot. The treatments on the whole area were carried out 2-3 days before emergence of carrot and in the inter-rows at the 2-3, 4-5 and 6-7 weeks after emergence. The flaming was performed by hand-held flame weeder, manufactured by Reinert Company, equipped with one propane gas burners with cover which produced a carefully controlled and directed flame that briefly passes over weeds. At the treatment the burner was driven at a height of 10 cm and directed perpendicular to the soil.

During the studies the weather conditions were recorded. The mean daily air temperature, at a height of 2 m above the ground and rainfall were specified in the place of experiment. During experiments the weeds control and phytotoxicity of using method to carrot, after 41-45 and 61-62 days post-emergence, were assessed. The number and fresh biomass of weeds was rated 63-65 days after sowing. Secondary weed infestation was evaluated 129-137 days after emergence. Before harvest the soil coverage by weeds and carrot were estimated. Carrot roots were harvested at maturity stage, at 132-127 days after emergence. The significance of differences between means was evaluated by analysis of variance, using the Newman-Keul's test, at a significance level α=0.05%. Soil samples for analysis of soil organism were taken immediately after the treatment and were transferred to the laboratory.

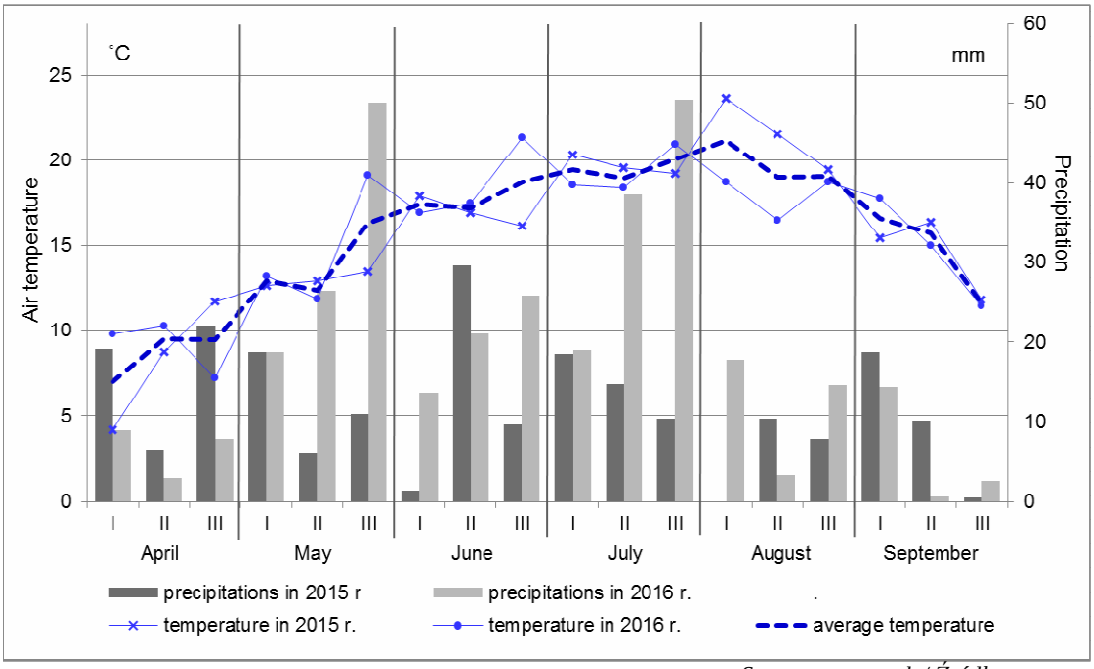
3. Results and discussion

The experiments on weeds flaming showed that the plot was highly infested by broadleaved weeds (Tab. 1). The number of total weeds, determined 61-62 days post-emergence of carrot was 152,7 per m^2 and broadleaved weeds 145.8 per m^2. In weed population *Chenopodium album* and *Galinsoga parviflora* were the main species. *Chenopodium album* had covered 50.4% of soil surface and amounted to 45.6 per m^2 and *G. parviflora* appeared in slightly lower abundance (40.3 no./m^2) and it covered 7.7% of soil surface. Ground coverage by *Thlaspi arvense* was 19.7% and by *Capsella bursa pastoris* 15.3% and the number of these species was 29.4 and 19.4 no./m^2, respectively. *Echinochloa crus-galli* was the only grass weed in the trials. It was found in the number of 6.9 no./m^2 and covered 0.9% of the soil surface. The low ground coverage by this species results from the fact that it is a thermophilic (prefers warmer weather conditions), emerging late in the spring and produced low biomass to the term of evaluation. Other broadleaved weeds did not exceed 3.0 no./m^2 and covered from 1 to 8.4% of soil surfaces. All weed species had covered 96.4% of the soil. In earlier research, conducted in carrot for many years, it was found that the average weeds biomass, 46 days after emergence was 18.8 t/ha and it ranged from 3.4 to 41.1 t/ha [8]. The weather condition in 2016 were more favourable to weeds and carrot growth than in 2015 (Fig. 1). The temperatures of 2016 were higher, in comparison to 2015, especially in May, June and August. There was also more rain in May and July. Such conditions accelerated the growth of weeds and crop. Better weather conditions caused faster re-growing of weeds after hand and mechanical weeding. Higher temperature also improves the effect of weeds flaming.

