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WEED CONTROL METHODS FOR ORGANIC VEGETABLE CROPS

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Abstract: Organic vegetable crops are part of niche crops that can provide farmers with high incomes. Controling weeds in these crops is an extremely important work, constituting today a real challenge for vegetable growers because only non-chemical methods are accepted in the organic farming system for plant protection. Physical weed control is mostly used, which is based on the application of several techniques, the most used being mechanical and thermal control. The paper shows a short synthesis of current non-chemical methods and technical devices used in integrated weed management in organic vegetable crops.
Keywords: plant protection, non-chemical weeds control, integrated management of weeds, thermal control, mechanical control

INTRODUCTION

The organic farming system must be seen as an integral part of sustainable development strategies and as a viable alternative to conventional farming, as it can provide, in particular: less contaminated air, water and agrifood products, safe working conditions for farmers, biodiversity preservation, fertile and healthy soil, nutritional quality of organic products, food security, environmental protection, reduced use of non-renewable resources, economic benefits (*Brumă, 2015*).

With regard to organic farming, Romania is ranked 7th in the top led by Poland, of the 23 Eastern European countries analyzed by FIBL Switzerland. On the other hand, in recent years Poland and Romania registered a decline in certified surfaces ecologically (*Mediafax 2018*).

The so-called minor crops produce over € 60 billion a year, which represents more than 20% of the EU's total agricultural output (*Pannacci et al., 2017*). These include fruit and vegetable crops, plus seed, spice, medicinal and aromatic plant crops. Among these niche crops, organic vegetable crops are also found.

According to some authors, the physical combating methods for plant protection fall into two basic types: active and passive. Active methods consist of using a certain form of energy for destroying, injuring, inducing stress in crop pests or eliminating them from the environment, having immediate effect during application. Passive methods, on the other hand, cause changes in the environment and have a more sustainable effect. Depending on the energy used, the physical methods are classified as: mechanical control, thermal control, electromagnetic control, pneumatic control, etc. In the case of weed control in organic crops, they include: manual weeding, hand pulling, mowing, thermal and mechanical methods (*Panneton et al., 2001*).

Also, in organic agriculture, weed control is achieved by applying certain measures / practices which, depending on the moment and the manner of application, can be preventive and curative (*Roman et al., 2008*). Preventive practices are necessary for long-term effective management of weeds (*Gabe et al., 2014*), preventing them from emerging and multiplying. They consist of: crop rotation, application of fertilizers, use of competitive species and varieties, germination bed preparation methods, irrigation / drainage systems, as well as the harvesting method (*Walsh et al., 2013*).

The curative methods keep under control the weeds already in the crop, using mechanical and thermal weed control equipment, which constitute the traditional non-chemical physical means for organic crops (*Shaner and Beckie 2014*).

Thermal combat is achieved through heat transfer from the specific equipment to weeds, by foliar contact, aiming at the destruction of their vital parts after a short period of time (*Nadzeikienė et al., 2009*). In order to be effective, heat treatments should lead to an increase of the internal temperature in weeds, between 55 °C and 70 °C, for a period of approx. 0.1 s. Therefore, the amount of heat transferred between the thermal control equipment and the target organism, as well as the duration of exposure to the treatment are important parameters. (*Ascard et al 2007*). The effectiveness of the treatments also depends on the stage of weed development, the young ones being much easier to destroy. Heat exposure determines the expansion of intracellular water, followed by cell membrane rupture, the primary effect being plant drying together with other chemical decompositions (*Peerzeda & Chauhan 2018*).

Over the past few years, concerns about the worldwide growth of weed populations resistant to herbicides, the low availability of active ingredients for minor crops (vegetables), the multiplication and development of organic farms have stimulated the development of new non-chemical weed control methods (Harker & O'Donovan, 2013).

In this brief analysis, it is not possible to address the many aspects of weed management, so the focus will be on new developments in non-chemical (mechanical / thermal) and intelligent weed control technologies, especially in vegetable crops.

