IMPROVED EFFICIENCIES IN FLAME WEEDING

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IMPROVED EFFICIENCIES IN FLAME WEEDING.

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ABSTRACT.

Possible areas of improving the efficiencies of the Lincoln University flame weeder are identified and investigated. The Hoffmann burner initially used in the Lincoln University flame weeder was found not to entrain sufficient air to allow complete combustion of the LPG used.

A new burner, the Modified Lincoln University burner, was designed to improve the entrainment of air. Results show that the new design entrained sufficient air to theoretically allow complete combustion of the LPG, and this resulted in a 22.7% increase in heat output per Kg of LPG used over the Hoffmann burner.

Temperature x time exposure constants required to kill weeds 0 - 15, 15 - 30, and 30 - 45 mm in size, were found to be respectively 750, 882, and 989 degrees Celsius.Seconds. These constants can be used to calculate the maximum speed of travel an operator can use a flame weeder at, once the temperature profile underneath its shields are established at various travel speeds, and therefore ensure that the flame weeder is used at its maximum efficiency. The constants can also be used to establish the cost efficiency of any flame weeder (in $/Ha), depending on the size of the weeds to be treated.

The materials and methods used in establishing the temperature x time exposure constants can be used to establish the temperature x time exposure constant of any weed species at any size.

Keywords.

Pre-emergence flaming, air entrainment, complete combustion, incomplete combustion, perfect combustion, burning velocity, bluff bodies, "blow off", temperature x time exposure constants.

1) INTRODUCTION.

Flame weeding is the practice of controlling weed populations through the application of intense heat in the form of either a direct flame or radiated heat from a burner. To establish control the weeds are exposed to a high temperature for a short period of time (eg. 100 degrees Celsius for at least 0.1 seconds, (HOFFMANN, 1989)).

In literature, the effect of flame weeding is stated to be partly due to a coagulation of protein at 50-70 degrees Celsius and partly due to the fact that by the sudden increase of temperature a strong dilation takes place so that the cell walls "burst". By both effects the cell is damaged so much that the plant can no longer grow. (KLOOSTER, 1983 ; VESTER, 1986 ; PARISH, 1987 ; HOFFMANN, 1989)

As no chemicals are leached into the soil or into plants using flame weeding, interest for this form of weed control has grown considerably during the past decade.

"Organic", a word increasingly being used by the general public in the 1990's, signifies the changing times we are currently experiencing world-wide. The Oxford Dictionary describes organic as; produced without the use of artificial fertilizers or pesticides.

Production of organically grown produce has up to date been a more labour intensive, and therefore usually more expensive, enterprise compared to conventional growing enterprises using artificial aids in production.

However, as people from all walks of life are showing more and more concern for the environment, their own health by reduced use of pesticides, and the preservation of the Earth for future generations, an increasing demand is being placed on the production of organic produce and an overall decrease in the use of environmentally damaging chemicals despite these increasing costs.

For example- overseas parents are demanding chemical-free baby food for their new-borne, locally, increased public demand sees more and more health shops and organic produce departments springing up in supermarkets, while City Councils are being pressured to stop spraying road-sides and other public areas and instead find some environmentally friendly method of keeping these areas weed free.

Chemical research has been very active since World War II to provide growers and City Councils with sprays to kill weeds, often with a high environmental cost.

In recent years this research has changed course slightly and is now producing chemicals much better for the environment, with less chemicals leaching into the soil and less being absorbed by the produce we eventually consume.

To organic growers and environmentally aware people however this is still not acceptable and their aim is to dramatically reduces the use of chemicals for weed control.

A real need has therefore arisen to provide organic growers and City Councils with an economic weed control method that does not rely on chemicals.

Flame weeding is one of those methods and this thesis will focus on improving the cost, weed kill and fuel efficiencies of pre-emergence flame weeding under New Zealand conditions using an LPG flame weeder. To achieve this, burner design, shield design and the temperature x time constants required to achieve weed control, will be studied and investigated.

2) BACKGROUND.

2.1 History of Flame Weeding.

The first reported flame cultivator was used and patented by one John A. Graig, of Columbia, Arkansas, in 1852. (EDWARDS,1964)

Quoting Mr. Harold Barr before the Southwest section of the American Society of Agricultural Engineers in 1947 :

"Numerous later machines and patents were recorded. In 1900 S. B. Jones of Illinois was granted a patent on a machine not unlike some of the early, home-made machines of our day.

This machine was an attachment to be mounted on a one-row cultivator and consisted of a fuel tank and two burners, one on each side of the row. The principal claim for this machine was that of an insect destroyer. Devices were brought out in 1907, 1908, 1913, 1917, and 1926, with some claims as 'this invention relates to devices including a burner or torch whereby extraneous growth may be burned from plants of various kinds from the ground around the roots of plants or in places which are otherwise inaccessible to ordinary weed and growth destroying implements such as hoes, cultivators, and the like, and has for one of its objects to provide a simple constructed device which may be carried from place to place, and in which some form of hydrocarbon liquid, such as crude kerosene oil, or the like, is employed as a fuel, and which may be readily adjusted to direct the flame of the torch or burner in any required direction.'" (EDWARDS, 1964)

In Australia in the early 1930's flame was used in the sugar cane fields. Hawaiian sugar plantations used flame weeders to burn weeds out of the sugar cane without injury to the growing cane. This practise was discontinued as it appeared uneconomical. (BARR, 1947)

In 1935 Colonel Price C. McLemore tried out his flame cultivator in the cotton field. (BARR, 1947; BAGGETTE, 1948)

It was in Louisiana, however, in the autumn of 1941 and the spring of 1942 that Harold T. Barr tested a two row tractor-mounted flame cultivator on sugar cane. Favourable results and the shortage of labour resulted in the construction and use of 10 machines in 1943. (EDWARDS, 1964)

Many improvements were made on these original flame cultivators.

In 1945 LPG equipment was introduced for farm use and since then Propane and Butane have been used as the main fuel for flame weeding. (PARKER, HOLSTUN, and FULGHAM, 1965)

Pressurized LPG replaced the original air compressor, air tank, fuel tank, fuel pump and kerosene/diesel fuels used in the early days. The change from the fuel oil system to the LPG system was not an easy task, agricultural research engineers had troubles trying to find the right combination of fuels, vapourizers and burners to give the type of flame and flame control desired.(EDWARDS, 1964)

Since the introduction of LPG the major changes in flame weeding have been those related to the design of burners and burner carriers.