Table 1. The structure of weed population, 61-62 days after emergence of carrot (the means from 2015-2016)
Tab. 1. Struktura populacji chwastów, po 61-62 dniach od wschodów marchwi (średnie z lat 2015-2016)

Weed species	Weeds number (no./m^2)	Ground coverage by weeds (%)
Thlaspi arvense	29.4	19.7
Capsella bursa-pastoris	19.4	15.3
Chenopodium album	45.6	50.4
Galinsoga parviflora	40.3	7.7
Matricaria inodora	3.0	3.3
Polygonum persicaria	1.0	1.0
Erodium cicutarium	2.8	6.5
Lamium amplexicaule	1.3	8.4
Senecio vulgaris	2.2	6.0
Amaranthus retroflexus	0.8	1.0
Echinochloa crus-galli	6.9	0.9
Total	152.7	96,4

Source: own work / Źródło: opracowanie własne



Source: own work / Źródło: opracowanie własne

Fig. 1. Weather condition during experiments in the years 2015-2016
Rys. 1. Warunki pogodowe w czasie doświadczeń w latach 2015-2016

The complete weeds control throughout the whole vegetation period of carrot was obtained only by hand weeding (Tab. 2). This method allows to remove the weeds both from intra-rows and inter-rows. However, due to the high labor intensity, duration and high costs it is almost impossible to implement this method on large areas [9]. It has been estimated that the manual labor expenditures for hand weeding of carrot, without mechanical treatments, can be as much as 300-500 hours per hectare [1, 7, 10]. In addition, the special care should be taken to avoid to pull up crop seedlings and later to damage the root system of the plants while weeding [10], because damaged roots can fork. The effect of hand weeding is short-lived, and in a short time the new weeds emerge again.

The lowest weed control (61.6%), was obtained 63 days post-emergence of carrot, after weeds flaming carried out in the period of pre-emergence and three times post-emergence, without any additional hand weeding in the rows, was obtained (Tab. 2). Although during weed flaming the soil is not loosen, as in case of mechanical treatment or hand weeding, which would boost the germination of the subsequent weed, the effect of flaming is short-lived, either. Hand weeding in the rows of carrot, executed immediately after weed flaming, raised the effectiveness of weeds control to 90.3% (Tab. 2) and reduced the number of weeds in inter-rows to 30.0 per m^2 and in the rows to 2.5 per m^2 (Fig. 2). Performing weeds flaming pre-emergence and 2-3 times post-emergence with additional mechanical treatments in inter-rows and hand weeding in the rows resulted in very good weed control (97.8-98.9%). The weed control at 24-25 and 41-55 days after carrot emergence was lower than that after 63 days.

After flaming the low control of *Echinochloa crus-galli*, both in the intra-rows and in the inter-rows, was observed (Fig. 2). In carrots in which no additional weeding in the rows was carried out, the low control of *Thlaspi arvense* and *Galinsoga parviflora* was obtained also. After replacing the successive flaming treatments by mechanical weeding, the effectiveness of weeds control increased. Disadvantage of weeds flaming is consuming non-renewable energy resources and the emission of carbon dioxide into the atmosphere [10].

