

## THERMAL WEED CONTROL, A TECHNOLOGY WITH A FUTURE?

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**Abstract** In recent years, there has been a revival of 'flame weeding', and the development of other ways of delivering heat to kill weeds.

The effect of heat on plants is examined and methods of applying heat to weeds are reviewed. These include hot water, steam, hot air, hot foam, as well as improved flame weeders. The paper concludes by examining the likely potential of the different methods in Australia.

### INTRODUCTION

In the last ten years there has been a renewal of interest and research in thermal weed control methods, due largely to 'food safety' and 'environmental' concerns, and now in Australia, also to herbicide resistance.

Thermal weed control with various patents and designs dating back to 1852, was a practical and commercial weed control option in the US in corn and cotton cropping from 1940 until the 1960's, when selective herbicides came into use. In Europe, development was slower, but didn't fade out entirely, with a revival in use with organic growers in the 1980's.

### THE EFFECT OF HEAT ON PLANTS

Heat kills plants, there being a "time-temperature relationship" which varies considerably between different species, with denaturing of cells starting at about 40°C. Measurements show that as temperature increases linearly, heat-killing time decreases exponentially (Levitt 1980). This is probably due to the relationship in radiant heat transmission, whereby the quantity of heat transmitted between two objects is proportional to the fourth power of the absolute temperatures of those objects. As temperature increases, the 'time to kill' differences between sensitive and insensitive plants will decline exponentially.

The critical temperature quoted for effective leaf mortality ranges from 55°C to 70°C, with an exposure time range of 65-130 milliseconds (Ascard 1997) but as a temperature gradient is required to drive heat into the plant, a greater minimum temperature is required. The mechanisms in the plant of how heat injury affects the plant are varied and complex, but in thermal weed

control are loss of membrane semi-permeability and cuticle breakdown (allowing plant desiccation), denaturing of proteins, and other chemical decomposition.

External or morphological differences are important in determining kill efficiency, and might be grouped as: leaf, location of growing point, nature of storage organs. Leaf orientation and shape, cuticle characteristics, presence of hair, growth stage, and degree of stress (both moisture and nutrient) will affect sensitivity to a passing heat source. The cuticle of the plant is the first means of defence against heat. It may be possible to reduce the effectiveness of the cuticle, for example, with chemicals that act as 'cuticle strippers'. Another method, successfully used in reducing (perhaps by a factor of ten) the amount of chemical needed to kill a plant, is to sandblast the plant, and this may also assist the effectiveness of thermal weed control.

Grasses have their growing points well protected compared to broadleaf plants, and survival of flame treatment is much better than for broadleaf weeds when small (under 5 cm height, an example might be 65% compared to 20%, unpublished data). In bigger plants the greater moisture content of leaves and the tap root of many broadleaf annual weeds compensate for the lack of protection from flame. Morphological oddities may give unexpected results. For example, wireweed has stems with air pockets which crackle and explode with application of heat, with no follow-up often required for plant kill. Repeat applications may give a selective control due to differences in the storage organs that supply the energy required to re-establish the plant, some species being much more vulnerable at this time than others, and make onions and carrots well suited to thermal weed control.

Air characteristics also affect results. Boundary air layers at the soil surface make very small weeds hard to kill if there is little radiant emission from the flamer. Western Australian experimentation has shown that wind can reduce temperatures recorded at ground level under a flamer to a third of that recorded in still air. This is a major obstacle to effective (let alone economic) use in broad-acre cropping.

Temperature in the flame might be 1300°C (up to 1900°C), but just above the soil may be 300-600°C. This is difficult to measure in the field, as thermocouples may have a time lag of 0.25-0.5 seconds, so that the flame has passed before the thermocouple has fully responded. A thin wire thermocouple (0.1 - 0.3mm) minimises this effect, but as the plant also has thermal inertia, the only real test of effectiveness is whether or not the plant dies. Ascard (1997, 1998) has improved the value of research into flame weeders by taking into account the weed species, plant size and propane consumption as well as the temperatures achieved. His work has developed good relationships between temperature recordings and plant kill.

### HEAT DELIVERY SYSTEMS

Heat can be delivered to plants in different ways, each having both advantages and disadvantages:

**Naked flame** 'Naked flame' has the simplest equipment and the cheapest capital cost, but a higher energy consumption than more sophisticated equipment. 'Red Dragon' of Kansas still makes the classic 'flame weeding' burners using 'fan-jet' nozzles, housed in a heavy sheet metal rectangular casing. They are used lined up either parallel to the row for inter-row weed control or blanket application, or angled down at the base of the crop plant (across the row) to take out weeds in the row, once the crop plants are able to withstand the heat. Both corn, with a base protected by layers of leaves, and cotton, with a woody stem, have excellent characteristics for this practice.

