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Alternative Methods of Weed Control in Apple Orchards

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Abstract: The efficacy and cost of three alternative methods of weed control were compared to the traditional chemical method. 1) **Flaming** method was performed in 7 day intervals, three times. The most resistant perennial weeds were *Taraxacum officinale* Weber and *Leontodon autumnalis* L.. From annual weeds the most vigorous species was *Polygonum aviculare* L. Flame weeding with lower driving speed gave good reduction of annual species in early growth stages (cotyledons to 4 true leaves). To obtain a higher efficacy of vigorous weeds, perennials, weeds in later growth stages and weeds with higher intensity of germination, the repetition of treatments were required. 2) The treatments of the **hot-steam** method were performed at 1 km h^{-1} driving speed, in 7 day intervals. The 1st weed counting was executed after the first hot-steam application. The 2nd and the 3rd weed counting were performed after the second treatment. This technology was less effective on perennial weeds. The efficiency in the 1st week was better than the 2nd week after the 2nd treatment. The most resistant species were *Linaria vulgaris* Mill. and *Polygonum aviculare.* For higher reduction of vigorous weeds and for the longer time effect, the repetition of treatments are necessary, maximum 2 weeks after previous treatment. 3) **Mulching** was a very good alternative method to herbicide use and the best results of weed control were obtained in the following order: saw dust→coarse bark→hay (weed reductions were as high as 99.4% with saw dust, 99.3% with coarse bark and 96.0% with hay). The most dominant weeds were: *Rumex accetosella* L., *Sonchus arvensis* L., *Taraxacum officinale* and *Chenopodium album*. Only one application of post-emergence **chemical weed control** was performed. 2.2 kg ha^{-1} of Simazine, 1 kg ha^{-1} of Paraquat and 1,000 L of water were used. Chemical application was effective method for weed control during 2 to 3 weeks after treatment. Very resistant species was *Hypericum perforatum* L. The effect of herbicide application was best during the 2nd and maximum the 3rd week after the application of the 2nd treatment due to its residual effect. Later on, more new weeds germinated and emerged to a greater extent and the repetition of treatment was inevitable.

Key words: Weed control, apple orchard, flame, hot-steam, mulching, herbicides

Introduction

Weeds are a major problem in the agricultural production throughout the world and according to Rasmussen and Ascard (1995) especially in organic farming systems. It is difficult to quantify the impact of weeds on crop yields and the risk of high crop losses (20%) from high weed pressure is possible. In order to maintain yields of crops, weeds must be controlled. Problems with herbicides, including underground and surface water contamination, pesticide residues in food, has sparked public awareness and restrictions of herbicide use. These problems have challenged weed scientists to consider alternative and integrated systems of weed management to reduce herbicide inputs and impacts. Some positive aspects of non-chemical weed control are: reduced environmental impact, the maintenance of low but stable weed population, improved soil nutrients and water quality, general reduction in variable costs and the availability of European Union support. Negative effects are crop damage, variable weed infestation, growth of the weed seed bank and breaking of seed dormancy, elevated costs in some instances and the need for specialized machinery (Barberi, 1997).

Flame weeding is one of the alternatives to chemical weed control. It is used in organic farming for pre-emergence control in slow germinating row crops, in some heat tolerant crops, selective post-emergence flaming is also used. Selectivity can be obtained by directing the flame pattern toward the weeds and away from the crop. Although flame weeding has been used for many decades, the method is often associated with problems such as high energy consumption, low driving speed, irregular weed control (Ascard, 1994; Rifai *et al*., 1996). Thermal weed control, which relies on heating plants until the cells burst (at 70-80°C), is particularly valuable for pre-emergence weeding in crops such as carrots, parsley and leeks, that are slow to germinate. Selectivity in post-emergence treatment depends on the differential sensitivity of the crop and the weeds and timing in relation to the stage of development of the crop is critical, particularly for overall use in crops such as maize and leeks (Morelle and Thomas, 1993).

Another alternative for non-chemical weed control is hot-steam based technology. Two companies, Waipuna Systems, Limited from New Zealand and Aqua Heat, Minneapolis, Minnesota, have developed equipment that delivers superheated water from a boom or spray nozzle attached to a diesel-fired boiler. According to Riley (1995) this equipment can be used in windy or rainy conditions with no concern about drift, run off or loss of efficacy. The high pressure and hot water damages the cellular structure and kills weeds within several hours or a few days. First signs of the effectiveness are change of leaf colour and plant withering.

