Flaming and Burning as Thermal Weed Control Methods: A Review

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Abstract

An important part of global pesticide consumption consists of herbicides. But, due to increasing pesticide costs, concerns about pesticides' risks on environment, increasing interest to organic farming, increasing resistance of weeds to herbicides, scientists are searching alternatives to herbicides. The most promising alternative methods are thermal weed control methods. The emissions resulted from these alternative methods don't produce any environmental risk if operated appropriately. Common thermal methods subjected to researches are flame, hot water, steam and infrared heater. The concerns and problems regarding these thermal methods consist of high fuel costs, variable effects depending on weed species, fire risks and injuries on cultivated plant tissues. In this paper, we reviewed international literature on flaming and burning thermal weed control methods.

Keywords: Burn, burning, flame, flaming,weed + flame; weed + flaming; weed+ burn;weed + burning.

INTRODUCTION

Weeds in agricultural fields result with crop yield losses by competing for water, light and land with crops. Chemical fight is the most preferred weed control method today due to its easiness to apply and its fast effect. Due to the negativities of pesticides on human and environment, increasing resistance of weeds to pests and increasing demand for organic products, the use of environmentally friendly new technologies in agricultural struggle is required. Herbicide leaching into surface and ground water and its residues in drinking water and food is an important public problem (Rifai *et al*., 2002).

In thermal weed control, weeds are heated in order to kill them or at least reduce their competitive ability. The heat transfer to the plant surface can take place by convection, radiation, condensation or by conduction for a sufficient period of time. For this purpose, different solutions (flame, hot water, steam, heat radiation) had been developed (Vanhala *et al*., 2004). The principle of thermal treatment is to target the plant for short periods, less than 1 second, with intense temperatures at, or greater than, 100^{o}C. Thermal weed control destroys plant cellular material, coagulating plant proteins, thus disabling respiration and normal plant functioning (Hewitt *et al*., 1998). All weeds can be controlled when the thermal weed control reaches a sufficient temperature.

Flaming

Flaming is the most widespread thermal weed control method in agriculture (Ascard, 1995). Weed control by flaming is based on heating plant tissue rather than burning it (Leroux *et al*., 2001).

Nozzle size, number of nozzles per metre burner width, the fuel (propane etc.), gas phase or liquid phase burner, flame temperature, gas:air ratio, place of gas and air mix, natural or forced air supply are important parameters (Vanhala *et al*., 2004). Flame applications may be conducted in open and protected flame form. Significant heat losses occur in open flame applications and can damage culture plants. To avoid this damage partly, round (pointed) end flame heads are used. Due to the low flame width of such flame heads, the work width is small and a large number of flame heads are required. This increases fuel consumption. To avoid heat losses, reduce damage to the crops and to increase working width of each flame head, flameproof heads (jet type) are used. Flame weeding is often used for weed control in organic production where use of herbicides are prohibited (Sivesind *et al*., 2009). Flaming has been more effective against broadleaf weeds than grasses (Cisneros & Zandstra, 2008). Any research experiment may include comparing the efficacy of different weed control tools or methods, assess the effect of timing, dose or intensity or different combinations of methods (Vanhala *et al*., 2004). Flaming would not be very competitive in areas where herbicides and conventional cultivation give satisfactory control of weeds. Chemicals gave the most effective weed control and the highest yield due to their selectivity and ability to move throughout the weed to control its underground and above-ground parts (Rifai *et al*, 1996). Flaming works best on small annual weed seedlings. Larger and more mature weeds require more intense heat and are difficult to kill with flaming (Holekamp, 1954).

Flaming is a good alternative to herbicide applications on hard urban surfaces and to mechanical means (e.g., string trimmers) which can seriously damage surfaces (Raffaelli *et al*., 2013). A greater knowledge on the development of dose–response curves for determining the appropriate propane dose for effective weed control in major agronomic crops is needed to improve flame-weeding strategies (Datta & Knezevic, 2013). Flame weeding is less costly than hand-weeding (Nemming, 1993). Flame weeding can be used when the soil is too moist for mechanical weeding (Domingues *et al*., 2008). Flame weeding can be used in pre-sowing, pre-emergence or pre-transplanting of culture crops (Peruzzi *et al*., 2007). Post-emergence flame weeding can be used in heat-tolerant crops like maize (Ulloa *et al*., 2011a), soybean (Knezevic *et al*., 2013), sorghum (Ulloa *et al*., 2011b). According to Rahkonen *et al*. (1999), flaming have little effect on microbial biomass deeper in the soil (5–10 mm). The soil temperature at 5 mm depth was raised by 4.0°C and at 10 mm by 1.2°C. The threat that flaming poses to soil microorganisms is small. The use of herbicides in urban areas are strictly regulated. As an alternative to herbicides, thermal equipments can be used successfully for weed control on hard surfaces (Peruzzi *et al*.,2010). Flaming was also used for insect control in dormant alfalfa (Thaddeus, 2001).