Table 2. Weeds control and secondary weeds infestation in carrot depending on weed management method
Tab. 2. Zniszczenie chwastów oraz zachwaszczenie wtórne w marchwi w zależności od metody ochrony przed chwastami

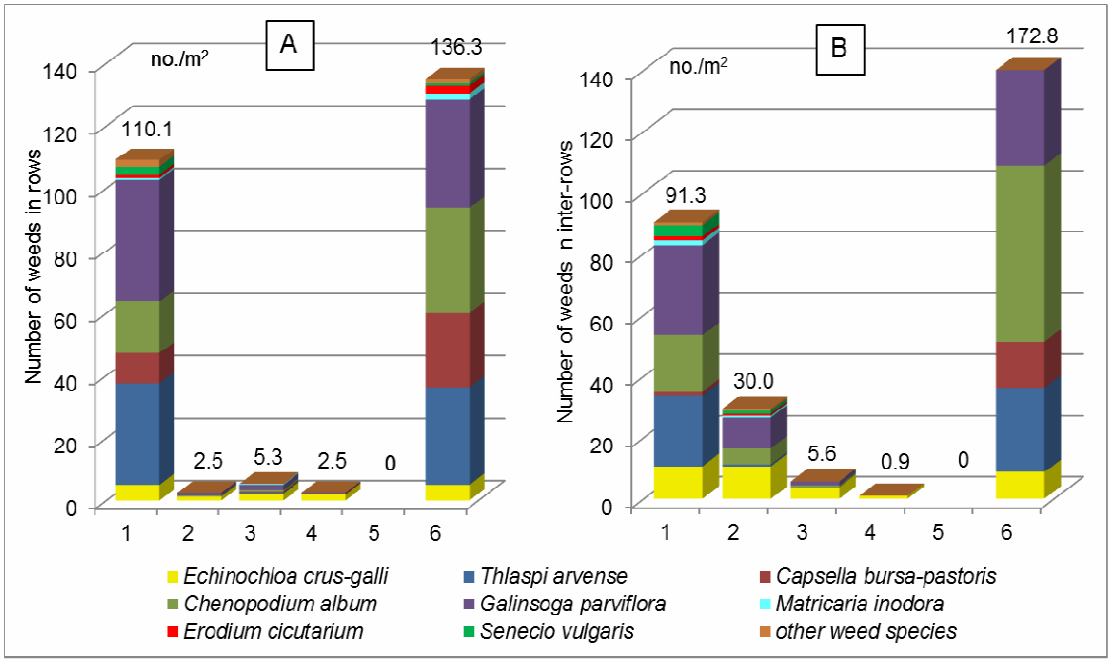
Weed control method	Weed control in %			Secondary weed infestation (%)
	24-25 DAE**	41-55 DAE	63 DAE	
Flaming – 4 x	63.7	44.8	61.6	30.2
Flaming – 4 x*	74.7	76.8	90.3	21.2
Flaming – 3 x* + mechanical treatment – 1 x*	81.2	87.2	97.8	15.5
Flaming – 2 x* + mechanical treatments – 2 x*	79.2	95.7	98.9	15.9
Hand weeding	100	100	100	0
Check	0	0	0	32.4

* Additional hand weeding in the rows during the flaming and mechanical treatments
** DAE – days after emergence

Source: own work / Źródło: opracowanie własne

The number of weeds in the rows of carrot was lower than in inter-rows, because of carrot competition. The total number of weeds from not weeded plots was 136.3 no./m^2 in the rows and 172.8 no./m^2 in inter-rows. The total number of weeds in inter-rows after flaming, determined 61-62 days post-emergence of carrot was 91 per m^2 and in the rows 110.1 per m^2. It was the highest number of weeds, except check plots. The number of weeds was strongly reduced by flaming combined with mechanical treatments and amounted 5,6 no./m^2 when one mechanical treatment was performed and 0.9 no./m^2 after two mechanical treatments (Fig. 2). The manual removing of weeds in the rows effected very low weeds number.

It was proved a high weeds biomass in untreated carrot (4909 g/m^2. The weeds biomass was significantly reduced in carrot after flaming combined with mechanical treatments and hand weeding.