Mulching like a convenient alternative method for apple growers is labour intensive, but results are long lasting. Hay, sawdust, straw, compost, wool dust, manure, coarse bark and black polypropylene can be used as mulching materials for apple orchards. Alternative strategies (e.g., organic mulches) have been called for, on the grounds that persistent herbicides may have undesirable effects on non-target organisms and may leach into the groundwater (Hartley *et al*., 1996). Combination of ground-cover and herbicide management can be very effective technique of weed control to reduce herbicide use with long-term effect.

The objectives of these studies are to determine the effectiveness and costs for flaming, hot-steam technique and mulching in comparison with herbicide spraying on weed regulation in apple orchards.

Materials and Methods

This study of alternative weed control in apple orchards was initiated in 1997 (for a 2 year period) as a co-operative project of Agricultural Engineering Department, in Truro, Nova Scotia and the Slovak Agricultural University in Nitra with advisory assistance

being obtained from Scotian Gold Cooperative Limited and Horticultural crops advisory services from Kentville Agricultural Center, Nova Scotia. The financial support of this project was obtained from Agri-Future, Nova Scotia, Fruit Growers Association and J.W. Mason & Sons Ltd. Field experiments were carried out on Apple Lane Farm (ALF) and Mountain Crest Farm (MCF) in Morristown, Nova Scotia. Average annual temperature of this area is 6.8°C and total annual precipitations are 1.177 mm. This climatic region (Annapolis Valley) is a sheltered low land with the warmest temperatures and the second lowest total precipitation's in the province. The experimental layout was a randomized blocks design, with three replicates for each experiment. At assessment, number of weeds were recorded in area of 0.5 m^2, which was randomly placed within each plot. Soils are sandy-gravelly glaciofluvial, resp. coarse loamy to gravelly. At all treatments meteorological conditions were recorded.

Experiment I

Post-emergence flaming: The flame treatments were performed with German made machine Reinert gas-propane weeder in apple orchard (2 rows at the ALF) from both sides, at a gas pressure of 0.3 MPa. Flaming was conducted in 7 day intervals three times (treatments T_1-first, T_2-second, T_3-third). The gas propane doses of single treatment were regulated by the tractor driving speed (2, 3.4 km h^{-1}) and were 35.0; 23.0 and 17.0 kg ha^{-1} respectively. Flaming was carried out in active width (treated band width) of 1.3 m for one side. Total treated width for both sides was 2.6 m. Angle of burners position was adjusted at 40° to ground surface (4 burners were mounted side by side parallelly to the ground) plus one burner along the side of the machine at 90° angle to control weeds between the trees. The burners were mounted at 0.14 m above the ground level. For annual weeds, observations were made for weed effect of single flaming at different growth stages of weeds at 2, 3 and 4 km h^{-1} driving speeds.

Experiment II

Post-emergence hot-steaming: The treatments were realized with prototype hot-steam machine (developed at the Nova Scotia Agricultural College, Agricultural Engineering Department in Truro, Canada), at the temperature of 150°C and 1 km h^{-1} driving speed. Width of active section was 0.8 m for one side of row (total width for both sides was 1.6 m). The position of the boom above the ground level was 0.15 m. Hot steam applications were carried out in 7 day intervals (altogether two treatments were applied in each plot). After second treatment two weed counts were done in 7 and 14 days interval. This machine involved HONDA EZ 5000 gasoline engine with generator for water pump and burner propulsion, electro-magic grime fighter which runs on kerosene (or No. 1 home heating fuel oils), 900 litter water tank and boom made of perforated steel pipe.