Burners are of two types, the liquid or self-vapourizing type, in which the LPG is in its liquid state when drawn from the tank and is vapourized at the burner into its gas state through the application of heat, usually by means of the LPG line coiling around the burner, and the vapour type, where the LPG is drawn from its tank already in the gas phase. (BAGGETTE, 1948) As separate vapourizers were improved, the vapour type burner became more popular.

One self-vapourizing burner is the round Barr-type burner of 1946, it was however troubled with flame "bounce" due to its round shape. (EDWARDS, 1964; BARR, 1947)

In 1948 a special vapour type burner of alloy iron had been cast to form a bottom-ventilated burner with an oval-cornered rectangular mouth opening and employing a standard fan-type spray nozzle as an orifice. Developed by a Mr. Stewart Poole the new burner gave much better flame control, practically eliminating flame "bounce". (JONES, 1950; CARTER, COLWICK, and TAVERNETTI, 1960)

Jones used the Poole burner's principles but built it out of 10 gauge steel sheet metal and weighed much less than the Poole burner. A strainer was added to the fan-type spray nozzle to decrease clogging.

Continued research on this vapour type burner eventually produced the "Stoneville" flat burner which gives a shorter, thicker, and easier controlled flame. (JONES, 1950)

A modification of this design by STANTON in 1953 incorporated a horizontal combustion chamber and a 30^0 angle deflector intended to minimize the heat rising into the cotton was marketed as the "Arkansas" burner. (STANTON, 1954)

In Germany, Manfred Hoffmann developed the Hoffmann burner, a vapour type burner which gives a very stable and controllable flame. It uses 0.5 mm nozzles spaced approximately 30 mm apart and comes in widths of 100 to 500 mm. (HOFFMANN, 1989)

The burners mentioned are only some of the more prominent burners developed to operate with LPG, most never made it to full-scale production and are therefore not mentioned.

2.2 Experimental Review.

Literature published on flame weeding is quite extensive and research can be divided into six major groups.

1) Effects of flame weeding on crop plants.
2) Effects of flame weeding on weeds.
3) Effects of flame weeding on insects.
4) Integration of flame weeding into pest management systems.
5) Economics of using flame weeding.
6) Development of flame weeding equipment.

These groups will be discussed individually in the next sections.

2.2.1 Effects of flame cultivation on crop plants.

This literature looks at the effects of flame cultivation on the crop being cultivated. Flame weeding for weed control has been used on a vast number of crops.

2.2.1.1 Sugar cane.

Sugar cane was flamed by BARR in 1944, he reports:" In a few cases the sugar cane was given a very severe burning and took on a golden brown colour the second day after burning, but this all disappeared in five days and at harvest the flamed cane out-yielded the hoe-cleaned plots by 1.3 ton/acre. (3.285 tonnes/Ha)

This result was obtained with only three to four flamings with burners set 475 mm apart and the flame hitting the base of the sugar cane plant."

2.2.1.2 Corn.

One of the more documented crops involving flame weeding is corn. WRIGHT (1947) stated that: "Flame weeding is a matter of differential burning. Just enough heat should be applied to kill the weeds, but not enough to kill the crop plants. Some crop plants, such as corn, have more resistance to flame than do the common weeds; therefore, corn is flamed successfully."

LILJEDAHL, WILLIAMS and ALBRECHT (1964a and 1964b) and LILJEDAHL, WILLIAMS, ALBRECHT, LIEN, and PERUMPRAL (1965) found that it was necessary to control the weeds when the corn was small, about 300 mm. The early flamings normally did not kill the corn, but some stunting did result, which in turn affected the yield.

Early flaming was deemed necessary as the early weeds and grasses offered competition for the corn and the weeds and grasses were often too large to control when the corn became tall enough to tolerate flaming.

Even in the early years of flame cultivation LILJEDAHL et al. (1964a, 1964b and 1965) recognised that: " Flame weeding should be planned and not used as a salvage treatment, it gives best results when used in combination with other methods of weed control, especially a sweep cultivator and a rotary hoe."

Although GEIER (1984) did not draw any conclusions, his preliminary results were similar to those of Liljedahl et al.

An increase in yield was noticed when flaming was done on corn only 30 mm tall to control the weeds at an early stage.

Guidelines given by HOFFMANN (1989) follow the same trend, he specifies that corn should be flamed up to 20 mm tall and then again when the corn is at least 150 mm, preferably 200-250 mm, tall. According to Hoffmann the flame resistant properties of corn are due to its thick layer of leaves at the bottom of the corn plant.

In order to control the weeds at an early stage of the corn's growth CHAPPELL and ELLWANGER (1969) experimented with pre-emergence flaming, where weeds were allowed to germinate first after which the corn was drilled in amongst them. Flaming was used to kill the weeds just before the corn was due to emerge, providing a weed-free environment for the germinating corn.

"The delayed seeding technique followed by pre-emergence weed flaming reported herein is an innovation that appears to have considerable promise for weed control in many crops. There is no chemical residue problem and seeded crops that have not emerged are insulated from heat by the soil and should not be injured by the flaming. This technique should be especially well adapted for all large seeded crops and for those smaller seeded ones whose seed germinate slowly." (CHAPPELL and ELLWANGER, 1969)

2.2.1.3 Grapes.

Grapes can be kept relatively free of weeds if the soil is levelled underneath the grapes to cause minimal interference on the flame. A two-weekly flaming regime was found to be unnecessary to effectively control weeds in grapes. (HANSEN and GLEASON, 1965; HANSEN, GLEASON, and HULL, 1966; ANDERSON, HANSEN, THOMAS, and HULL 1967)

Problems were encountered with the intense heat from grass, 200-250 mm tall, being incinerated in the subsequent flaming (HANSEN and GLEASON, 1965).

Defoliation for the harvest of grapes was successful but gave no advantage in reducing the harvest time of grapes and is therefore an unnecessary cost. (HANSEN et al., 1966)

2.2.1.4 Blueberries.

Results of flaming for weed control in blueberries were found to be very similar to those in grapes. (HANSEN and GLEASON, 1965; HANSEN et al., 1966; ANDERSON et al., 1967)

2.2.1.5 Strawberries.

HANSEN and GLEASON (1965) tried using flame weeding on strawberries, results showed little or no effect of the intensity of heat on the regrowth of strawberry plants.

Mr. Henk Nuyten, Stichting Proeftuin Noord-Brabant (Personal Communication, 1990), was aiming to use flame weeding on commercially grown strawberry plants in 1991 in The Netherlands. Although no results are available he expressed great confidence in a successful result.