Explanation: 1. weed flaming (4x); 2. weed flaming (4x) + hand weeding in the rows (3x); 3. weed flaming (3x) + mechanical treatments (1x) + hand weeding in the rows (3x); 4. weed flaming (2x) + mechanical treatments (2x) + hand weeding in the rows (3x); 5. hand weeding; 6. check

Source: own work / Źródło: opracowanie własne

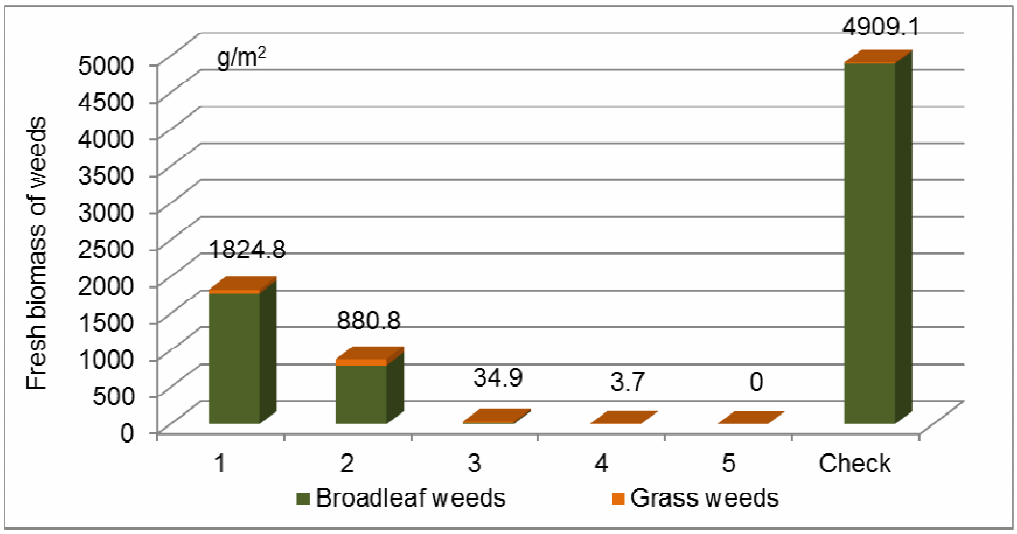
Fig. 2. Number of weeds in the intra-rows (A) and in the inter-rows (B)
Rys. 2. Liczba chwastów w rzędach (A) i w międzyrzędziach (B)

In the system included mechanical treatments the weed biomass was 34.9 and 3.7 g/m^2, depends on the number of mechanical treatments. After flaming, without additional treatments weeds biomass was 1824,8 g/m^2 and with additional treatment 880,8 g/m^2.

The mechanical treatments should not be done too often, especially under low soil moisture, as this can lead to degradation and drying of the soil, as well as accelerating the organic matter mineralization and damages the crops or the spread of diseases. Performing the mechanical treatments only when needed, after emergence of weeds, not only limiting their occurrence, but also favorably affect soil microorganisms and improve soil aeration [9].

Secondary weed infestation was completely eliminated from the plots where hand weeding was carried out systematically. The flaming combined with mechanical treatments reduced secondary weed infestation by 50.9-52.2%, while flaming combined with additional hand weeding in the rows by 34.6% (Tab. 2). No additional weeding of the plots on which flaming was performed, did not effected the secondary weed infestation, in comparison to untreated plots.

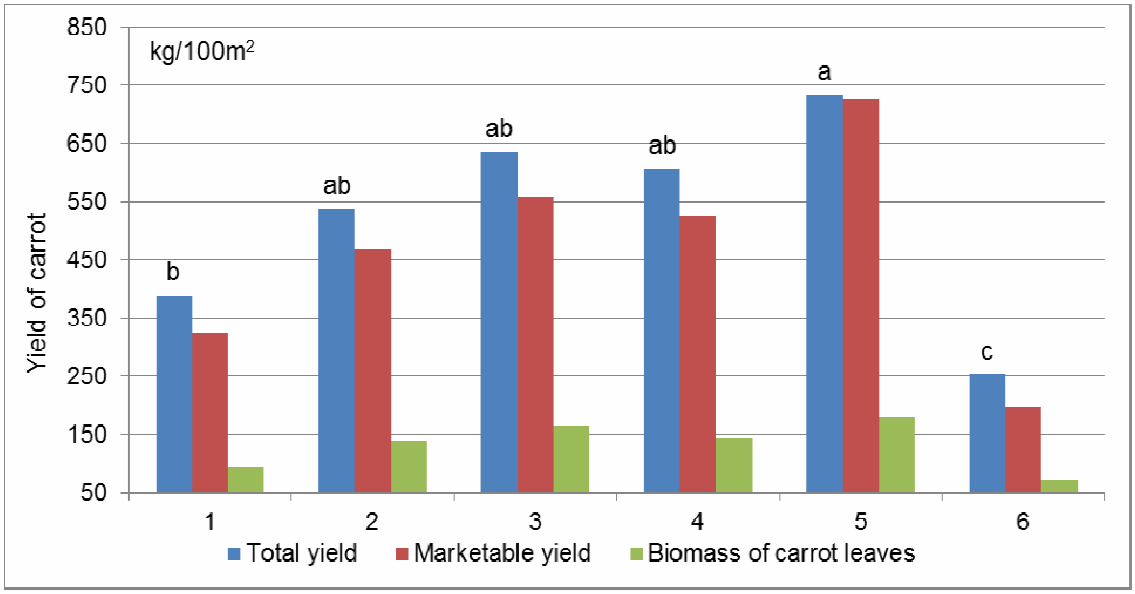
The mechanical treatments did not damage carrot plants while the flaming causes burning of above ground parts of the plants closest to the flame and also drying of lower leaves (Fig. 4). The rate of these damages ranged from 0.8 to 9.4% (Tab. 3) and depended on the number of treatments, execution accuracy and development stage of carrot.