Experiment III

Post-Chemical mulching: Ground-covering was used as a third alternative method to reduce the amount of herbicides in apple orchards. Sawdust, coarse bark (at MCF) and hay (at ALF) were used as the three different mulching materials for different plots with 3 replicates for each material. Number of weeds were recorded in area of 0.5 m^2 in each replicate, three weeks after mulching. The objective of this investigation was to prolong the effect of herbicides. One week before mulching, herbicides were applied as follows: Simazine at a rate of 2.2 kg ha^{-1} (Princep Nine-T, 2.5 kg ha^{-1}) and Paraquat at a rate of 1 kg ha^{-1} (Gramoxone, 5 L ha^{-1}) with 1000 L of water at ALF. 2.4-D Amine at a rate of 0.94 kg ha^{-1} (Amsol, 2 L ha^{-1}) and Glyphosate at a rate of 1.92 L ha^{-1} (Touchdown, 4 L ha^{-1}) with 450 L of water at MCF.

Experiment IV

Post-emergence herbicide application: Only one treatment was applied at the beginning of experiments by ground boom sprayer (G. White & sons. Co., Limited, London, Canada) with one spray nozzle (DELAVAN type) for lateral application. This one nozzle system operated with active width of 0.9 m for one side, so total treated band width was 1.8 m. Above ground height of nozzle was 0.4 m at driving speed of 3 km h^{-1}, pressure 200 kPa at 1.200 engines rpm. At both farms Simazine (Princep Nine-T) and Paraquat (Gramoxone) were tank-mixed to give residual weed control in the rate of 2.5 kg of Princep Nine-T (2.2 kg a.i. = Simazine) and 5 L of Gramoxone (1 kg a.i. = Paraquat) per hectare covered with 1,000 L of water. Number of weeds was observed three times after treatment in 7 day intervals.

Control plots: These plots were used like check for all IV. weed control methods. Number of weeds was recorded in area of 0.5 m^2 with 3 replicates (later converted on the 1 m^2 area), by the end of the experiment.

Results and Discussion

Flaming is usually most effective on smaller plants at the seed leaf stage, but differences between annual and perennial weeds can be expected. The control effect in practice also depends on weather and technical parameters of the machine. Thomas and Juncker (1996) mentioned, that efficacy of flaming is variable and depends on weed species and density and crop growth stage. According to Parish (1989), the effectiveness of gas burner depended on its design, angle to the horizontal and the height of the burner above the ground.

Experiment I: The prevailing weed species at Apple Lane Farm were perennials, *Taraxacum officinale* Weber, *Epilobium ciliatum* Raf., *Hypericum perforatum* L. and others. The most important annuals were *Chenopodium album* L. and *Amaranthus retroflexus* L. Total reduction of perennial weeds after three treatments was 60.4% at driving speed of 2 km h^{-1} and total gas dose (TGD) of 105 kg ha^{-1} (Fig. 1). There was almost no difference in weed reduction between driving speeds of 3 and 4 km h^{-1}, where 26.2 and 29.2% efficacy was achieved, at TGD of 69.0 kg $ha^{-1}$and 51.0 kg ha^{-1} respectively. At driving speed of 2 km h^{-1} the third treatment with 38.7% weed reduction was the most effective. The effect of a single flaming at different growth stages of annual weeds and three various driving speeds is shown in Fig. 2. The most resistant perennial weeds were *Taraxacum officinale* and *Leontodon autumnalis* L. in which average weed reduction for all driving speeds was 17.0 and 35.6% respectively. Excellent results were achieved with annuals, in particular at lowest speed, with reduction from 82.5 to 100%. The efficacy of single treatment depends on the driving speeds and decreases in the order of 2, 3 and 4 km h^{-1}. The driving speed of 4 km h^{-1} and the lowest TGD (51,0 kg ha^{-1}) was less effective with 93.1% of weed reduction. The most sensitive species was *Lamium amplexicaule* L. (100 % of reduction), however the most resistant weed was *Polygonum aviculare* L. with 62 % reduction at lowest speed of 2 km h^{-1} and 0 % reduction at higher speed and growth stage of 8 and more true leaves. The best results were at 2 km h^{-1} and early growth stages (cotyledons to 4 true leaves), although at later growth stages and at weeds with higher intensity of germination (*Chenopodium album* L.) for 100% reduction the repetition of treatments was needed. Flame weeding gave good reduction of annual species in early growth stages and at lower driving speeds, but some vigorous weeds and weeds with higher intensity of germination required the repetition of treatment. According to Ascard (1995), the tolerance of different plants towards flaming