2.2.1.6 Cotton.

Both parallel (flame parallel to the crop row) and cross flaming (flame perpendicular to the crop row) have been used on cotton. Either practice will give a good weed kill, although reports by PARKER and HOLSTUN (1961) and PARKER, HOLSTUN and FULGHAM (1965) show that parallel flaming will result in less damage to the cotton as well as enabling flame weeding to be used when the cotton is relatively small, about 100 mm.

Cross flaming is not safe to use until the cotton plants reach the 300 mm stage (PARKER and HOLSTUN, 1961; PARKER, HOLSTUN and FULGHAM, 1965).

2.2.1.7 Cole crops.

Cole crops, including broccoli, brussel sprouts, cabbage and cauliflower, were flamed by WILSON and ILNICKI (1966 and 1967).

"In all crops studied cross flaming more effectively controlled weeds than did parallel flaming. Most effective control was achieved when weeds were less than 2 inches (50 mm) tall and increased control resulted from more than one application of flame. There was a tendency towards increased injury with more than one flame application." (WILSON and ILNICKI, 1966)

"It is believed that flame can be used, either alone or in combinations with mechanical or chemical methods, as an effective means of controlling broadleaved and grassy weeds in cole crops. If time and methods of application are carefully selected so that crop injury is kept to a minimum, yields will not likely be affected." (WILSON and ILNICKI, 1967)

2.2.1.8 Carrots and Onions.

Due to their slow germinating seeds, crops like carrots and onions are particularly suited to pre-emergence flame treatments, giving them a weed free start.

GEIER (1984) and MOREZ (1984) both studied the effects of flame weeding on carrots. GEIER (1984) reports: "The flame weeding itself was effective. Up to 1500 weeds per square metre were counted before treatment and destroyed. But the weed seed potential of the field was (partly due to the neglect of mechanical weed control in the previous crop) so great, that many weeds germinated after the flame weeding, thus demanding still a lot of hand weeding." This again emphasizes the need for integration of flame weeding into an integrated pest management system, similar to the findings of LILJEDAHL et al. 1964a, 1964b, and 1965.

Onion crops can be divided into two distinct groups, seedling onions (sown and left to germinate and grow) and transplanted or set onions (sown and left to germinate, then transplanted to another area).

"In Sweden flaming can compete economically with chemical control in set onions since there are no approved herbicides for use post-emergence of the crop...... Short-term effects of flame weeding can be compensated by repeated treatments. The first flaming need not be done until the onions are around 50 mm high.

Set onions then rapidly grow past their susceptible stage and can be treated selectively again after they have reached a height of 150 mm. In hand-planted set onions it was possible to do three flamings without yield reduction." (ASCARD, 1988a)

A similar result was found by BOWSER (1963), however he also concluded that cross flaming applies more heat than parallel flaming and would not recommend cross flaming for use in set onions.

To overcome this problem ASCARD (1988a) practised cross flaming but installed burner screens of ceramic fibre to shield the top part of the onions, while only the soil below and the bottom of the onion stem were exposed to the flame. Good weed control was achieved and no negative influence on yield was noted.

In seeded onions, flame weeding is practised both pre- and post-emergence. Although claims of pre-emergence flaming halving the labour requirement in comparison with only inter-row hoeing by ASCARD (1988a), care must be taken to ensure the onions have not yet germinated.

While VESTER (1986 and 1987), ASCARD (1988a) and DE ROOY (1989) noted that flaming done one day after emergence wilted the onion tips partly but did not inhibit their further development, CASTILLE and GHESQUIERE (1983) found that in seeded onions flaming at the crook and whip stage killed the onions.

The reason they stated: "Young seeded onions are extremely sensitive to heat, and thus, heat destroys as well weeds or onions."

CASTILLE and GHESQUIERE (1983), VESTER (1986) and ASCARD (1988a) all agree that post-emergence flaming of seeded onions should be left until the crop is relatively more heat tolerant than weeds. According to ASCARD (1988a) this occurs when the onions are around 50 mm and then again after a height of 150 mm.

2.2.1.9 Potatoes.

Although some flaming for weed control has been practised in potatoes (BOWSER, 1963; VESTER, 1986; and ANDERSON et al., 1967) it is more commonly used as a method for killing the potato haulm before harvest.

"In order to prevent spread of virus in seed potatoes the authorities in Holland and Denmark have stated a 'last date' when the haulm must be withered. With thermal haulm-killing the potatoes can grow a week longer than with chemical haulm-killing, which may be of great importance for the yield." (ASCARD, 1988b)

LUMKES (1989) also mentions this 'last date' in his report. VAN 'T ROOD (1987) claims that the flames also kill fungal spores of, for example, Phytopthora infestants which causes late blight.

VESTER (1986), ASCARD (1988b) and LUMKES (1989) all agree that thermal haulm-killing can be physically achieved but that costs are very high, up to twice as expensive as chemical haulm-killing in The Netherlands according to ASCARD (1988b).

2.2.2 Effects of flame weeding on weeds.

Literature on heat injury to plants is not very extensive. Most work involving flame cultivation results in a 'percentage killed' indicator, to show the effectiveness of the flame treatments.

Early flame weeding reports only went as far as to say that, "intensive application of heat is not advisable, since frequent scorching is a more effective method of control." (BARR, 1947)

During the 1960's, scientists started to investigate the effect flaming had on plants and plant cells.

Papers, not specifically written with regard to flame weeding, look at how air temperature fluctuations affect plants.

MELLOR (1963) reports that leaves can be thought of as purely physical bodies, they will approximate fairly well Newton's law of cooling (which in its exact form holds only for dry bodies) in response to normal environmental temperature fluctuations.

WOLPERT (1961) also applies heat transfer theories to plant leaves exposed to the sun at midday hours, and studies the effect of leaf hairs on heat transfer to the leaves.

MELLOR, SALISBURY, and RASCHKE (1963) goes on to mention that "physiological adaptations became apparent only at high radiation intensities and at high wind velocities."

Further studies by ALEXANDROV (1964), DANIELL, CHAPPELL, and COUCH (1969), and ELLWANGER, BINGHAM, and CHAPPELL (1972a), and ELLWANGER, BINGHAM, CHAPPELL, and TOLIN (1972b) describe these physiological and cytological effects of high temperatures on plant cells.

All agree that cellular dehydration occurs very soon after flaming, within one minute according to Ellwanger et al. (1972a). Dehydration is thought to occur as a result of cell membrane failure.

"Cellular death resulting from plant exposure to flame-generated ultra-high temperatures was primarily due to the initial thermal disruption of cellular membranes rapidly followed by dehydration of the affected tissue."
(ELLWANGER et al,1972b)

A more detailed analysis of cell death due to exposure to high temperatures is given by ALEXANDROV (1964), and DANIELL et al. (1969). Suppression of protoplasmic streaming, bleached chloroplasts, plasmolysis, and changes in membrane permeability of the tonoplast, chloroplast, and nucleus causes cell dehydration and death.

