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Research Article

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Optimization of hot foam applications for thermal weed control in perennial crops and open-field vegetables

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Abstract: Thermal weed control can contribute to the development of sustainable integrated weed management systems. This study aimed to optimize hot foam use for thermal weed control in vineyards (*Vitis vinifera* L.), spinach (*Spinacia oleracea* L.), and onions (*Allium cepa* L.). In the vineyard, a randomized complete block design (RCBD) was established with four treatments repeated three times. The treatment list included three different hot foam application rates (13.33, 26.67, and 39.99 L m^{-2}) and a control. The results showed that at the application rate of 39.99 L m^{-2}, the total weed density and biomass were reduced by 91 and 98%, respectively, compared to the control. This treatment was very effective on *Conyza canadensis* (L.) Cronquist. For both vegetables, four treatments were replicated three times (RCBD): untreated control (SSB-0) and stale seedbed with hot foam for thermal weed control before sowing but after 1 (SSB-1), 2 (SSB-2) and 3 weeks (SSB-3) of seedbed preparation. Compared to the control, SSB-3 reduced the biomass of *Sinapis arvensis* L., *Papaver rhoeas* L., and *Lolium rigidum* Gaud. in spinach by 85, 83, and 91%, respectively, and that of *Amaranthus retroflexus* L. in onions by 90%. In perennial crops, weed infestation appeared to decrease as the application rate of hot foam was increased. For open-field vegetables, the longer the period between seedbed preparation and pre-sowing thermal weed control, the greater the efficacy of hot foam in a stale seedbed. Further research is required to optimize hot foam as a thermal weed control tool in more cropping systems and environments.

Keywords: hot foam, thermal weed control, vineyard, onion, spinach

1 Introduction

Weed flora is an integral part of any cropping system in agriculture. In perennial crops such as fruit orchards, olive groves, and vineyards, the presence of weeds can provide valuable ecosystem services such as improvement in soil quality and increase in biodiversity [1]. However, the establishment of specific noxious weed species that become dominant creates problems to field operations and negatively affects the biodiversity or crop health due to the attraction of pests [2]. In annual crops such as open-field vegetables, weeds always compete with crops for water, nutrients, and light [3]. Severe yield losses are attributed to interference from low-diversity weed communities infested with troublesome weeds that form competitive weed monocultures [4]. Despite that, the effects of weed competition become less significant when neutral weed communities with high weed diversity levels co-exist with a given crop [5]. Therefore, the objective of weed management is to eradicate

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noxious weed populations that can become problematic in both perennial and annual crops.

Herbicide application has been the most prevalent and effective practice for managing weeds in perennial and annual crops for many decades [6]. There are many concerns on the overreliance of growers on chemical weed control as the negative effects of herbicide on the natural habitat, non-target organisms, and human health [7]. In addition, the consecutive use of active ingredients with the same site of action favors the development of herbicide-resistant weed populations that adapt to specific cropping systems and become dominant [8]. At present, there are 534 unique cases of herbicide-resistant weeds globally, with 156 dicotyledonous and 117 monocotyledonous weed species having evolved resistance to 168 different herbicides [9]. Thus, there are several reasons for investigating ways to reduce herbicide use and search for alternative, non-chemical weed control tools [7]. Thermal weed control should play a pivotal role as a non-chemical practice in controlling weeds in any cropping system and contribute to the development of sustainable integrated weed management schemes and strategies [10]. Since thermal weed control methods offer a "new" mode of action, it can be hypothesized that they can provide solutions for the eradication of noxious weed species that have developed resistance to herbicides and/or dominating a given agricultural area.

In thermal weed control, heat is transferred from a local energy source to the plants, which leads to a local increase in temperature. Weed control is based on exposing the above-ground weed material (such as stems, leaves, and flowers) to temperatures above 45°C, which are lethal to plant tissues [10]. High temperatures destroy the cell structure and denature the plant proteins of all weeds without inducing plant resistance [11]. Heat damage to plants depends on the temperature, the duration of exposure, the energy input, and the targeted weed species [12]. At this point, it should be noted that although thermal methods are not selective, they do not jeopardize biodiversity, as they can be used to control noxious weeds that have displaced other species, which indirectly promotes biodiversity. In any case, in agriculture, various thermal weed control methods such as flaming, hot water, and steam have been tested to control weed seeds and seedlings [13–15]. However, these methods have the disadvantage that the heat escapes into the atmosphere very shortly after treatment, which in most cases leads to inadequate weed control [12].