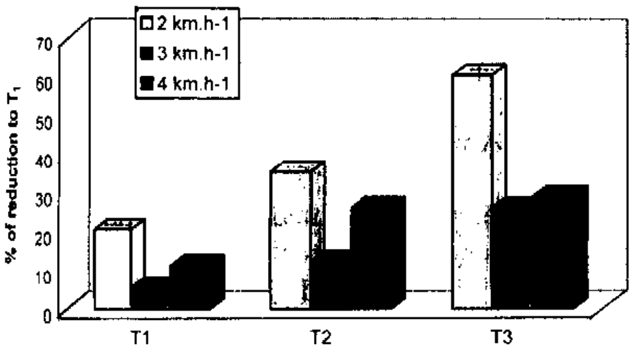

Fig. 1: Flame effect on perennial weeds at driving speed of 2, 3, 4 km ha^{-1}

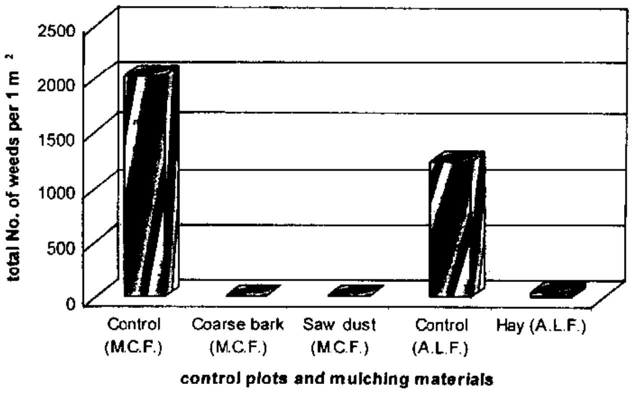

Fig. 4: Number of weeds on control plots and mulching effect

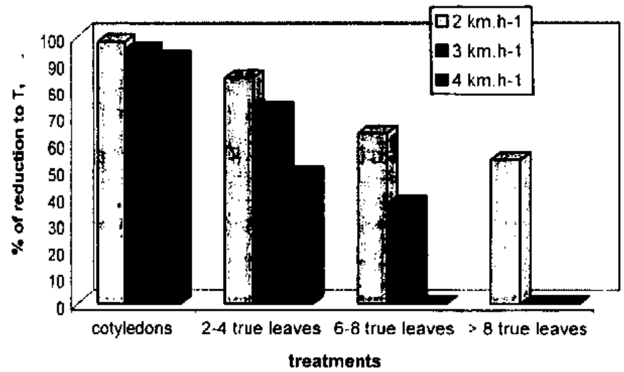

Fig. 2: Flame effect on annual weeds at driving speed of 2, 3, 4 km ha^{-1}

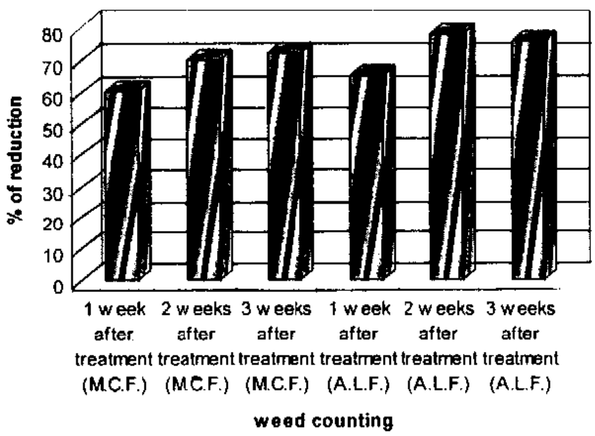

Fig. 5: Herbicidal effect on weeds

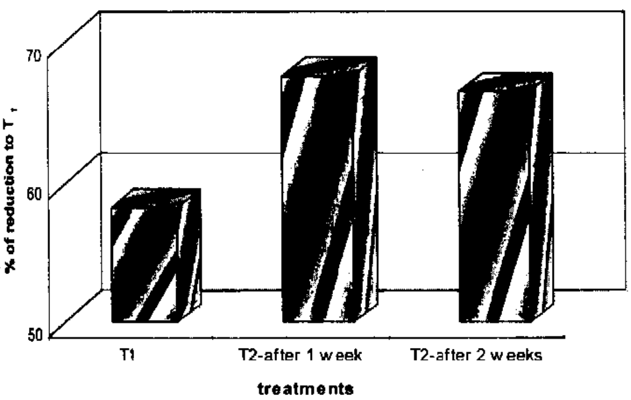

Fig. 3: For hot steam effect on weeds

depends on factors such as the presence of protective layers of hair and wax, lignification, conditions of water status, developmental stage, type of plant habit (upright, prostrate, creeping), protection of growth points. *Chenopodium album* L. is considered as sensitive species, with unprotected growth points and thin leaves. This species at a stage of 1-4 leaves can be completely killed at rates of 20-50 kg ha^{-1}, but at later stages considerably higher rates are required (50-200 kg ha^{-1}). In the experiment under study, *Chenopodium album* was controlled at cotyledons growth stage for minimum 93.1% (at 4 km h^{-1}), however weed reduction decreased at later stages and higher speeds and wasn't sufficient at the growth stage over 8 true leaves. At the some species the above-ground parts of the weeds were only partly desiccated, sensitive parts were not damaged and regeneration was evident after several days e.g., *Malva rotundifolia* L., *Polygonum aviculare* L., *Echinochloa crus-galli* (L.) Beauv. Ascard (1995) pointed out, that weed species with prostrate and creeping habit (*Capsella bursa pastoris*, *Poa annua*, *Chamomilla suaveolens*) at later developmental stages (five leaves and more) could not be controlled with one treatment regardless of the gas rate, because of their capacity for re-growth. The propane dose and number of treatments have to be adjusted to the weed flora present, the developmental stage of weeds and the desired control level.

At the plots, where dominant species was *Malva rotundifolia* (cca 90%), flaming was uneffective for other weeds, because *Malva rotundifolia* weeds in 8 true leaves made dense and high canopy and the other weeds were protected against the flame. The costs for flaming per 1 ha (propane) was $61 Canadian at 2 km h^{-1}, $40 at 3 km h^{-1} and $30 at 4 km h^{-1}(propane is $1.75/ kg).

Daar (1994) reported that one hot-steam treatment kills most annual weeds and young perennials. Top growth of older perennials can be killed in one or two treatments, but impact on roots may be minimal unless repeated kill of top growth is employed to starve roots of nutrients.