MATERIAL AND METHOD

Soil heating is a promising, preventative ecological method for controling weeds in niche crops that bring high incomes, such as vegetables and flowers.

Ecostar SC 600 selfpropelled machine (*Celli Spa.*) (Figure 1) is used for disinfecting the soil with steam and zeolite type (potassium hydroxide and carbon oxide) ecological substances, using the Bioflash system (Figure 2). The machine is destined to be used in greenhouses, solariums and on the field, being equipped with rubber tracks for improving manoeuvrability and reducing soil compaction. It is fitted with horizontally placed steam generator, for reducing height. The disinfection section placed in the back can be displaced transversally, giving the possibility to conduct the treatment in the inferior and lateral parts of a tunnel greenhouse. The speed of a rotary cutter is of 40-60 rot min^{-1}. The machine is fitted with an automated and ergonomic command and control system, with a biaxial joystick controlling the movement and the speed. Due to the hydrostatic transmission, a continuous range of speeds between 60-6000 m h^{-1}.

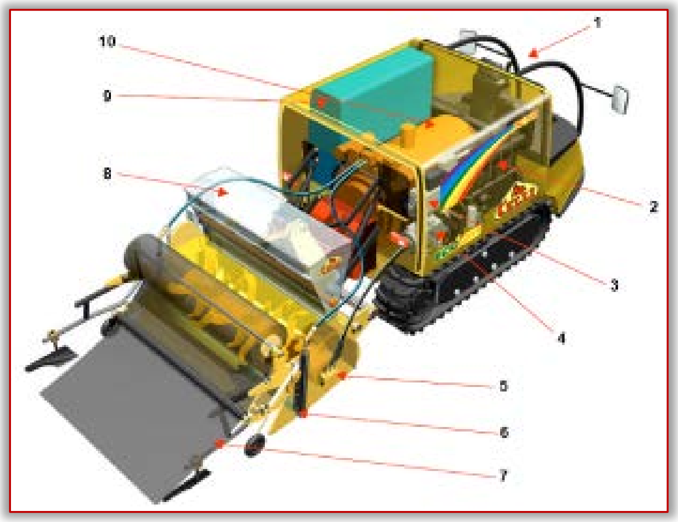

Figure 1 – Ecostar SC600 Equipment (Celli Spa)
1-drive joistick;2 –Diesel engine; 3- electric generator; 4-hydraulic transmission; 5- hydraulic rotating hoe; 6-steam injection bar; 7-plastic film mulch system;8-bunker for exothermal reactive;9-water tank; 10-boiler.

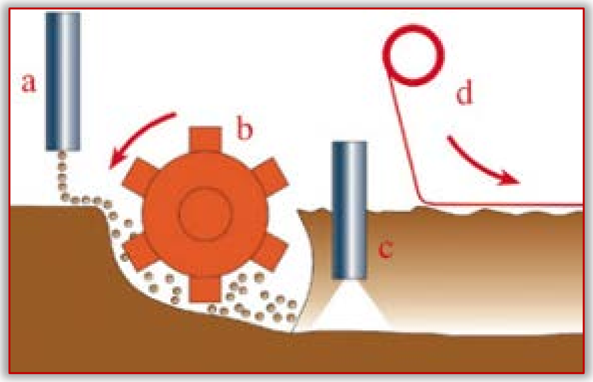

Figure2 –Bioflash system diagram (Celli Spa)
(a) substance distribution; (b) soil incorporation with a rotating hoe;(c) steam injection; (d) treated soil mulching.

The remote-control system allows driving without the operator on board. During the experiments, all the main components of the self-propelled machine (the rolling system, the rotary cutter hydraulic motors and the exothermic compound distribution system) were controlled electronically by a control card and its related software. (*Peruzzi et al., 2011*).

The technical characteristics of the machine are presented in table 1. (*Celoo, Peruzzi et a., 2011*).