An evolution of the simple hot water or steam applications is weed treatment with hot foam. The advantage of this approach compared to most thermal weed control methods is the lower leakage of temperature from weed parts to the atmosphere [16]. This is due to the fact that hot water treatment is combined with the use of biodegradable foaming agents that lock in the temperature of the weed parts for a longer period of time after treatment [17]. Foamstream® machines (Weedingtech Ltd., London, UK) enable the practical application of hot foam. Although the method sounds promising, it should be remembered that most of the evidence on the performance of hot foam in terms of weed control has been evaluated in non-cropping areas in most cases, with the exception of a few studies on perennial crops [16,18–21]. Consequently, evaluating the performance of hot foam in agricultural areas and under real-field conditions remains a challenge, with important questions such as the optimal application rate and timing for both perennial and annual crops to be clarified.

The aim of this study was to optimize the use of hot foam for thermal weed control in vineyards and in open-field vegetables through field trials on experimental areas infested with specific noxious weed species. In the perennial cropping systems studied, the optimal application rate of hot foam was the main topic of investigation. In the vegetable crops, the effects of hot foam on weed growth were assessed under different stale seedbed manipulations.

2 Materials and methods

2.1 Site description

The efficacy of hot foam was tested as a weed control method in a vineyard (*Vitis vinifera* L., *cv. Merlot N*, VNB – Bakassietas Vine Nurseries, Leontio Nemea, Greece) and open-field spinach (*Spinacia oleracea* L., *cv. Silver Whale RZ F1*, Rijk Zwaan Zaadteelt en Zaadhandel B.V., Welver, Germany) and onions (*Allium cepa* L., *cv. Stardust*, Bejo Samen GmbH, Sonsbeck, Germany) during the growing season 2023–2024.

A field trial was conducted during the winter months of 2023 in a vineyard in the wine region of Nemea, Greece (22°38′01.5″ east latitude (E), 37°50′32.1″ (N) north longitude) at an altitude of 300 m above the sea level. The 10-year-old vines, grafted onto the rootstock *Paulsen 1103* (VNB – Bakassietas Vine Nurseries, Leontio Nemea, Greece), were grown in slightly alkaline clay soil (pH: 6.80) with an organic matter content of 1.28% under a drip irrigation system. This is a commercial field conventionally managed in terms of fertilization and crop protection. During the winter period, the vines were grown under rainfed conditions. The inter-row vine spacing was 2 m and the intra-row vine spacing was 1 m. The dominant weed species were *Sinapis arvensis* L.

Table 1: Main soil physico-chemical characteristics of experimental sites

Characteristic	Nemea	Athens
Sand (%)	35.2	36.8
Silt (%)	35.7	33.9
Clay (%)	29.1	29.3
Soil type	Clay (C)	Clay (C)
pH	6.80	7.17
Organic matter (%)	1.28	1.19

(wild mustard), *Lolium rigidum* Gaud. (rigid ryegrass), and *Conyza canadensis* L. Cronquist (horseweed).

The field trials with spinach and onions were conducted at the experimental field of the Agricultural University of Athens (23°42′09.3″ east latitude (E), 37°59′02.3″ north longitude (N); altitude: 30 m above the sea level) during the winter growing season of 2023 and the summer growing season of 2024, respectively. The soil type was a clay loam whose physicochemical properties (0 to 20 cm soil depth) were 36.8% sand, 33.9% silt, and 29.3% clay with a pH of 7.17, and an organic matter content of 1.19%.

The main soil physico-chemical characteristics of both sites are summarized in Table 1.

The climatic conditions that prevailed on both sites during the experimental period are presented in Table 2.

The soil of the experimental field was plowed 30 cm deep in late autumn and disked twice (20 cm depth) before sowing to create a firm seedbed. The previous crop was sesame (*Sesamum indicum* L.). Spinach was grown with an inter-row spacing of 40 cm and an intra-row spacing of 20 cm. The sowing depth for spinach was 2.5 cm, and the sowing rate was 20 kg ha^{-1} seeds. Onion bulbs were planted at an inter-row spacing of 30 cm and an intra-row spacing of 12 cm. Both crops were organically managed. Spinach and onions received 20 t ha^{-1} cattle manure as a basal fertilizer, which was incorporated during the second disking operation. Irrigation was provided by the same irrigation system that ran through two neighboring fields and supplied spinach with 200 mm water and onions with 250 mm water (together with rainfall). No serious diseases or pest infestations were detected in any of the crops studied. As for the weed flora, spinach was mainly infested with *S. arvensis*, *L. rigidum*, and *Papaver rhoeas* L. (corn poppy), while the dominant weed in the onion field was *Amaranthus retroflexus* L. (redroot pigweed).