According to ALEXANDROV (1964), the thermostability of plant cells is determined by (a) the resistance of protoplasmic proteins to the denaturing action of heat; (b) the reparatory capacity of the cell; and (c) the capacity of the cells to increase their resistance as a response to the injurious action of heat,ie., heat hardiness.

Recent papers by VESTER (1984 and 1986) refer to this work by Alexandrov and Daniell et al.

Apart from destroying growing weeds it is also possible to destroy weed seeds.

An experiment by FENWICK and LIEN (1968) looks at the effect of flaming on weed seeds exposed to flaming. They concluded that flaming exposed weed seeds on the surface of the soil can result in a reduced germination percentage.

However a 'light' flaming can give an increased germination rate by breaking the dormancy of the seeds.

2.2.3 Effect of flame weeding on insects.

Although not very common, flame weeding has been used to control insects in crops.

One example is the control of the Egyptian Alfalfa Weevil in Alfalfa lucerne crops. NORRIS (1973) noticed a larval population reduction of the weevil from between 40 to 90 %.

Economic levels of control were only achieved when the lucerne crown was exposed to between 32-43^0 Celsius for at least 5 seconds.

PITRE, HURT, and BRISCOE (1970) also used flaming to control the Alfalfa Weevil.

According to VESTER (1986) the flame used in insect control is very strong, and cannot be directly compared with flame weeding of weeds.

Flaming has also been used to control micro-organisms such as fungi, like Phytophtora (VAN 'T ROOD, 1987), and Alternaria solani (LAHMAN, HARRISON, and WORKMAN, 1981).

2.2.4 Integration of flame weeding into pest management systems.

The most important point concerning flame weeding is that this practise must be integrated into a total pest management system. Flame weeding cannot be used as an isolated method to control weeds, but should be carefully planned to fit in with other weed control methods to ensure maximum efficiency.

PARISH (1987) describes a number of weed control methods, one of which is flame weeding. He emphasizes that these methods should be combined, using each one as appropriate , considering such things as timing of application and what crop is being grown.

As an example LILJEDAHL et al.(1964a and 1964b) used a rotary hoe to control weeds in corn up to 100 mm height, a time when flame weeding can destroy the corn due to its low heat tolerance. The rotary hoeing controlled the weeds while at the same time levelled the soil around the corn, which in turn aided the flame weeding that followed.

2.2.5 Economics of using flame weeding.

The economics of using flame weeding will in the majority of cases determine whether the practise is going to be used by any grower. In an organic enterprise the common choices of weed control practises usually consist of mechanical hoeing, hand hoeing, or flame weeding.

Mechanical hoeing is at present still the cheapest method of weed control for organic growers, in cases where this cannot be used growers have usually resorted to hand weeding. In situations where hand weeding requirements are great flame weeding may be a cheaper alternative, depending on the particular crop and its suitability for flame weeding.

EKSTROM, LILJEDAHL, and ROBBINS (1964) states the cost of flame weeding in American dollars, it takes into account cost and consumption of tractor fuel, tractor oil, flamer fuel, labour cost, repair costs, and fixed costs (including depreciation, interest, insurance, taxes, and housing).

Papers stating the economics of flame weeding on a purely monetary basis are of little use unless they are used by growers at the time of print and in the country of origin.

Comparing the cost of flame weeding to, for example, chemical costs is another method of working out the economics of flame weeding.

HOFFMANN (1989) concludes that flame weeding is more expensive than chemical spraying when using flaming post emergence and all cost factors are included.

DE ROOY (1989) made the assumption that the fixed costs of using either a flame weeder or spraying equipment are very similar and can therefore be excluded in the comparative analysis.

Using the flame weeder as a pre-emergence weed control method in onions, he established that flaming can be used at a cost comparable to that of using a pre-emergence spray like Diquat.

Ultimately, the economics of flame weeding must be looked at by each individual grower. Only he/she can take into account such things as labour cost, labour availability, practicality of using mechanical weed control, cost of chemical control (both monetary and environmentally) and the final value of the crop (usually higher for organically grown produce).

2.2.6 Development of flame weeding equipment.

Since the introduction of LPG for farm use in 1945, most of the work done on flame weeding equipment has been involved with burner design. A detailed development history of LPG burners can be found in 2.1 History of flame weeding.

Performance of LPG burners have been measured mainly by the use of thermocouples to establish the temperature profile of the flame (THOMAS, 1964; BUTTIGLIERI, HARRIS, and MARCHELLO, 1967; and HARRIS, 1968), CARTER et al. (1960) uses photography to show the flame pattern characteristics of LPG burners.

Using both thermocouples and photography, part of this paper will concentrate on the design and construction of the Lincoln University burner.

To avoid crop damage several different types of shielding have been developed over the years. LALOR and BUCHELE (1967,1968) and LIEN (1968) describe the principles of using an air-curtain shield. An air stream provides protection to the crop by lifting the lower leaves of the crop, while also preventing heat from the flame to penetrate to the base of the crop plant.

Water shielding involves the spraying of water above the burner. Results by MATTHEWS and SMITH (1971) showed that air temperatures were greatly reduced above the water spray shield as compared to no shielding.

In order to prevent heat loss and to keep the heat at ground level as much as possible a different type of shield is used for inter-row flaming, pre-emergence flaming, and for thermal haulm-killing.

It consists of some form of insulated box into which the flame is directed. KLOOSTER (1983) and DE ROOY (1989) tested the effect of shield length on the performance of flame weeding. Both concluded that a longer shield will allow the heat to act on the weed population for an extended time and will produce a better result.

Part of this paper will include a look at the influence of shield length on temperature profiles under the shield and its effect on the temperature x time constant.

The mounting of burners and shields will not be discussed in this paper, the same mounting system will be used as in previous experiments (DE ROOY, 1989). Different mounting systems can be found in papers by PARKER and HOLSTUN (1962), and PARKER, HOLSTUN, and FULGHAM (1965).

3) PROJECT AIMS.

1) Review the history and practise of flame weeding.

2) Examine the relevance of European flame weeding practices in relation to New Zealand.

3) Investigate burner design, output characteristics and performance with the objective of identifying areas of possible improvement.

4) Design and construct an efficient burner for local manufacture.

5) Investigate the relationship between the temperature x time exposure required to kill weeds at various growth stages.

4) FLAME WEEDING: EUROPE AND NEW ZEALAND.

Flame weeding has been practised in Europe for many years. Weed control programs have been established for use by organic growers incorporating many non-chemical weed control practises, including flame weeding.