Explanation: as below Fig. 2.

Source: own work / Źródło: opracowanie własne

Fig. 3. Biomass of weeds in carrot depending on weed control method
Rys. 3. Biomasa chwastów w marchwi w zależności od metody ochrony przed chwastami



Explanation: as below Fig. 2.

Source: own work / Źródło: opracowanie własne

Fig. 4. The influence of weed management methods on the yield of carrot
Rys. 4. Wpływ metod ochrony przed chwastami na plonowanie marchwi

Source: own work / Źródło: opracowanie własne:

Fig. 5. Damages of carrot: A – caused by thermal weed control, B – check
Rys. 5. Uszkodzenia roślin marchwi: A – po zabiegu wypalania, B – kontrola

Table 3. Damages of carrot, crops number and soil coverage by carrot at harvest depending on weed management method
Tab. 3. Uszkodzenia marchwi, liczba roślin i pokrycie gleby przez marchew przed zbiorem w zależności od metody ochrony przed chwastami

Weed management method	Damages of carrot (%)			Soil cover by carrots before harvest (%)	Number of carrot plants at harvest (per 1 m of row)
	24-25 DAE**	41-55 DAE	63 DAE		
Thermal weed control – 4x	4.4	5.4	5.3	83.4	28.1
Thermal weed control – 4x*	6.9	9.4	4.8	91.7	28.4
Thermal weed control – 3x* + mechanical treatment – 1x*	6.7	8.9	4.0	95.2	29.2
Thermal weed control – 2x* + mechanical treatments – 2x*	8.3	3.8	0.8	92.2	28.4
Hand weeding	0	0	0	97.1	30.1
Check	0	0	0	79.3	23.9

* Additional hand weeding in the intra-rows during post-emergence thermal and mechanical treatments
** DAE – days after emergence

Source: own work / Źródło: opracowanie własne

As a consequence of these damages, the soil coverage by carrot leaves (83.4-95.2%) before harvest, was lesser than hand weeded plots (97.1%). Despite carrot plants damages, this coverage was higher as compared to untreated plots (79.3%).

The results show a positive effect of weed control on the number of carrot plants (Tab. 3) and yield of roots (Fig. 5). At harvest the number of carrot plants from treated plots was higher than from untreated (Tab. 3). After hand weeding the highest number of carrot plants and the highest yield of carrot and the highest yield of carrot roots were recorded. The lowest yield of carrot roots (Fig. 5) was obtained from not weeded plots (252.7 kg/100 m^2). The yield of carrot roots from the plots with weed flaming alone (389.0 kg/100 m^2) and flaming with additional hand weeding in the intra-rows, performed immediately after flaming (537.5 kg/100 m^2) was signifi-cantly higher than from the check. In carrots, where flaming was replaced by mechanical treatments, the yield was slightly higher and ranged from 606.6 to 636.1 kg/100 m^2.