2.2 Experimental setup and design

2.2.1 Thermal weed control in the vineyard

A randomized complete block design (RCBD) was established in the vineyard with four weed control treatments replicated three times, resulting in a total of 12 experimental plots. The treatment list included the application of hot foam at three application rates and an untreated control. Treatments were applied around the straight line of the vine row; each plot was 0.6 m wide and 4 m long having a total size of 2.4 m^2.

The hot foam was applied on December 4, 2023, using the Foamstream® M1200 machine (Weedingtech Ltd., London, UK). The solution used (Foamstream V4) was a 100% mixture of plant oils and sugars (e.g. alkyl polyglucoside surfactants). The foam was manually applied using a 0.3 m wide hot foam spreader. The flow rate was 12 L min^{-1}, which corresponds to 0.2 L s^{-1} (from 96% water and 4% Foamstream V4). Based on preliminary tests, a hot foam treatment should take 30 s to adequately cover an area of 0.45 m^2 with a width of 0.3 m (as a hot foam spreader) and a length of 1.5 m [18]. Based on this assumption, in the present study, hot foam was applied for 160 s to cover a single plot of 2.4 m^2, which means that 32 L of hot foam was applied to each plot. This corresponded to an application rate of 13.33 L m^{-2}, which was considered the standard application rate for a complete treatment. Hereafter, this treatment is abbreviated as "Hot foam 1X."

Table 2: Mean monthly temperature (°C) and total rainfall (mm) at the two sites during the trial period

Site	Parameter	2023				2024							
		Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.
Nemea	Mean T (°C)[a]	20.9	17.5	14.1	9.1	7.8	9.0	16.6	16.3	18.2	26.4	27.5	26.4
	Rainfall (mm)	151.8	16.6	37.0	45.5	61.4	16.6	43.2	2.0	13.4	2.2	31.8	2.8
Athens	Mean T (°C)	24.8	24.4	17.8	13.6	11.1	13.2	15.1	19.9	21.1	29.6	31.4	30.3
	Rainfall (mm)	97.8	1.6	20.6	53.2	22.0	31.0	32.6	8.2	6.4	0.0	3.8	7.2

[a] Mean T: mean temperature; Sep.: September; Oct.: October; Nov.: November; Dec.: December; Jan.: January; Feb.: February; Mar.: March; Apr.: April; Jun.: June; Jul.: July; Aug.: August.

The application of hot foam at twice the standard rate therefore resulted in an application of 26.67 L m^{-2} (320 s $plot^{-1}$). A hot foam treatment at three times the standard rate means that 39.99 L m^{-2} hot foam was applied (480 s $plot^{-1}$). The explanation for the choice of these different application rates in the treatment list together with an untreated control lies in the weed flora. While many weeds were between growth stages BBCH 14 and 18, there were also many weed plants at more advanced growth stages. This was consistent with the typical situation in perennial orchards and vineyards, where weeds emerge within a longer time window and take up a lot of space because there is no intense crop competition as in arable fields [22]. Our hypothesis was that the larger weeds must be crimped first with the first pass of the foam spreader (standard application rate) and then treated with either one (twice the standard rate X) or two repeated hot foam passes (three times the standard rate X) to be successfully controlled. Hereafter, hot foam treatments with application rates of 26.67 and 39.99 L m^{-2} are abbreviated as "Hot foam 2X" and "Hot foam 3X," respectively.

2.2.2 Thermal weed control in open-field vegetables

The potential of pre-sowing thermal weed control with hot foam in stale seedbeds was investigated in spinach and onions; the same treatment protocol was applied in both vegetable crops. Spinach and onions were studied according to the RCBD with four treatments and three replicates. The plots were 2 m wide and 4 m long having a size of 8 m^2. The treatment list included the following treatments: SSB-0, SSB-1, SSB-2, and SSB-3.