Experiment II: Hot-water technology offers many benefits over chemical herbicide applications, as it eliminates potential exposure of human and wildlife to pesticide residues. In some studies (Daar, 1995) this system was as effective as the herbicide Roundup after 41-49 days. Just one treatment eliminated the annual weeds and grasses, several treatments were necessary to gain control of certain perennial weeds. Mayer (1997) mentioned, that computer calculations and hot air wind tunnel tests were used to measure the time taken by mixtures of hot air and water vapour to raise the temperature of a measuring instrument from 30 to 60°C at different speeds. Tests of the procedure with prototype low temperature weed control equipment developed at the Munich TU agricultural machinery institute confirmed that the addition of water vapour to hot air enabled plants to absorb heat more quickly and, therefore, achieved a satisfactory level of weed destruction at higher tractor speeds. In our experiment, (Fig. 3), it is clear that hot-steam treatment was less effective technology, because total reduction of all species was lower-58.2 % after T_1 and 67.7% one week after T_2. At perennial weeds - *Epilobium ciliatum* Raf., *Malva rotundifolia* L. and *Plantago major* L. was minimum 70% reduction achieved, what can be explained by young growth stage of plants. The first treatment was at about of 33.5% more effective than the second. Efficiency of the second treatment was higher one week after treatment, than 2 weeks after treatment. The most resistant species were *Linaria vulgaris* Mill. and *Polygonum aviculare*. Low reduction of *Amaranthus retroflexus* was influenced by the extent of weed re-emergence before second treatment and at *Chenopodium album* by the older growth stage. The results showed, that for higher reduction of vigorous weeds and for a longer time effect, the repetition of treatment is necessary, already 2 weeks after previous treatment. All weed species in older growth stages were more resistant to hot - water weeding techniques. Riley (1995) pointed out, that the use of a hot steam machine may not be practical or ecologically sound in dry areas. Some believe that direct searing of weeds with infrared heat or propane flamers is more energy efficient and preferable to hot steam, although it is unclear if there are data to show it. In any case, for large-scale application, the hot steam technology is not yet cost effective. The hot steam system is most effective when used within an integrated programme using a variety of cultural, physical, mechanical and biological tactics to solve the weed problem.