In pre-emergence flaming the emphasis is placed on providing intense heat to the crop row to kill all weeds. To achieve this the burners are usually shielded to contain the heat and provide insulation from the wind. (DE ROOY, 1989)

The author chose to use flame weeding as a pre-emergence weed control method as there is little chance of crop damage. It therefore provides New zealand growers with an opportunity to become familiar with the practise of flame weeding without the risk of major crop damage.

Post-emergence flaming is a much more critical practise in when and how it is used. It commonly uses an unshielded burner travelling either parallel or at right angles to the crop row. Importance is not placed on how much heat is applied but rather where the flame hits. Ensuring that the flame hits the base of the crop plants is very important in controlling weeds around the base of the plant while exposing the crop plant to a minimum of heat.

A flaming at the wrong time of crop development, using the wrong burner settings, or travelling at the wrong speed can easily result in large scale crop damage, not a good start when trying to introduce flame weeding to New Zealand growers.

Most European research is now focusing on post-emergence flame weeding as pre-emergence flame weeding is considered to be mastered in Europe. (HOFFMANN, 1990)

Post-emergence flame weeding can be introduced once New Zealand growers have become familiar with the process of weed control using flame.

This report will only concern itself with pre-emergence flame cultivation.

5) EFFICIENCY OF THE FLAME WEEDER.

In order to increase the efficiency of flame cultivators it is necessary to consider the main factors affecting efficiency. KLOOSTER (1983) and DE ROOY (1989) both reported that the cost of LPG is not a very significant factor in the total operating costs of a flame cultivator.

Even so, a burner design which uses less gas while producing the same or a higher amount of heat, can be regarded as a more fuel efficient burner. It may, however, not be a very desirable burner for flame weeding purposes.

To ensure an even weed kill underneath a shield, temperatures along the width of the shield must be relatively constant. To achieve this a burner must have a flame temperature profile which is relatively square. This means that at any distance from the burner the temperature must be constant along the entire width of the flame. Weeds flamed at the edges of the shield will then be exposed to the same heat as weeds in the centre of the shield, resulting in a more even weed kill.

Using flame temperature profiles this report will focus on the design and construction of a more fuel efficient burner with a more desirable flame temperature profile than the burners currently used in the Lincoln University flame cultivator, the Hoffmann/Reinert burners (Reinert is the German company manufacturing the Hoffmann burners).

Tractor operating costs and labour costs contribute most to the overall operating costs of flame cultivation (KLOOSTER, 1983 and DE ROOY, 1989). These problems can be tackled by increasing the working width of the flame cultivator, a task which can be done quite easily.

A problem much harder to solve is to ensure that the operator travels at the optimum speed, taking into consideration the number and size of the weed population, soil conditions and atmospheric conditions, while ensuring a satisfactory level of weed control.

Through the combination of field trials and laboratory work this report will establish temperature x time constants for particular weed sizes, which, when combined with shield temperature profiles for a grower's particular flame cultivator set-up, allows optimum travel speed while achieving 100% weed control.

6) BURNER DESIGN AND EFFICIENCY.

6.1 Introduction.

To increase the efficiency of a LPG burner, first the principles of how such a burner operates must be known.

Liquified Petroleum Gas is fed into the burner head at a certain gas pressure, from here the gas is forced out through a row of nozzles along the length of the burner head. The gas stream that follows draws in primary air between the burner head and the burner shield. The gas and the air are mixed, and more secondary air is mixed in as the gas stream leaves the confines of the burner shield. Once this gas stream is ignited a stable and uniform flame will form (see Figure 1).

To achieve maximum fuel efficiency during combustion all of the fuel used must be completely combusted. Any fuel not burned is lost without gaining any useable energy from it.

Complete combustion is achieved by supplying the burner with an excess quantity of air above that theoretically needed to burn the fuel completely. (WALSHAW, 1963)

Incomplete combustion occurs when the available air supply is insufficient or because of inadequate mixing. (WALSHAW, 1963)

Figure 1: Primary and secondary air entrainment, into a typical LPG burner.

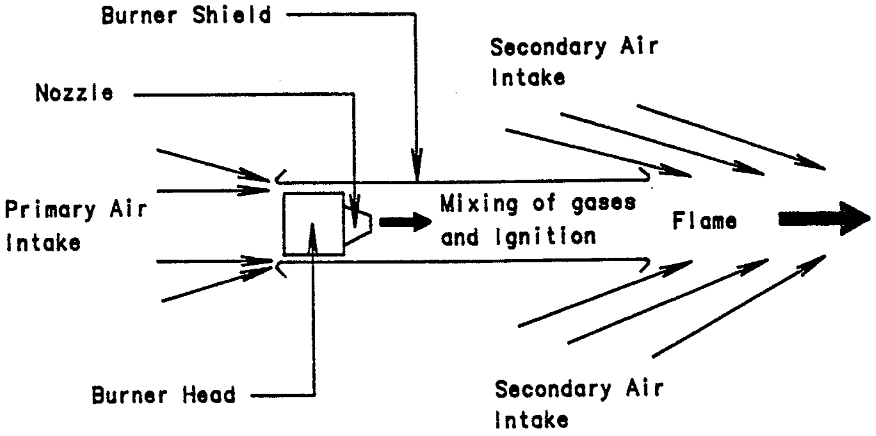
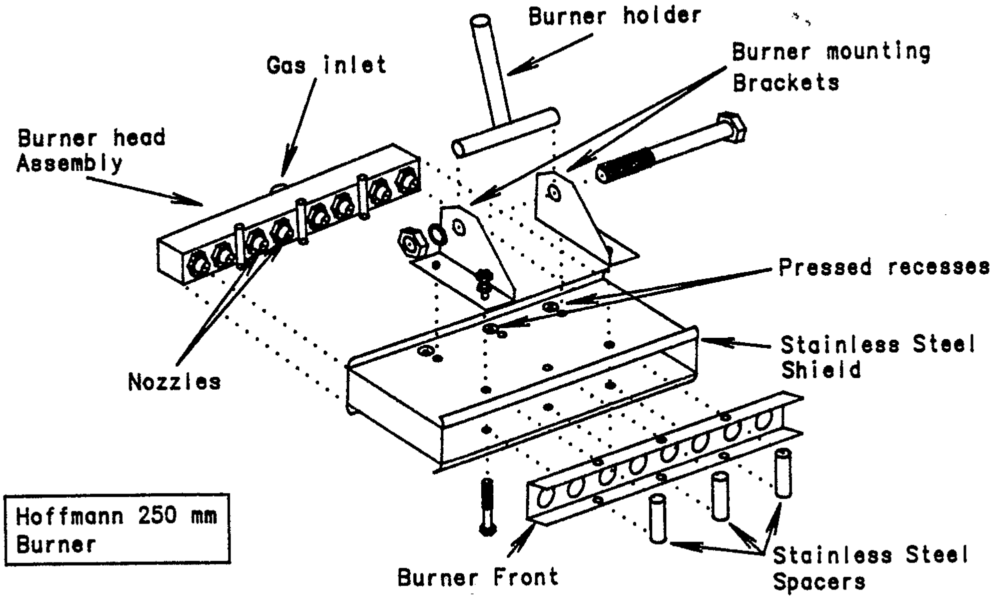


Figure 2: Hoffmann burner design.