Burning

Soil burning is a traditional agricultural practice in restricted areas of the Ethiopian highlands (Pülschln & Koch, 1990). The main grazing management practice in the Kansas Flint Hills is burning annually in spring in March or April. This is followed by intensive grazing with beef cattle for a short period from April to August (Alexander *et al*., 2016). Windrow burning is a tool implemented in Western Australia for harvest weed seed management (Walsh & Newman, 2007). Burning can recycle nutrients tied up in old plant tissue, control many woody plants and herbaceous weeds, improve poor quality forage, increase plant growth, and improve certain wildlife habitat. To minimize smoke impacts and protect public health, burning would be conducted under appropriate atmospheric conditions. (Howenstine *et al*., 2012).

Stubble burning is probably the oldest form of weed seed control, however, there is very little information on the effectiveness of this practice as a means of destroying weeds seeds (Walsh, & Newman, 2007).Articles and their selected core results on flame and burning weed control are listed in Table 1.

Table 1. Articles on Flaming/Burning Weed Control (in chronological order)

No	Article	Method	Application	Main Results
1	Holekamp, 1954	Flaming the drill row in cotton. Two flat burners staggered on opposite sides of the row.	Flame	Excellent control of annual weeds in cotton has been obtained by supplementing regular cultivation with the application of flame to the drill row.
2	Cannon & Hamilton, 1963	Flame compared with herbicides	Flaming	Flame cultivation was effective in controlling weed seedlings in the drill row from the first irrigation until layby. The flamer destroyed many of the lower leaves.
3	Peacock *et al.*, 1965	Chemical, mechanical and flame treatments	Flaming	The flame cultivator gave preemergence weed control.
4	Jeffery, & Henard, 1970	Burning wheat stubble before sowing soybeans.	Burning	Soybeans were direct sown into a wheat stubble, burning the stubble before sowing enhanced weed control regardless of herbicide treatment. Burning the wheat stubble provided season-long weed control regardless of row-spacing.
5	Whitney *et al.*, 1970	Grapefruit trees. Compared flaming, mechanical tree hoeing, and herbicide.	Flaming	Generally, flaming was the most expensive method of weed control while the mechanical tree hoe was the least expensive.
6	Parish, 1990	Greenhouse and field trials. Weed seedlings.	Flame	Treatment of seedlings which germinated over a short period was more effective.
7	Pülschln, & Koch, 1990	Soil of grazed fallows are burnt and unburned.	Burning	On burnt spots weeds developed just about 1/3 of the cover on unburnt ones with a comparatively low share of monocotyledonous species.
8	Balsari *et al.*, 1993	Post-emergence of the weeds before transplanting the lettuce.	Flame	Best results were obtained at 0.27 – 0.42 m · s-1 speed, 0.20 MPa pressure, with weeds at first stage of growth. Flame weed control alone at 0.27 m s-1 gave a lettuce yield that did not differ from the one obtained with the chemical application.
9	Storeheier, 1993	Open flamers compared to shielded flamers	Flaming	Shields should be long and relatively low roofed in order to keep the combustion gases close to the ground for as long time as possible.
10	Ascard, 1995	Field experiment, natural weed flora at different developmental stages.	Flame	Weed species with unprotected growing points and thin leaves were susceptible. When these plants had 0-4 true leaves, complete kill was achieved at propane doses of 20-50 kg ha-1. Species with protected growth points were tolerant due to regrowth after flaming, and they could be completely killed only in the early stages. Increasing leaf numbers resulted with