The changes in quantity of some groups of soil organisms, including the negative impact on the frequency of bacterial colonies (*Actinobacteria*, *Pseudomonas*, *Bacillus*) and fungi in the top of soil profile after flaming execution have been observed. Reducing the quantity of some soil organisms occurred directly after flaming, while in the soil samples collected after 24 hours showed no significant reduction. The flaming method significantly limited the weeds infestation, in comparison to untreated plots and affected the population of soil microorganisms, determined immediately after the treatment. Lee et al. [11] and Xiang et al. [12] reported that the highest concentration of microorganisms occurs in the top of soil profile and in the rhizosphere. Zawadzki [13] agrees with these authors adding that on average of 70 kg of bacterial mass and 10-15 kg of fungi can be found on the area of 100 m^2. According to Rahkonen et al. [14] flame weed control has little effect on microbes in the 5-10 mm of soil layer, so the threat from this weed control method to soil microflora is rather small.

4. Conclusions

1. The complete weeds control ensured hand weeding performed systematically throughout whole vegetation period. The lowest weed control gave flaming treatment.
2. The flame weeding combined with mechanical treatments substantially limited the weeds number.
3. Thermal weed control caused burning and drying the leaves of carrot closest to weeder. The rate of these damages depends on execution accuracy, number of treatments and carrot growth stage.
4. The highest yield were obtained in case of hand weeding and weed flaming combined with mechanical treatments.
5. Replacing the post-emergence flame treatments by mechanical treatments causes increase in the yield of carrot roots.
6. A small reduction of soil organisms population, directly after flaming was noted, while in the samples collected after 24 hours was no significant reduction.

5. References

[1] Anyszka Z., Dobrzański A.: Integrowana ochrona marchwi przed chwastami (cz. I). zachwaszczenie - charakterystyka i zapobieganie. Hasło Ogrodnicze, 2004, 10: 76-78.

[2] Dobrzański A.: Rola różnych metod ochrony przed chwastami w integrowanym systemie produkcji warzyw. W: Materiały Ogólnopolskiej Konferencji Naukowej „Ekologiczne aspekty produkcji ogrodniczej". 17–18.11.1998. Wydawnictwo AR w Poznaniu, 1998: 86-93.

[3] Dobrzański A., Adamczewski K.: Niechemiczne metody zwalczania chwastów. Stan obecny i perspektywy. 2009. Ekspertyza dostępna w serwisie www.agengpol.pl

[4] Adamicki F., Nawrocka B.: Metodyka integrowanej produkcji buraków ćwikłowych. Warszawa 2005. (http://www.piorin.gov.pl).

[5] Woźnica Z.: Metody walki z chwastami. W: Herbologia. Podstawy biologii, ekologii i zwalczania chwastów, (M. Krupa red.). PWRiL, Poznań, 2008: 87-127.

[6] Dobrzański A., Pałczyński J.: Problem chwastów i metody ograniczania zachwaszczenia w cebuli ozimej. Now. Warz./ Veget. News, 2005, 40: 37-51.

[7] Adamicki F., Dobrzański A., Felczyński K., Robak J., Szwejda J.: Metodyka integrowanej produkcji marchwi. PIORIN Warszawa, 2015: 12-14.

[8] Dobrzański A.: Biomasa chwastów w zależności od gatunku roślin warzywnych i sposobu uprawy. Pamiętnik Puławski, 2003, 134: 51-58.

[9] Dobrzański A., Adamczewski K.: Perspektywy wykorzystania nowych narzędzi i maszyn do regulacji zachwaszczenia w integrowanej i ekologicznej produkcji roślinnej. Prog. Plant Prot./Post. Ochr. Rośl., 2006, 46 (1): 11-18.

[10] Adamczewski K., Dobrzański A.: Znaczenie i możliwości wykorzystania metod agrotechnicznych i niechemicznych do regulowania zachwaszczenia w ekologicznej uprawie roślin. W: Poszukiwanie nowych rozwiązań w ochronie upraw ekologicznych. IOR, Poznań, 2008: 221–241.

[11] Lee S.H., Oh B.I., Kim J.: Effect of various amendments on heavy mineral oil bioremediation and soil microbial activity. Bioresour. Technol., 2008, 99: 2578-2587.

[12] Xiang S.R., Doyle A., Holden P.A., Schimel J.P.: Drying and rewetting effects on C and N mineralization and microbial activity in surface and subsurface California grassland soils. Soil Biol. Biochem., 2008, 40: 2281-2289.

[13] Zawadzki S.: Gleboznawstwo. Warszawa: PWRiL, 1999.

[14] Rahkonen J., Pietikanen J., Jokela H.: The Effects of Flame Weeding on Soil Microbial Biomass. Biological Agriculture and Horticulture, 1999, 16: 363-368.