The Ecostar SC600 machine (Figure 3) was tested using several types of steam injection bars to obtain different steam and heat distribution in the soil. Thus, it was equipped with: standard bar for Bioflash systems, which injected steam at a 200 mm depth; double bar, designed to have a more uniform distribution of steam in the treated soil and to reach deeper layers; carter bar, for surface treatments. During the experiments, a mix of the standard bar and the carter bar was used, with different ratios of steam distribution between the surface and the deep area. During the steam treatment, exothermic substances (CaO and KOH), applied in different doses (0, 1000, 2000, 4000 kg ha-1) were tested with or without plastic film mulching (*Peruzzi et al., 2011*).

Table 1. Technical characteristics of Ecostar 600

Characteristics	Measurement unit	Value
Equipment type	-	Self-proppeled
Power source	-	Thermal engine
Engine power	kW	44
Cubic capacity	cm^3	2.068
Fuel consumption	kg h^{-1}	11
Running system	-	Rubber tracks
Sleight dimensions (length x width x height)	m	1.9x0.32x0.52
Transmission type	-	Hidraulica
Speed	m h^{-1}	60-6000
Exothermal substances bunker capacity	m^3	0.23
Water tank capacity	m^3	0,6
Steam generator type	-	Electric
Electric motor power	kW	2.5
Steam flowrate	kg h^{-1}	600
Steam pressure	MPa	1.18
Working width	m	1.6
Overall dimensions (length x width x height)	m	3.8 x 1.6 x 1.5
Equipment weight	kg	3000

Following the experiments, soil temperature was measured using a dedicated system. The measured temperatures were divided into four "Classes" (T<40 °C; 40 °C < T < 60 °C; 60 °C <T < 80 °C; T > 80 °C). The amount of time each class persisted in the soil was recorded, along with the highest, average and final temperature (after 3 hours), in order to compare the effects of different treatments. A parameter - thermal addition (ΣT) was calculated as the sum of individual temperatures (measured every minute) for 3 hours after the treatment, including the temperature levels, duration and length of heating (*Peruzzi et al., 2011*).

The machine was also used to test the effect of five different systems of steam injection (surface or deep steam injection bar and three mixed systems at different steam distribution ratios between the surface and the deep bar: 1:2; 1:1 and 2:1) on an artificial infestation of Brassica juncea and on the natural weed seedbank. Treatments were performed using only steam or in combination with exothermic substances (CaO, KOH) applied at doses of 1000 and 4000 kg ha-1 (*Peruzzi et al., 2012*).

In order to evaluate both weed control and crop yield after applying different doses of steam in the soil strips together with exothermic substances, a prototype machine (Figure 4) using the Bioflash system (Figure 2) was built, for applying strips. The machine, being towed, operated in aggregate with a 135 HP tractor, from which the hydraulic system and the electric generator were actuated. It was made of a two-wheeled pneumatic chassis that supports: the steam generation system, the steam application system and an exothermic compound (Bioflash system), the electrical system and the hydraulic system. The machine was coupled to the tractor via a drawbar. The application system for steam and exothermic compound was obtained by modifying a rotary cultivator with 12 units. Each unit acted on a width of 0.18m, being covered by a carter, on which the steam injection bar was placed.

The rotary cultivator (with 30-60 rpm min-[1] speeds) was divided into three parts, each equipped with four units and a hopper for the exothermic compound. Each hopper was equipped with an adjustable metering unit, a measuring device and the four exhaust tubes, the system being driven by an electric motor. The steam obtained with a fast generator (Diesel type) was applied in 12 strips of 0.18 m, with 4 units grouped for each of the three ridges of 1.28 m width, resulting in a total working width of 4.58 m. In one day after using the machine, it was sown in the middle of the steam-treated strips. The tests were conducted in a carrot crop, organically grown under real field conditions, in order to study the effect of different doses of steam on the crop and on a natural weed seed bank over the entire growth cycle (*Raffaelli et al., 2016*).