**Flame, combined with insulation and infrared radiation** Kleenheat, of WA are the importers of the 'HOAF' machine, developed in Holland, which is claimed to be 3-5 times more efficient than naked flame. Refractory material, held in place under the top by stainless steel expanded metal, glows red, radiating heat downwards. There is still danger from unwanted fires, but the enclosed burners are less affected by wind than naked flame. Kleenheat has improved the design by shielding the front of the machine to reduce wind flow underneath. Another improvement might be to use flammers in tandem, whereby the exhaust from the first flamer heats the oncoming air of the second.

**Infrared radiation** Infrared radiation thermal weeder, with gas burners also called non-catalytic atmospheric burners, operate with essentially no visible flame on the combustion surface. Ascard (1998) compared this style with an insulated covered flamer. Burner surface temperatures were lower at about 900°C, and whilst there were poorer results with bigger weeds (4-leaf

*Sinapis alba*) there was better control at the zero- to two-leaf stage. He reports work by Hoffmann who found that infrared radiators cause a higher temperature increase in the upper soil layers compared to flammers, due to avoiding a boundary layer effect.

**Hot water** Hot water. 'Waipuna International' of NZ has over the last seven years developed hot water weed control from a patent into a commercial product, although other firms are, or have, also been involved. Hot water has a high heat content, but the temperature can never be more than 100°C, resulting in a low temperature gradient to move the heat into the plant, requiring more time. But conduction from water to the plant is better than from hot gas to the plant. It's major disadvantage is that it needs about 24,000-30,000 L ha<sup>-1</sup> for total weed control. This amount of water is practical (and the cost is generally only slightly greater than chemical weed control) for the urban weed control situation, but not for agriculture. In sandy soil, hot water movement into the soil will kill guildford grass (*Romulea rosea*) bulbs (an onion like plant), and possibly some seeds (although dry seeds will withstand temperatures up to 120°C, according to Levitt). Aqua Heat Technology of the US claimed the cost of hot water weed control in Florida citrus groves with their technology in 1994 was estimated at US\$15-20 acre<sup>-1</sup>, but their brochure did not quote water rates.

**Steam** Steam has the advantage of having a greater heat content than boiling water due the latent heat of vaporisation, plus a little bit more if superheated. Water at 100°C has 251kj kg<sup>-1</sup> of useful heat above the 40°C minimum. Steam at 100°C has 2508kj kg<sup>-1</sup>, but occupies 1673 litres kg<sup>-1</sup>, compared to 1 litre kg<sup>-1</sup> for water, so as heat content per litre, 100°C water has 251kj L<sup>-1</sup> and 100°C steam has 1.5kj. There is difficulty in getting the steam to condense on the plant to make use of the latent heat, requiring trailing covers over the weeds. The apparent advantages of steam are difficult to capture. Maybe the steam could be charged to attract it to the plant, as is done with ultra-low volume spraying. Work in NZ (Collins, 1994, unpublished) showed that 3,000 L ha<sup>-1</sup> could give a similar effect to a light paraquat application (ie, producing a 'knockdown' from which the pasture soon recovered) on a perennial ryegrass-white clover pasture. Best results were achieved with a mixture of steam and water, ensuring the hottest water delivery temperature, with the steam also ensuring good plant surface coverage. It is possible to generate the steam in the flame, and there is a product being developed from a patent of this principle.

**Hot air** The inspiration for the use of hot air was the possibility of a more efficient use of energy (through recycling heat), a safer appliance, and no water to collect and carry. It has been found that the most effective plant damage is done where there is some part of the machine radiating heat, and the air must be directed to the base of the plant for the most effective kill (Tindall, pers com). Where hot air is recycled, there must be a heat exchanger, as too much exhaust added to the burner air will lead to poor combustion because of oxygen depletion. Waipuna is one company developing this system.

**Hot foam** Another patented development by Waipuna, foam has the advantage of using less water (initial tests indicate 1/6th the amount of water needed, Tindall pers com), and has a much longer heat transfer time. Limited tests have been done on very small weeds to find what the minimal water use might be. Foaming agents need to be biodegradable yet heat stable in formulation and foaming characteristics, and could possibly be used to affect the cuticle, assisting plant desiccation. The long heat transfer period might be useable to give selective control and economy by using lower temperatures.

**Direct contact, or conduction** This is where something like a hot iron is placed on the weed and the heat conducts directly to the plant without relying on a gas or liquid carrier, or radiation. Although there was development in Western Australia by one inventor in 1997 (and no doubt elsewhere in the world at various times), this author knows of no commercial application. An iron with a central spear to take heat to the taproot might suit 'spot' application to weeds such as plantain in lawns.