In the SSB-0 plots, which were considered the untreated control, the crops were sown immediately after seedbed preparation, and the weeds were not controlled throughout the growing season. In these plots, the sowing dates for spinach and onions were November 25, 2023 and April 19, 2024. In the SSB-1 plots, weeds were allowed to grow 1 week after seedbed preparation and were controlled with a hot foam treatment before sowing. The concept of stale seedbed can be found in a recent article by Travlos et al. [23]. It was chosen because hot foam is not selective and possible treatments with the vegetables present in the field would damage the crops.

In the SSB-2 and SSB-3 plots, the time window between seedbed preparation and thermal weed control before sowing lasted 2 and 3 weeks, respectively. In all plots with a stale seedbed, the emergence of weeds was further stimulated by irrigation or random rainfall, and the crop was sown the day after hot foam application. Based on the assumption made previously, hot foam was applied for 533 s to cover a single plot of 8 m^2, meaning that 106.67 L of hot foam was applied to each plot. This corresponded to an application rate of 13.33 L m^{-2}, which was considered the standard application rate for a complete treatment. This was the application rate in all plots, as all weeds were at very early growth stages (BBCH: 12–16) and could be effectively controlled with a single pass of the foam spreader.

2.3 Data collection

The density and biomass of the dominant weeds and the total weed density and biomass were the parameters measured in all three field trials. Two metallic 0.25 m^2 quadrats were established in central areas of each plot where the weed flora was uniform. Weeds were harvested by hand from the top soil surface of each quadrat, placed in numbered plastic bags, and taken to the laboratory. The weeds were counted to measure the weed density for each species, and the samples were oven-dried at 70°C for 48 h (Binder FD023, Binder GmbH, Tuttlingen, Germany) until a constant weight was achieved. The dry weight of each weed species was then measured using a precision balance (Kern FCF 30K-3, KERN & Sohn GmbH, Balingen, Germany). To estimate the total weed density and biomass, the density and biomass values of the minor weeds (which occurred at very low densities) were added to the values of the dominant weeds. The evaluations were carried out 3 and 4 weeks after treatment in the vineyard and in the vegetable crops, respectively.

2.4 Statistical analysis

All data were subjected to one-way analysis of variance (ANOVA) using the SigmaPlot 12 statistical software (Systat Software Inc., San Jose, CA, USA). Normal distribution of data was checked with the Shapiro–Wilk test [24]. Before analysis, the weed data (density and above-ground biomass weight) were converted as square roots to ensure variance homogeneity. Differences between treatments and their interactions were compared by using Fisher's least significant difference (LSD) test, where probabilities are equal to or less than 0.05 (a = 0.05).

3 Results

3.1 Thermal weed control in the vineyard

The results showed that all hot foam treatments reduced the weed density of all the dominant weeds that infested

Table 3: Treatment effects on weed density (no. of weeds per m^2) and biomass (g m^{-2}) in the vineyard

Treatments	*S. arvensis*		*L. rigidum*		*C. canadensis*		Total weeds	
	Density no. (m^{-2})	Biomass (g m^{-2})	Density no. (m^{-2})	Biomass (g m^{-2})	Density no. (m^{-2})	Biomass (g m^{-2})	Density no. (m^{-2})	Biomass (g m^{-2})
Control	11.7a[a]	557.3a	12.3a	20.5a	10.0a	206.7a	44.3a	809.5a
Hot foam 1X	7.0b	74.0b	4.3b	6.5b	7.3b	69b	27.7b	169.5b
Hot foam 2X	2.7c	14.0bc	1.7bc	1.8c	1.7c	22c	10.3c	48.8c
Hot foam 3X	0.7c	4.3c	1.0c	0.2c	0.7c	1.3c	5d	10.2c
$LSD_{0.05}$	2.10	60.63	2.94	3	2.97	32.94	4.51	81.61
p	***	***	***	*	**	*	***	***

[a]Different letters indicate significant differences. *, **, and ***: *p* ≤0.05, 0.01, and 0.001, respectively.

the vineyard compared to untreated control ($p \leq 0.05$ at the least; Table 3).

Specifically, hot foam 1X reduced *S. arvensis* density by 40%, while hot foam 3X achieved a 94% reduction compared to the untreated control. Similar results were obtained regarding the biomass of this weed species. Hot foam 1X, hot foam 2X, and hot foam 3X reduced the dry weight of *S. arvensis* by 86, 97, and 99%, respectively, compared to untreated control. Concerning *L. rigidum*, hot foam 1X, 2X, and 3X resulted in 64, 86, and 91% lower density, respectively, compared to the untreated control. As for *L. rigidum* biomass, hot foam 3X did not significantly differ with hot foam 2X treatment. The untreated control plots had 99 and 91% more biomass of *L. rigidum* than the hot foam 3X and hot foam 2X plots, respectively.