Figure 3 –Ecostar SC600 Equipment (Celli Spa)

Figure 4 – Machine for soil disinfection in strips (prototype) (Raffaelli et al. 2016)

Hot water and steam are very effective in destroying annual weeds, some perennials ones, and permeable seeds close to the soil surface (*Banks & Sandral 2007*).

Hot water is effective in thermal combating when being used especially against young weeds. The water flows gravitationally, possessing other important properties (table 2) appropriate to this method (*Kristoffersen et al., 2008, Heatweed Technologies AB*). If the energy is correctly transferred to the weeds, their cellular structure is destroyed in a tenth of a second, then the roots are also dying. *Heatweed* equipment provides a stable water temperature of 98-99 °C, with the possibility of operating with vehicles, trailers, etc. They are intended to be used in areas with dense weeds: stadiums, parks, squares, etc., ensuring protection of surrounding plants due to low water pressure (*Heatweed Technologies AB*).

Table 2. Water characteristics

Thermal agent	Specific heat (kJ/kg⁰K)	Thermal conductivity (W/m ⁰K)	Energy density (kJ/kg)
Hot air (100⁰C, 1 bar)	1,01	0,03	101
Hot water (100⁰C, 1 bar)	4,18	0,682	418
Steam (100⁰C, 1 bar)	2,08	0,025	2675

The main technical characteristics of the XL140 (*Heatweed Technologies SB*) destined for large surfaces (figure 5) are: 1.4 m working width; 34 l / min water consumption; 98-99.6 °C water temperature; 0.5-2.5 km / h working speed (depending on degree of weeding); 2 Diesel / BioDiesel burners; hydraulic transmission, 7x20cm application system with independent sections, 800 l tank volume, burner tank volume 105 l.

Because weeds and crop plants have similar biometric data, there is a problem of crop protection. Thus, the Hydra - Boom (*Weedtechnics*) system employs two heads of application of the Rowtech 55 (*Weedtecnics*) saturated steam and hot water mixture for organic horticultural farms. These conical heads follow the shape of the jet, retain the heat and protect the crops. Their main technical characteristics are: diameter 0.55 m, height 0.23 m, flow rate 4-19 l / min, weight 3.5 kg. The Hydra-Boom system is mounted in front of the tractor, with the position of the Rowtech 55 applicators being hydraulically controlled from the cabin. They also have the ability to easily follow the field (Figure6).

Figure 5 – Equipment XL140 (Heatweed Technologies)

Figure 6 –Hydra-Boom System (Weedtechnics)

The effect of controlling weeds with two types of steam (wet and overheated) obtained using electricity is studied. For this, an innovative self-propelled chassis with the possibility of speed control, steam pressure and application width (*El-Sayed & El-Hameed 2017*) was used.

Mechanical control of weeds between rows without damaging the cultivated plants or their roots can be achieved with brush-type cultivators destined for use in vegetable growing, medicinal plants crops, etc. The technical characteristics of Fobro Hoe Brush are shown in Table 2. (*Baertschi Agrartecnic AG*).

Table 3. Technical characteristics Fobro Hoe Brush (AGB)

Tip Fobro Hoe Brush	Type 500	Type 760
Working width	1.5 m - 2,7 m	1.5 m - 2 m
Wheel track	adjustable	adjustable
Weight (according row on_iguration)	from 300 kg	from 600 kg
HP required	from 20 HP	from 50 HP
Diameter of Brush-Disc	500 mm	760 mm
Plant protector tunnel clearance	22 cm	33 cm
Tunnel width	6,10,14 cm	6 cm or 14 cm
Minimum row spacing	12 cm	12 cm
Power source	PTO 540 rpm or hydraulic	PTO 540 rpm or hydraulic

Fobro Hoe Brush equipment (Figure 7) consist of rotating brush units to which the fixed ones are added (Figure 8). The hairs of the brushes are made of durable and flexible materials that allow action near crops, protected by tunnels. The brushes do not move or scratch the ground like other devices, and the weeds dry quickly because the flexible wires pull them out of the root and affect the protective layer.