**Solar.** There are also possibilities with solar heat, perhaps not at the cropping time of the year, but in the summer, killing surface weed seeds. Other 'radiations' that work by heat include microwave and UV-light. Microwave control of all organisms (including fungi and seeds) to a certain depth (depending on energy input and presumably moisture content) was developed at Texas A and M University and commercialised in 1971 (Davis 1975). Although this method seems to have disappeared without trace (although it is used in the US for termite control), UV-light for weed control has recently been patented, and claimed to use about 1/4 the amount of energy as flame weed control (Jensen, 1999).

## POTENTIAL FUTURE IN AUSTRALIA

In the last few years there has been a steady increase in both interest and development in Australia, especially since Tony Atkinson of GAMECO presented a paper at a national gas industry conference in 1995, postulating a gas demand of 200,000 tonnes of LPG per year if 30% of the total crop area had 35L ha<sup>-1</sup> applied (Atkinson 1995). This would be a new market for gas, and help establish an economical supply line, where there was farm delivery in tankers, on farm storage and the farmer using gas in his tractors and vehicles as well. At least two suppliers (Kleenheat and Boral) are involved in research and equipment development.

Hot water equipment is supplied by Waipuna International and Steamwand Australia (Mayo 1998), and in urban weed control can only become more popular due to the growing public suspicion of chemicals.

Adoption in agriculture is occurring in horticulture, where small areas, higher value produce (vineyards) and organic growers of crops that particularly suit flaming (carrots and onions), or where chemical use is suspect (burn down of potato tops prior to harvest), are able to bear slow work rates and high energy costs. Agriculture Western Australia has recently started a GRDC funded project investigating alternative weed control technologies for broad-acre cropping, in which thermal methods (amongst others) are being researched. Limited trial work has shown promise in the following applications:

1. Pasture topping. Late (October) application is likely to be most successful, as the drying pasture will require less heat, yet seed-heads (barleygrass and ryegrass) are still killed. This could be helpful where the pasture was grazed and had some value.
2. There is a rapid development of technology that could accurately guide shielded thermal weed control equipment in a 'row crop' situation. Simpler 'set ups' may also work at slower speeds, and there are trials this year in the WA wheatbelt using an insulated flamer and a hot air machine.
3. Experimentation with burning canola residue in March has shown a reduction in ryegrass seedling emergence from no burning (2400/m<sup>2</sup>), to 400 for 'unassisted burning' and 200/m<sup>2</sup> for 'HOAF assisted burning' (unpublished data).

4. 'Knockdown' and 'post emergence' trials with wheat have not been encouraging due to wind, staggered weed emergence, and wet weather affecting the timing of early post seeding application. Precise seed depth and operation timing will be important. Faba beans and chickpeas, with cotyledons below the soil, might recover well from this treatment.

#### ECONOMICS

Ascard (1998) quotes fuel usage around 60kg ha<sup>-1</sup> to obtain a 95% reduction of plants at the zero- to two-leaf stage. This equates to \$48 ha<sup>-1</sup>, assuming a gas price of 40c L<sup>-1</sup>. Our work in Western Australia has yet to achieve that economy, due to the weeds being bigger (grasses up to 50mm in height) and the wind problem. One estimate (Fawcett, 1997) put a figure of 160 times the total energy input (including application) comparing flame with a low rate herbicide chemical (for example, Logran™). In the future, it may be possible to use 'biofuels', which would answer the criticism about the 'greenhouse gas' of fossil fuel use. 'Chaff carts' (collecting chaff and weed seed at harvest) would collect about enough material for one 'knockdown', and recent gasifier developments might make wood-burning flame weeders a practical proposition. In Western Australia the proposed development of co-generation power stations, producing electricity, oil and activated charcoal from coppiced mallees, may provide the infra-structure (eg, harvesting and handling systems) to facilitate other wood based energy systems. In the northern hemisphere, canola oil is being used more and more as a biofuel, which could be used for power generation for UV-light.

Imported equipment has been expensive but volume sales and/or local manufacture will reduce this. Equipment leases may tie use to the gas supply.

#### CONCLUSIONS

1. Each heat delivery system has disadvantages that will lead to niche uses.
2. There is difficulty in achieving adequate damage to the plant, because of thermodynamic

limitations. Further development will likely improve this situation, particularly when combined with 'benign chemistry' (eg cuticle strippers, foaming agents).

3. Energy cost is currently a disincentive. Use on very small weeds will greatly help energy economy.
4. It is difficult to achieve selective weed kill. Careful timing can exploit this to advantage (eg, post seeding - pre-emergence).

The next few years will see some interesting new ways in the use of heat to kill weeds.

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