Furthermore, hot foam 3X was the most effective in reducing the *C. canadensis* density, achieving a 93% reduction compared to untreated plots, while hot foam 1X was not effective, resulting in only 26% reduction. Similar observations were made for the biomass *C. canadensis*, where hot foam 3X almost eliminated *C. canadensis* growth. The higher the application rate of hot foam, the higher its efficacy on *C. canadensis*, and this is especially noted for plants that were at more advanced growth stages. As for total weed density, plots treated with hot foam 3X had eight times lower values than untreated plots. Similar observations were made on total weed biomass.

3.2 Thermal weed control in spinach

Hot foam treatments in stale seedbeds significantly affected all weed parameters measured in the spinach trial ($p \leq 0.001$; Table 4).

In particular, the lowest *S. arvensis* density was observed in SSB-3 plots and 90% of the value was obtained in the untreated plots. In addition, *S. arvensis* biomass decreased by 27, 46, and 85% in SSB-1, SSB-2, and SSB-3 plots, respectively, compared to control plots. *P. rhoeas* density was 27, 52, and 90% lower in SSB-1, SSB-2, and SSB-3 plots, respectively, than in the control plots. SSB-2 and SSB-3 suppressed *P. rhoeas* biomass by 58 and 83%, respectively, compared to SSB-0. Very low biomass suppression was achieved in SSB-1 plots (17%). Moreover, SSB-3 treatment was the most effective in reducing *L. rigidum* density and biomass, achieving reductions of 87

Table 4: Treatment effects on weed density (no. of weeds per m^2) and biomass (g m^{-2}) in spinach

Treatments	*S. arvensis*		*P. rhoeas*		*L. rigidum*		Total weeds	
	Density no. (m^{-2})	Biomass (g m^{-2})	Density no. (m^{-2})	Biomass (g m^{-2})	Density no. (m^{-2})	Biomass (g m^{-2})	Density no. (m^{-2})	Biomass (g m^{-2})
SSB-0	17.0a[a]	48.5a	23.3a	69.7a	10.3a	29.7a	62.7a	169.8a
SSB-1	9.0b	35.0b	17.0b	57.3b	7.0b	20.0b	41.7 b	129.0b
SSB-2	5.7bc	26.0c	11.0c	28.7c	4.0c	8.0c	27.7 c	72.7c
SSB-3	1.7c	7.0d	2.3d	11.7d	1.3d	2.7d	7.7d	24.0d
$LSD_{0.05}$	5.12	8.35	4.27	6.74	2.36	4.67	9.7	18.74
p	***	***	***	***	***	***	***	***

[a]Different letters indicate significant differences. ***, *p* ≤0.001.

and 91%, respectively, compared to SSB-0, while SSB-1 showed very poor performance.

The untreated control showed the highest values of total weed density (62.7 weeds m^{-2}), while SSB-3 led to the lowest values (9.7 weeds m^{-2}). SSB-3 achieved a 85% reduction in weed biomass compared to SSB-0. In addition, SSB-2 and SSB-1 treatments reduced the total weed biomass by 57 and 24%, respectively, compared to SBB-0. SSB-3 showed an 85% reduction in weed biomass compared to the control plots. In addition, SSB2 and SSB1 treatments reduced the total weed biomass by 57 and 24%, respectively, compared to the control (Table 4).

3.3 Thermal weed control in onions

In the onion crop, *Amaranthus retroflexus* was the major weed, and its density was significantly decreased by all applied treatments (p ≤0.01 at the least; Table 5).

SSB-1, SSB-2, and SSB-3 reduced *A. retroflexus* density by 52, 71, and 89%, respectively, compared to SSB-0. Concerning the biomass of this weed, SSB-3 suppressed it by 91% compared to the untreated control (SSB-0). The total weed density was 53, 70, and 90% lower in SSB-1, SSB-2, and SSB-3 plots, respectively, than the values recorded in SSB-0 plots. Moreover, similar results were noticed for total weed biomass; SSB-1, SSB-2, and SSB-3 treatments reduced the total weed biomass by 46, 61, and 90%, respectively, compared to SSB-0 treatment.