				increased propane requirement.
11	Rifai *et al*., 1996	In onions and carrots.	Flame	Flaming should be a preventive method, weeds should be controlled as soon as they appear in the crop. Flaming weeds without crop damage becomes increasingly difficult as the weeds grow larger. Flaming is not a cure for every crop. Supplement it to herbicides or mechanical cultivation for better weed control.
12	Ascard, 1998a	Testing flame burner angle in the field.	Flame	No significant differences observed between the effects of the different burner angles. Weed species with protected growing points were tolerant to flames, whereas species with sensitive leaves and exposed growing points were susceptible.
13	Ascard, 1998b	Comparison of flaming and infrared radiation techniques in Sinapis alba	Flaming, infrared radiation	The flamer showed better performance than the infrared radiator on plants at the four-leaf stage, but the opposite was true on plants at the cotyledon stage. Both thermal weeders required an effective dose of propane of about 60 kg ha^{-1} to obtain 95% reduction of plants at the zero- to two-leaf stage. At equivalent propane doses, the flamer gave higher temperatures than the infrared radiator at 1 cm above ground, but temperatures were similar at 3·5 cm height.
14	Hewitt*et al*., 1998	Conducted on a surrogate oat crop and a weed infested pasture	Flame, hot water	Hot water was equally as effective as glyphosate. Flaming was not as effective, however, acceptable weed kill was obtained on juvenile weeds. Thermal weed control is most effective when two sequential applications occur 3-4 weeks apart. Repeat applications of thermal methods markedly increase the efficacy of weed kill.
15	Rahkonen *et al*. 1999.	Soil microbial effect.	Flaming	Flaming have little effect on microbial biomass deeper in the soil (5–10 mm). The soil temperature at 5 mm depth was raised by 4.0°C and at 10 mm by 1.2°C. It is concluded that the threat that flaming poses to soil microorganisms is small.
16	Rifai *et al*., 1999	Flaming, hot-steam and mulching on the natural weed flora at different developmental stages in apples.	Flaming, hot-steam	The effect of flaming on annual weeds depends mainly on the developmental stage of weed species and the propane dose required for the desired control level. The hot steam technology was not effective. An exposure time of 540 s at 150°C of the steam was not sufficient to control weeds. Mulching was a good alternative to reduce herbicide use.
17	Brunclík & Lacko-Bartošová, 2001	Susceptibility of different weed species.	Flaming	At least two flaming treatments at ground speed of 4 $km.h^{-1}$, angle of burners position adjusted at 40° to ground surface, above ground level of burners 0,14 m, gas pressure of 0,2 MPa at the gas propane doses (consumption) of single treatment of 27 $kg.ha^{-1}$ were good resulted.

18	Thaddeus, 2001	Flaming winter annual weeds and/or insect pests compared with herbicide and insecticide treatments	Flaming	Alfalfa yield evaluations revealed the flamed alfalfa treatments had higher yields than the untreated check.
19	Mojžiš, 2002	Onion field with wild oats and wild radish	Flame	The change of gas consumption influenced the effectivity of weed control. Control of the wild oats varied from 31% to 93% . Control of wild radish varied from 21% to 93%.
20	Rasmussen, 2003	Punch or normal planting with or without flame weeding in fodder beet for five planting dates.	Flame	Punch planting with flame weeding offers a promising method of weed control in organic farming.
21	Raffaelli *et al.*, 2004	Comparison of hand hoeing with flaming for intra-row weed control in Artichoke	Flaming	Flaming permitted a work saving. Yield was not different. Flaming is efficient for intra-row weed control in artichoke.
22	Shimi & Faghih, 2004	Flaming compared to hand weeding and herbicides in onion fields	Flaming	All treatments plus one hand weeding controlled weeds effectively and boosted yields. Flaming can replace herbicides in onion fields.
23	Fereidonpoor *et al*, 2006	Field experiment; flame and herbicide	Flame	Treflan+ once hoeing at 8th weeks and the application of flamer twice at the 20cm and 40 cm height of plant were the best result.
24	Narwal *et al.*, 2006	Effect of tillage practices and stubble burning on seed bank.	Burning	In 2005 wheat straw burning with chisel ploughing and mould board ploughing treatments were similar in reducing the weed biomass.
25	Bower *et al.*, 2006	Burning grazing plots to reduce Urochloa mutica. Frogs were also monitored.	Burning	Marbled frogs declined correlated with vegetation biomass. Knowledge about impacts of planned weed control is critical.
26	Ostojić, 2007	Maize crop, flame temperatures from 110 to 350°C at up to the 8 true leaves stage.	Flame	110°C flame temperature destroyed all weed seedlings up to the 2 true leaves stage. At the 4-6 true leaves stage 175°C was required for 80% control. Over 85% control at the 8 true leaves stage was only achieved by using 350°C flame temperature.
27	Walsh & Newman, 2007	10% of field area is exposed by burning narrow windrows to kill weed seeds practice	Burning	Preliminary kiln studies determined that temperatures in excess of 400 ^{o}C for at least 10 s were needed to guarantee the death of ryegrass seeds while 500 ^{o}C for the same duration was required to kill wild radish seed within their pod segments. Burning exposes the soil surface, increasing the potential for erosion.
28	Cisneros & Zandstra, 2008	Conducted with a conveyor bench burner apparatus. Applied to broadleaf and grass seedlings at different stages.	Flame	A few plants survived when flamed at 8 km/h. Some seedlings were more tolerant. Some large plants survived flaming at both growth stages.