Experiment III: Zaragoza *et al*. (1995) mentioned, that weed control (*Portulaca oleracea*, *Echinochloa crus-galli*) with organic mulches (pine bark) was satisfactory, but 2 herbicide treatments (Glyphosate) were necessary. Hartley and Rahman (1997) stated, that straw and sawdust could provide effective alternatives to herbicides, if a cheap source of material is available. At Apple Lane Farm and Mountain Crest Farm ground-cover management was a very good alternative to reduce herbicide use and the best control was in the order of saw dust→coarse bark→hay in comparison with control plots (Fig. 4). The most dominant weeds were: *Rumex accetosella* L. (40.6 pcs), *Sonchus arvensis* L. (13.3 pcs), *Taraxacum officinale* (11.2 pcs) and *Chenopodium album* (10.6 pcs). All mulching materials suppressed the growth of weeds in comparison with the control, where new annual weeds started to emerge and re-growth of perennials took place. With mulching, the number of chemical applications could be lowered to only one or two, instead of 3-4 commonly used in apple orchards. These mulch materials from last year (almost two seasons) were less effective this year, than last year. Most degradation was at the hay and coarse bark was the most resistant against to decay. It means, that mulch with previous herbicide application is greatly effective for 1-2 growing seasons, mainly depending on the kind of mulch, amount of mulching materials (height), weather conditions and the rate of herbicides. The combination of flaming technique with mulching method can not be recommended for hazard of fire. Mulch can be beneficial not only for weed regulation, but also for preservation of soil moisture and increase of organic matter in soil. Bhutani *et al*. (1994) pointed out that grass mulch + 0.8 kg post-em. Glyphosate gave the greatest weed control efficiency 120 days after treatment (92.9 %). Costs for mulching per 1 ha was $13,854 for sawdust, $1,856 for coarse bark and $13,862 for hay ($1.67 per 1 m^3 regardless of mulching materials; bulk density for saw dust is cca 321 kg m^3, for coarse bark cca 178 kg.m^3 and for hay cca 68 kg m^3).

Simazine (50% a. i.) + Paraquat (200 g l^{-1}) at 12 kg ha^{-1} + 5 L ha^{-1} resulted in complete control of *Lolium perenne*, but poor control of *Agropyron repens* (Jankovic and Jovanovic, 1990). According to Askarian *et al*. (1993), Simazine + Paraquat (2.25 + 0.6 kg a. i. per/ha) applied in winter before active spring growth controlled many annual weeds (e.g., *Poa annua*, *Coronopus didymus*), but no longer controlled *Trifolium repens* L..

Experiment IV: Chemical application was effective method at both farms for weed control during 2 to 3 weeks after treatment. Very resistant species was *Hypericum perforatum* L., 0% reduction was observed one week after treatment with increase of weed number 3 weeks after treatment (Fig. 5). The prevailing weed species were *Chenopodium album* (494.6 pcs), *Taraxacum officinale* (413.3) and the most sensitive species of perennials were *Plantago major* (100% reduction 2 weeks after treatment) and *Sonchus arvensis* (100%). The best herbicide effect on annual species was recorded for *Amaranthus retroflexus* (93.9 to 100%). According to Jensen and Embree (1979) Paraquat can be tank-mixed with Simazine to give residual weed control. Excellent relative control can be reached at annual grasses, excellent to good for annual broadleaf weeds, good at *Agropyron repens* (L.) Beauv., fair weed control at *Barbarea vulgaris* R. Br., *Sonchus* spp., *Cirsium* spp., *Carduus* spp. and poor weed control at *Taraxacum officinale* Weber and *Leontodon autumnalis* L. Generally, the best weed reduction was after 2 - 3 weeks due to the residual effect of herbicides. Later, new weeds germinated and emerged to a great extent and the repetition of treatment was inevitable. Costs for herbicide application was $55.7/ha (mixture consumption of water + herbicides was 375 L/ha and cost of herbicides were: Simazine $79.7/5 kg; Paraquat-$108.8/5 L).