Perfect combustion occurs when a stoichiometric mixture burns completely- an air/fuel ratio being stoichiometric when air contains just sufficient oxygen to burn the fuel completely. (WALSHAW, 1963)

Therefore in any burner design an attempt must be made to ensure adequate air entrainment occurs, to enable all of the fuel to be burned completely.

6.2 Materials and Methods.

To establish whether the Hoffmann burner (see Figure 2) entrains enough air for complete combustion, first its rate of fuel consumption had to be determined.

To measure this the Hoffmann burner was run at 2 Bar gas pressure for 30 minutes in a controlled environment, no wind, air temperature at 15^0 Celsius and atmospheric pressure (101.325 kPa).

By weighing the LPG bottle supplying the burner before and after the test the fuel consumption of the Hoffmann burner was established. For results see Table 1, section 6.4.

Once the gas consumption was known for the Hoffmann burner, the quantity of air needed to achieve the theoretical ratio of fuel/air could be calculated.

1 Kg of LPG = 460.59 Litres of LPG vapour (*)

Hoffmann burner uses 4.30 Kg of LPG/Hour

4.30 Kg of LPG/Hour = 1980.54 litres of LPG vapour/Hour

Stoichiometric ratio of LPG =

volume of air/volume of fuel = 26.4 (*)

Therefore volume of air required =

1980.54 Litres/Hour * 26.4 = 52286.26 Litres of air/Hour

At atmospheric pressure (101.325 kPa) and 15^0 Celsius

1 Litre of air = 0.001 M^3 of air

Therefore the Hoffmann burner requires

52286.26 Litres of air/Hour * 0.001 M^3 of air/1 Litre of air

= 52.29 M^3 of air/Hour minimum for combustion at the stoichiometric ratio.

(*) Note: Figures used above are from "Technical Data on Fuel" J.W. ROSE and J.R. COOPER (1977)

To establish whether the Hoffman burner entrains this quantity of air to achieve the theoretical air/fuel ratio, apparatus was set up as shown in Figure 3.

Figure 3: Apparatus to measure the total volume of air drawn into the burner.

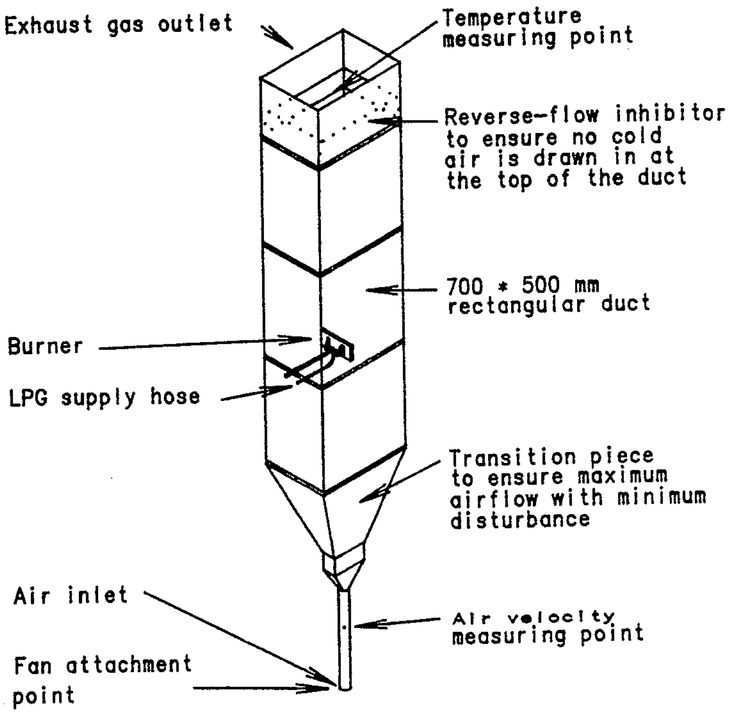
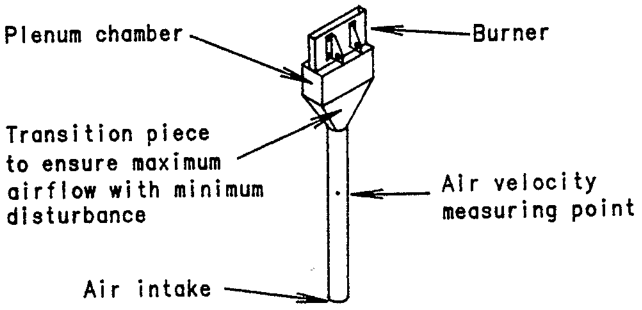


Figure 4: Apparatus to measure the volume of primary air drawn into the burner.



The apparatus allowed the measurement of entrainment of primary air, that is the air entrained between the burner head and the burner shield to allow mixing of the gases within the burner shield. A hot-wire anemometer was used to establish the average air velocity through the inlet tube, multiplying this by the intake area of the tube, the quantity of primary air drawn in could be calculated.

The total air entrained into the gas stream, primary and secondary, was measured using the apparatus shown in Figure 4.

As the results show, see Table 1, section 6.4, the Hoffmann burner does not entrain enough air in total to satisfy the theoretical air/fuel ratio.

To overcome this problem, it was decided to design a new burner, one which entrains more air, to bridge the gap between the volume of air required for the theoretical air/fuel ratio and the actual volume of air entrained.

6.3 Lincoln Burner Design.

After establishing that the air entrainment between the square burner head and the burner shield, (see Figure 5), on Hoffmann's burner is not very effective, thought was put into designing a better air entrainment system.

The system finally settled on involved replacing the square burner head with a round one, in an attempt to achieve a better air flow into the primary air entrainment gap. (see Figure 6).

Figure 5: Diagrammatic view of the primary airflow into the Hoffmann burner.