29	Da Silva *et al*, 2008	Organic field beans	Flaming	Flaming with machine on organic soil beans is feasible, but equipments require a re-engineering work to adequation of crop characteristics.
30	Domingues *et al*., 2008	Broadcast flaming on four weed species	Flaming	Unlike the broadleaf species, the growing points of grass species remained undisturbed below the soil surface at the time of flaming. Grass species were more tolerant to propane flaming than broadleaf species. The sensitivity of grass to flaming also varied between the species.
31	Sivesind *et al*., 2009	Five common weed species	Flame	Dicot species were more effectively controlled than monocot species. Flame weeding can be an effective and labor-saving weed control method, partially dependent on the weed flora. Knowledge of the local weed flora and their susceptibility to flame weeding is vital for the effective use of this method.
32	Saglam & Kiran, 2010	Vineyard	Flame	82% of narrow leaf weeds and 72.5% of broad leaf weeds were eliminated with flame.
33	Peruzzi *et al*. 2010	Flaming treatments on weed density reduction and LPG consumption and cost.	Flaming	The specific nozzles and rod burners used, together with the water heat exchanger, allowed a high efficiency of the machine and a reduced LPG consumption.
34	Ulloa *et al*., 2010a	Broadcast flaming; propane dose and crop growth stage; field experiment in sweet maize.	Flaming	V7 was the most tolerant while V2 was the least tolerant stage for broadcast flaming. V7 stage can tolerate higher dose of propane for the same yield reduction compared to the other growth stages. Flaming has a potential to be used effectively in organic sweet maize production if properly used.
35	Ulloa *et al*., 2010b	Six annual weed species' tolerance to broadcast flaming	Flaming	Broadleaf weeds were more susceptible to flaming than the grass regardless of the growth stage. Overall response to flaming varied among species, growth stage and propane dose.
36	Knezevic *et al*., 2011	Seven treatments applied at several growth stages of maize. Banded and broadcast flaming	Flaming	The best treatment was a combination of cultivation and banded flaming conducted twice, at the V3 and V6 stages of maize.
37	Petrović & Đurić, 2011	Effect of different propane dozes in weed flaming in soybean and corn crop on the number of systemic group of microorganisms in soil.	Flaming	The most sensitive group of microorganisms on weed flaming was the group of bacteria and the most tolerant were fungi in both investigated crops.
38	Avishek *et al*., 2012	Propane flaming in combination with cultivation in maize and soybean. banded flaming, broadcast flaming	Flaming	In maize, the combination treatment of mechanical cultivation and banded flaming applied at the V4 and V6 stages provided >90% weed control, which was similar to the weed-free control. In soybean, the highest yields were obtained in the weed-free control and the plots flamed plus cultivated twice at the VC and V4 stages (2.8 t ha^{-1}).