4 Discussion

Application of hot foam is an effective non-chemical method of weed control in the vineyard, as it significantly reduces the weed density and biomass. Its efficacy was already visible in the first days after application, when the aerial parts of the weeds were damaged and showed chlorotic symptoms and epinasty (Antonopoulos, visual observation). Although there was no complete denaturation of the plant tissue within the first 2 days after application, green pigments persisted in the leaves of broadleaf weeds. It took 4–5 days for these pigments to show necrotic symptoms, with the duration varying depending on the dose of hot foam used. This tissue desiccation is a common feature of thermal weed control methods such as hot water and flaming [12]. Similar effects of hot foam were reported by Martelloni et al. [16] on broadleaf weeds. These observations are consistent with recent studies conducted in olive groves in the Peloponnese region [18]. This is particularly true for the application of hot foam at two and three times the standard rate.

Table 5: Treatment effects on weed density (no. of weeds m^{-2}) and biomass (g m^{-2}) in onions

Treatments	*A. retroflexus*		Total weeds	
	Density no. (m^{-2})	Biomass (g m^{-2})	Density no. (m^{-2})	Biomass (g m^{-2})
SSB-0	12.7a[a]	450.0a	23.7a	578.0a
SSB-1	6.0b	218.3b	11.0b	308.7b
SSB-2	3.7bc	165.7b	7.0bc	223.7c
SSB-3	1.3c	36.3c	2.3c	53.7d
$LSD_{0.05}$	3.52	52.84	5.85	47.70
P	**	***	**	***

[a] Different letters indicate significant differences. ** and *** indicate p ≤0.01 and 0.001, respectively.

Hot foam 3X almost completely eliminated weed infestations near the vines and controlled noxious weeds such as *C. canadensis*, *S. arvensis*, and *L. rigidum*. In the case of *C. canadensis*, even plants in advanced stages of growth were controlled with this treatment. This is very important as this broadleaf species is one of the most noxious in Mediterranean perennial cropping systems and has several herbicide-resistant populations that are very difficult to control by chemical means [25–28]. The efficacy of hot foam on *S. arvensis* is also consistent with the earlier studies of Antonopoulos et al. [18]. The efficacy of the highest rate of hot foam on *L. rigidum* is consistent with the results of other studies investigating the effects of treatments on annual weeds in non-crop areas [16,20].

In the open-field vegetable crops studied, it was found that hot foam can provide thermal weed control prior to sowing if a stale seedbed is prepared. Low weed density and biomass values corresponded to stale seedbed plots, and the key finding is that the effectiveness of hot foam increases when the period between seedbed preparation and pre-sowing weed control is extended. Regarding the importance of this period, similar results were reported by Gazoulis et al. [29] in forage crops where weeds were controlled using the false seedbed concept. These results are also consistent with the corresponding results of Shem-Tov et al. [30] in spinach. However, this is the first study in which weeds were controlled with a hot foam treatment in a stale seedbed. In any case, it is important that hot foam suppressed the growth of *L. rigidum* and *P. rhoeas* in stale seedbeds, as both weed species are notorious for developing herbicide resistance patterns [31,32]. The efficacy of our method on *A. retroflexus* was also very encouraging, as it is a highly competitive species with aggressive growth rates [33]. Furthermore, our approach represents a cultural method for weed control in two crops that are poor competitors to weeds and where herbicide options are quite limited [3,34].

However, the concept of hot foam application under real-field conditions has some limitations. First of all, the machinery is quite heavy and difficult to pull onto the field with a tractor. In addition, the amounts of water and foam agent that must be consumed to treat a commercial field make the cost extravagant. Lack of selectivity is another problem with annual crops because even if weeds are controlled in a stale seedbed, later weed cohorts can still outcompete crops with low competitive ability; regrowth of weeds is also a problem to consider with perennial crops. Furthermore, there is a research gap regarding the influence of hot foam on weed seeds on the soil surface and the weed seedbank as it can be hypothesized that there may be soil sterilization effects.

5 Conclusions

Hot foam application are effective for weed control both in the perennial and annual cropping systems, as evaluated in the current study. In perennial crops, efficacy seems to depend on the application rate as weed infestation appears to decrease when the application rate of hot foam increases. For open-field vegetables, the longer the period between seedbed preparation and pre-sowing thermal weed control, the greater the efficacy of hot foam in a stale seedbed. Further research is required to optimize hot foam as a thermal weed control tool in more cropping systems and environments.

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