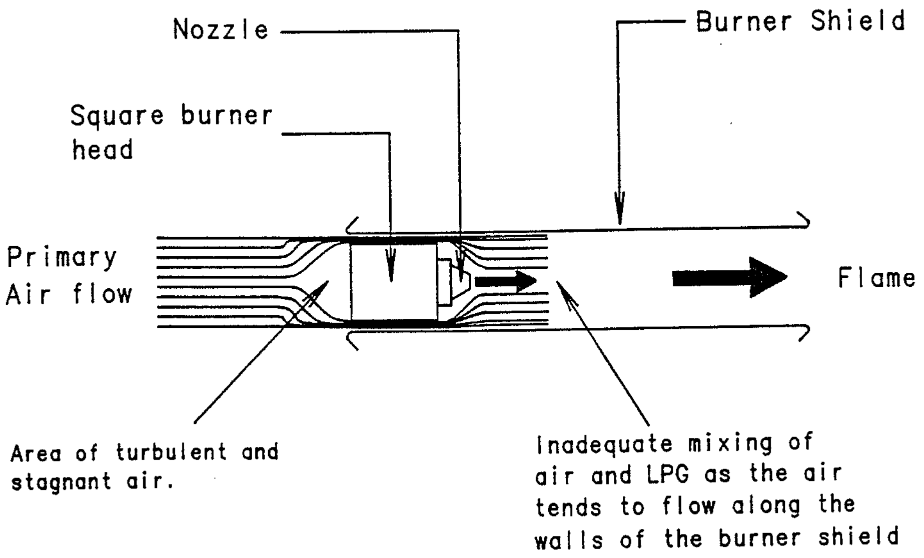
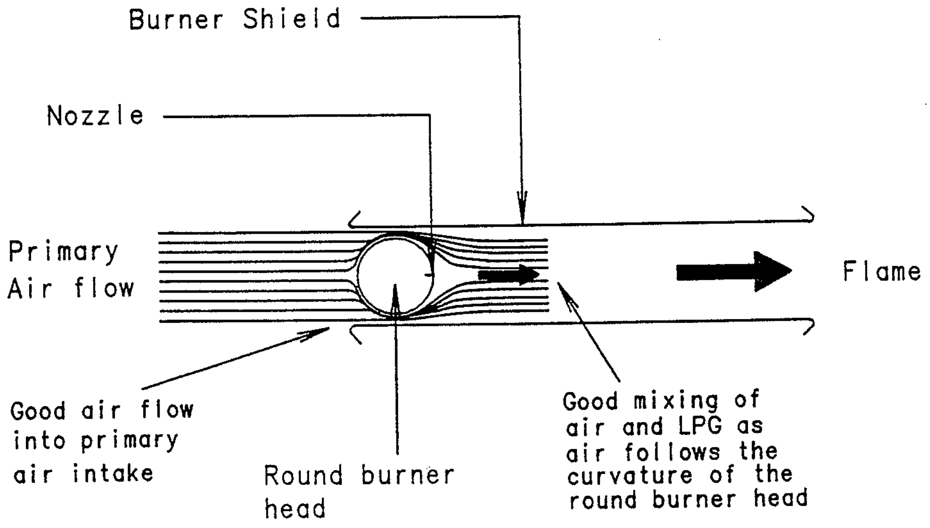


Figure 6: Diagrammatic view of the primary airflow into the Lincoln University burner.



Using the same burner shield as the Hoffmann burner, which still provided a 1.5 mm high primary air entrainment gap between the burner head and the burner shield as in the Hoffmann burner, the Lincoln University burner was tested. (see Figure 7).

However, the burner suffered severely from "blow off", a condition which arises when the gas mixture velocity exceeds the burning velocity of the flame. The velocity, relative to the unburned gas, at which a one-dimensional adiabatic flame propagates normal to itself through a homogenous gas mixture (ROSE and COOPER, 1977), causing the flame to "blow off" and extinguish itself.

Due to an apparent increase in primary air flow through the 1.5 mm high gap, the resultant increased velocity of the air has increased the total mixed gas velocity beyond the point where a stable flame can be maintained.

Literature concerned with flames and burners (BEER and CHIGIER, 1972; and GAYDON and WOLFHARD, 1960) was consulted to find a solution to the "blow off" problem.

To lower the gas velocity a number of "bluff bodies", objects placed in the gas flow to decrease the velocity of the gas (see Figure 8), were tested inside the burner shield. (see Figure 9).

Figure 7: Lincoln University burner.

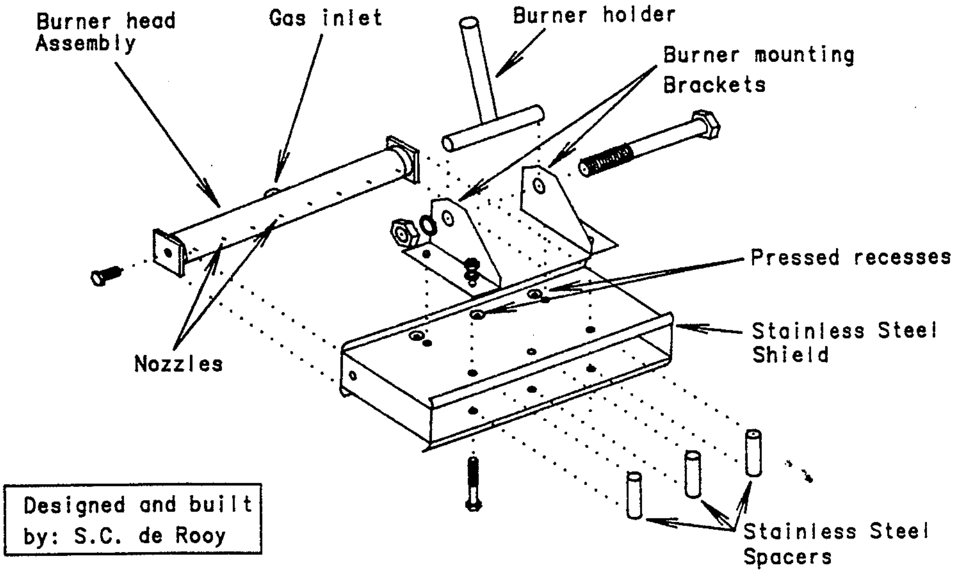


Figure 8: Bluff bodies tested.