This study on the use of flame weeding, hot-steam technique, mulching and herbicide spraying in apple orchards have shown the following results:

- The efficacy of flaming in perennial fruit crops depends on weed flora composition and occurrence of perennial weeds with high flame tolerance.
- The ability of perennial weeds to re-grow after flaming is high and species specific.
- Very flame tolerant perennial weeds were *Taraxacum officinale* Weber and *Leontodon autumnalis* L. in which low weed reduction was achieved at 2 km h^{-1}, after third treatment (T_3) and at total gas dose of 105 kg ha^{-1}.
- The most vigorous annual species was *Polygonum aviculare* L., in which 0% reduction was at higher speeds, because this weed was in growth stage of 8 to more true leaves.
- The most resistant species against the hot-steam were *Linaria vulgaris* Mill. (24.2% reduction after T_1; 54.5% one week after T_2) and *Polygonum aviculare* (9.1% reduction).
- At later growth stages and weeds with higher intensity of germination for higher reduction of vigorous weeds and for the longer time effect, the repetition of treatment is needed.
- Weed effect of flaming and steaming depends on the weed species and their growth stage, propane dose, ground speed, adjustment of gas pressure, angle of burners position, uneven of soil and on a driver ability to drive machine without tree damage, on the actual atmospheric conditions etc.
- Flaming in orchards, can be a dangerous treatment, where possibility for fire should be controlled. A disadvantage of hot-steam and flaming in orchard is, that the treatment is not enough effective in the middle of alley. The lateral burner of flame weeder doesn't treat the target area, enough.
- Ground-cover management was a very good alternative to reduce herbicide use and the best control gave the saw dust and coarse bark (weed reduction in comparison with control plots was 99.4% at saw dust and 99.3% at coarse bark). The most dominant weeds were these: *Rumex accetosella* L., *Sonchus arvensis* L., *Taraxacum officinale* and *Chenopodium album*.
- The very resistant species to chemicals was *Hypericum perforatum* L., in which 0% reduction was observed 1 week after treatment. Total weed reduction was 74.2%, 3 weeks after treatment. The prevailing weed species were *Chenopodium album*, *Taraxacum officinale*, most sensitive species of perennials were *Plantago major* (100% reduction) and *Sonchus arvensis* (100%), most sensitive annual weed was *Amaranthus retroflexus* (93.9 to 100%).
- The cost is most advantageous for mulching, but only if a cheap source of material is available. Herbicide application is an effective and the cheapest method (one application per 2-3 weeks is needed for effective treatment), but this weeding technique caused most problems on the environment and food contamination.
- Flaming costs are higher (3 treatments are needed in 7 days intervals), mainly at lower driving speeds. Hot-steaming is also more expensive (2-3 treatments are needed during 3 weeks).

Factors which affected the efficacy of flaming and steaming can be divided into 2 groups

Natural factors involve different weed species and occurrence of perennial weeds (habit, morphology of weeds), density and growth stage of weeds, weather and soil conditions. Mostly these factors can't be controlled, however we can recommend to use treatment in earlier growth stages of weeds (the most 4 true leaves) and avoid the application closely before, during and soon after the rain (according to the weather forecast and actual atmospheric conditions), in the morning (because of a dew) and in foggy weather. In principle, dry (lower humidity), sunny weather with higher temperatures and the lower wind (calm), or more dry and warm wind (south wind) can enhance the effect of flaming.

Technical factors: It include driving speed, gas pressure, angle of burners position (at the flamer) and above-ground level of burner for active section, skill of driver. Results showed, that the treatment at lower driving speed (max. 3 km h^{-1}) with higher pressure (0.2-0.3 MPa) and max. 0.15 m of height from soil surface for active section is better for weeding. For the most effective treatment, the angle of burners should be 35-45°. We can recommend for more effective treatments, that lateral (accessory) burner for flaming in the middle of alleyways should be adjusted less than 90° angle position at above-ground level of 0.13 m. In our case (90°) this gas-jet hit only upper parts of weeds (at higher growth stage), but prevailed majority of species were in lower growth stages and then the treatment efficiency was very low (unnecessary loss of propan - higher consumption of gas). Better efficacy can be achieved, if the machine was equipped with a „deflector", which would cause the boom to clear trunk of the tree.

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