Figure 7 – Fobro Hoe Brush cultivator (*AGB*)

Figure 8 –Fobro Hoe Brush tunnel cultivator detail (*AGB*)

In general, mechanical methods for weed control between rows in vegetable crops are based on traditional spring harrows and cultivators, but new devices such as finger-weeders, torsion-weeders and intelligent weeders have emerged. (Peruzzi et al., 2017)

An automatic / intelligent weed control system has to achieve: guiding the mechanical devices, detecting and identifying weeds, eliminating them and eventually mapping. At this moment, only four companies sell automatic weed control machines: Robovator (Frank Poulsen Engineering ApS - Denmark); Robocrop (Garford Ltd. UK), IC Cultivator (Machinefabriek Steketee BV - The Netherlands) and Remoweed (Costruzioni Meccaniche Ferrari -Italia).

The Robocrop In Row cultivator is equipped with a hydraulic driven disc module for each crop row. As the cultivator advances on the row, the rotating disk controlled by a video image analysis system detects the location of the plants in the crop and rotates for correct alignment of the cut so as to remove the weeds between the rows and the plants one at a time (Garford Ltd). The Robocrop InRow cultivator has been tested to evaluate the effectiveness of weed control and soil loosening in salad, celery, radicchio, bok choy (obtained from seedlings), and in the cultivation of bok choy salad crops directly sown in the field. The cost of using the rotating cultivator in the two types of crops was also evaluated (Fennimore et al., 2014).

RESULTS

After testing the Ecostar EC 600, it was found that at a working speed of 150m h^{-1} the operating time was very high (20% was lost for auxiliary operations, eg: recharging). The advantage of Bioflash is that despite the relatively long working time, it has no toxic effects on crops. The tested system allowed to obtain higher temperatures compared to steam applications (in average + 17%), obtaining different results depending on the type of active compound and speed. Regarding thermal addition, CaO led to higher values compared to KOH (+ 7%) for the same rate of application. The higher dose for both active compounds led to a higher value for thermal addition (+ 10%) compared to lower doses. In terms of temperature classes, CaO applied at a dose of 4000 kg ha^{-1} led to temperatures above 60 °C for 50 minutes. In addition, for CaO applied at a dose of 1000 kg ha^{-1}, a temperature persistence time similar to the one KOH applied in high dose was obtained. The significant effect of soil heating due to the use of plastic mulch has been highlighted by the persistence time of the four different soil temperature classes. Mulching limited heat loss and allowed higher thermal addition (+ 30%) on treated parcels, compared to uncovered soil (*Peruzzi et al 2011*).

Also, the use of a single steam injection bar (surface or standard depth application) was more effective in achieving a high soil temperature and the holding time at a 100 mm depth, compared with mixed injection systems (*Peruzzi et al., 2011*).

For the machine prototype that applies the steam in strips using the Bioflash system, the best results for the temperature induced in the soil, over 60 °C at a depth of 25 mm, were obtained by applying a dose of CaO of 4000kg / ha and a maximum dose steam of 2.78 kg / m^2 (Figure 9). The authors recommended a steam dose of at least 2.3kg / m^2 at a working speed of 240m h^{-1} for a gradual satisfactory seed bank reduction in the soil, although economically it would have satisfied a dose of 1.9 kg / m^2 (*Raffaelli et al., 2016*).

Due to its thermal conductivity properties, hot water can transfer 23-27 times more energy than hot air or steam. A study conducted at the University of Copenhagen shows that after the hot water treatment of a weed infested surface, their least regeneration occurs (Figure10), even at the lowest treatment frequency (*Heatweed Technologies*).