39	Loghavi & Loni, 2012	Machine vision and image analysis techniques used in real time application of variable rate flame weeding in maize	Continuous or targeted flaming	In general, continuous and targeted flaming showed similar results in weed eradication, while fuel consumption of the targeted method was significantly lower. Weed eradication was higher at lower travel speeds. Targeted discrete flame weeding by using machine vision technology has a potential for uniform flaming with lower fossil fuel consumption and air pollution.
40	Ulloa *et al.*, 2012	Greenhouse, maize, soybean, two weed species, propane, doses, hand flamer	Flaming	All plant species were more susceptible to flaming during the afternoon. Leaf relative water content could be one of the factors affecting plant response to flaming. Broadleaf species were more susceptible to flaming than grasses.
41	Raffaelli *et al.*, 2013	LPG fed flaming machines used in urban and sub-urban in comparison with herbicides or mowing.	Flame	Flaming can be both less expensive and more effective than the ordinary treatments in urban areas. Flaming was more effective than mowing in the suburban area but much more expensive, thus an integrated approach would be advisable.
42	Knezevic *et al.*, 2014	Testing tolerance of selected early-season weeds to broadcast flaming in no-till systems.	Flaming	Response to broadcast flaming varied among species and growth stages. Single application of broadcast flaming can be an effective tool for controlling a few weed species.
43	Loni *et al.*, 2014	Targeted-discrete flame weeding by using machine vision technology; laboratory and field tests	Flame	Optimum position of burners were 25 cm above the ground surface and inclined at 30º for achieving acceptable accuracy in laboratory application of targeted flaming. First flaming was significantly more effective than the second and third flaming.
44	White & Boyd, 2016	Blueberry fields.	Dry heat, direct flame, straw burning	Germination decreased more rapidly at higher temperatures in all species. Duration of heat exposure required to reduce germination by 50 and 90% varied across temperatures and species. Exposure of seeds to direct flame rapidly reduced germination. Less than 1 s of exposure required to reduce seed germination of 3 varieties by > 90%. Thermal technologies that expose weed seeds to direct flame will be the most consistent in reducing seed viability.
45	Stepanovic *et al.*, 2016	Field experiments with organic soybean; flaming and cultivation with and without manure	Banded & broadcast flaming	The combination of mechanical cultivation and banded flaming applied twice (at VC and V4–V5) was the best treatment resulting in 80–82% weed control and 6–9% crop injury. Soybean recovered well after all flaming treatments, with the exception of broadcast flaming conducted twice. Combining flaming with cultivation effectively control weeds in organic soybean production.
46	Stepanovic *et al.*, 2016	Flaming and cultivation with and	Banded & broadcast	No interaction between manure application and weed management treatments. Maize

		without manure in organic maize	flaming	showed good tolerance to all flaming treatments. Best weed control was achieved with banded flaming. Flaming and cultivation applied separately or combined in a single operation, as a single trip across the field, have a potential to be used for weed control in organic maize production systems.
47	Martelloni *et al*., 2016	Maize, LPG, cross flaming	Flaming	Overall response of maize yield to flame weeding was influenced by LPG dose, number of flame weedings, maize growth stage, and presence of weeds. Two cross-flaming treatments applied separately with an LPG dose ranging from 36 to 42 kg ha^{-1} can provide an acceptable level of weed control in maize for economically acceptable yields.
48	Martelloni *et al*., 2016	Cross-flaming, LPG on dry beans	Flaming	Bean flamed at BBCH 13 stage had little tolerance to cross-flaming. Bean flamed at BBCH 14 stage was tolerant until an LPG dose of 39 kg/ha.

RESULTS and DISCUSSION

To see the effects of flaming on ecology in scientific literature, “burning” and “weed” combined keywords produce very much info related to these kinds of applications. This keyword combination also gives too many patents.

In noxious-weed covered irregular sloped pastures, which covers huge areas in the world, flaming may be a good way to destroy weeds without increasing erosion sourced from plowing or without environment contamination sourced from herbicides. Image analysis techniques may be used used with real time application of variable rate flame weeding technique with man drivers. Targeted flaming will reduce fuel consumption significantly compared to continuous flaming. These types of areas cover huge areas all around the world; one example is East Europe countries including Turkey. An operation covering three years with 4-5 applications will possibly reduce tough perennials successfully, too. A shape recognition system with endemic plants image database may be used to protect selected species to reduce spraying application but will destroy undefinied species. So, using a noxious-weeds image database to select and flame target will be a more environmental method. Declines in vegetation biomass will effect accompanying animals. To reduce this effect and protect these communities, unflammed spots will be needed in this system. Flaming these areas early in the season when weeds are small will be more effective. Flaming is also a very appropirate method to use in urban areas, organic fields, railways and raodways to fight weeds without environmental pollution. Also flaming will reduce the negative effects of burning on vehicle traffic on roads. Flaming reduces workpower requirement significantly compared to plowing and handweeding. Flaming is a promising method to use in ridge cultivation and drip irrgiation techniques due to no disturbance and damage to soil level and pipes. Flaming may be a very economic method in conventional agriculture if targeted-discrete flame weeding by using machine vision technology used. Very few studies exists in insect fighting in between weed fighting, so more researches may be needed on this subject. There exists researches on open and shielded flamers but looks like need researches on appropirate nozzle types.

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