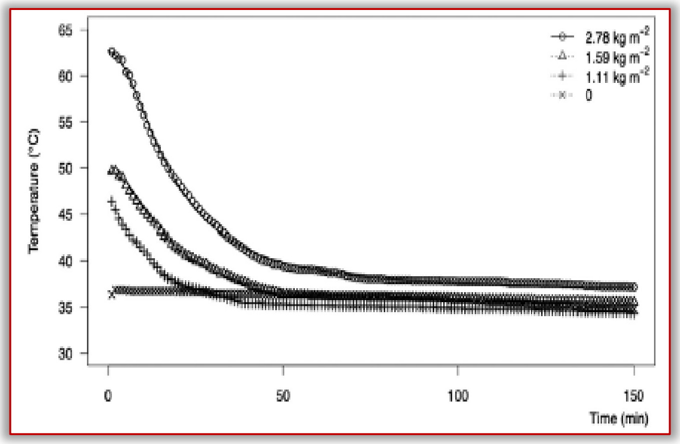

Figure 9 – Soil temperature variation in strips depending on the time and steam dose applied (*Raffaelli et al. 2016*)

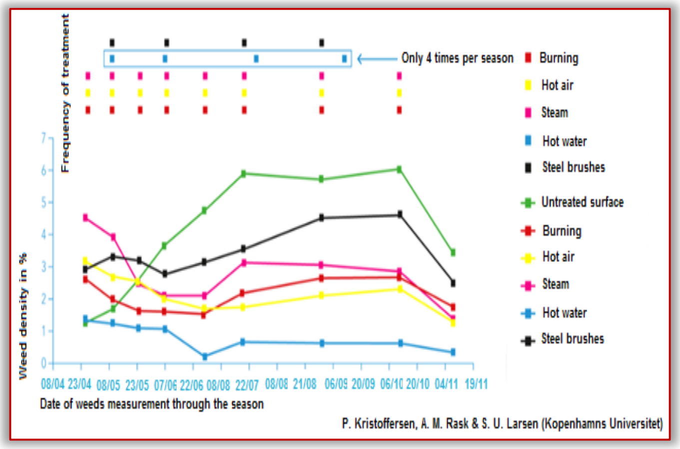

Figure10 – Weed density variation depending on the treatment applied (*Heatweed Technologies*)

Using the innovative chassis, for the same experimental conditions (working speed, pressure, application height), the results obtained in combating weeds using superheated steamed were superior to those obtained combating using wet steam. They were expressed through several indices, the most important of which was the weed extermination rate and their chlorophyll content, determined by: 2 and 3 days of treatment, as well as by weed regrowth determined after 1, 2, 3 weeks after treatment. (*El-Sayed & El-Hameed 2017*).

In general, for niche organic crops, treatments with traditional hoe with rigid shanks or brush-weeder for inter-row weed control, combined with finger-weeder for intrarow weed control, seems to be the better weed control strategy. For this type of crops obtained by sowing, characterized by small distances between the rows, is recommended to use high precision cultivators.

Robocrop rotating cultivator was in general more effective than the standard cultivator, concerning weed density as well as times consumed for removing weeds between the plants on the row, which is executed manually. It behaved well in the transplanted crops, especially in salad crop, where plants were bigger than weeds. In crop sowed using Robocrop achieved a thinningof 22-28%, compared with manual thinning and standard hoeing, therefore yield and net profits were lower.

CONCLUSIONS

In non-chemical weed management in organic vegetable crops, physical and mechanical weed control plays a fundamental role. The type of machine that can be used for this depends on the plant type, the cultivation technology, the size of weeds and the type of soil. For these methods of weed control, the development and adoption of efficient precision farming technologies can be a solution. Intelligent camera-based systems, capable of guiding mechanical and / or thermal devices contribute to increasing the working width and speed, which implies financial benefits.

The protection of vegetable plants against thermal destruction represents an important and seldom crucial factor in the technological process of chemical weed control, therefore different techniques need to be created and adpted, adequate for each type of crop. The study and development of weed control using hot water in organic vegetable crops, combined wih mechanical ones, in one pass, could constitute an important premise for achieving efficient equipment.

The preventive and curative control methods adopted, together with low tech, low cost or intelligent equipment, should be used within an integrated weed and pest control system in organic vegetable crops, in order to achieve an efficient weed management.

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