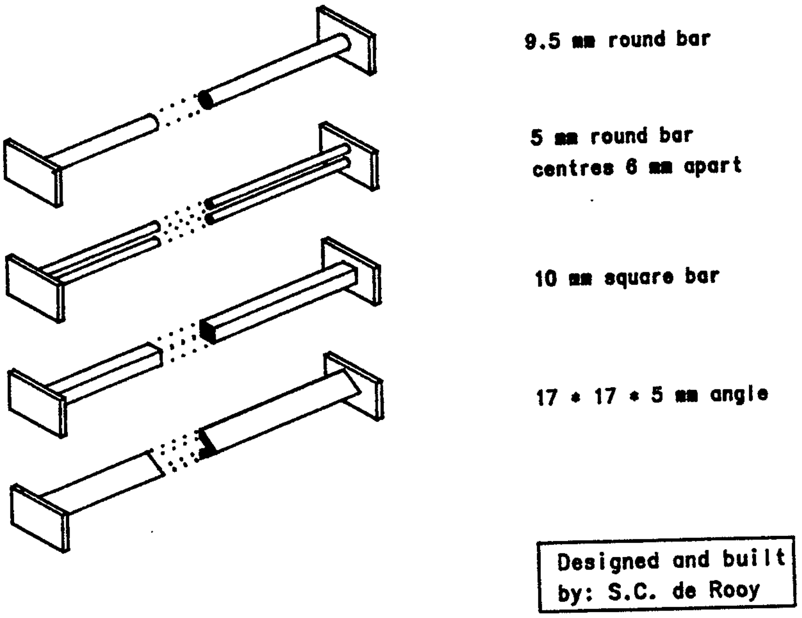
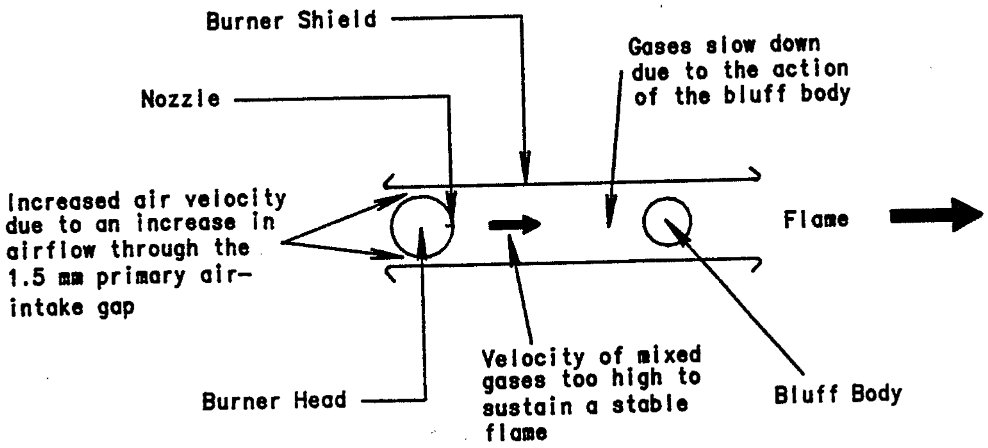


Figure 9: Position of bluff bodies inside burner shield.



All of the bluff bodies tested, resulted in a flame of some sort. However visual analysis established that the flames were very unstable and not very uniform; large, yellow flickering tips were observed at the end of the flame. A different approach was needed to decrease the gas velocity.

As more air was now apparently entering the 1.5 mm high gap, it was decided to experiment with the gap height, in order to decrease the gas velocity. Visual analysis established that a 3.5 mm gap gave the most stable and flame.

Even though at this stage a very stable flame was formed, the flame did not appear to be as uniform in its profile as the Hoffmann burner and to check this, temperature profiles were taken from both burners running at 2 Bar gas pressure.

A type R thermocouple, (Platinum/13 % Rhodium versus Platinum), was inserted into the flame using a 20 * 20 mm grid pattern covering the right half of each burner, (it is assumed that the burners are symmetric in their flame temperature profiles), data was recorded on a CR7X data logger. Similar methods for establishing flame temperature profiles were used by THOMAS (1964) and BUTTIGLIERI, HARRIS, and MARCHELLO (1967). For the results see Figures 11 and 12 in section 6.4.

The results clearly show that the Lincoln University burner did not have a very even temperature profile and something needed to be done to cure this problem.

To increase the uniformity of the flame a burner front similar to the one used in the Hoffmann burner was constructed and fitted to the Lincoln University burner.

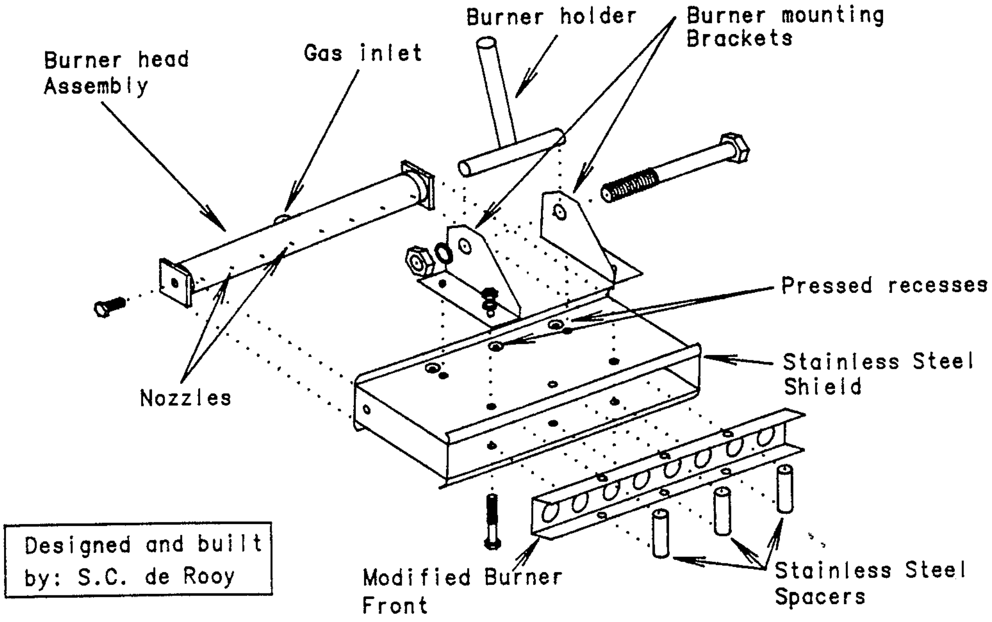
The aim of the burner front is to even out the flow of gases and therefore produce a more uniform flame temperature profile. The resultant burner was given the name, Modified Lincoln University burner. (see Figure 10).

Using the same techniques as used with the Hoffmann burner, the Modified Lincoln University burner was then tested to find out its flame temperature profile (see Figure 13, section 6.4), rate of fuel consumption , theoretical air requirement, and its primary and secondary air intake. The results are shown in Table 1, section 6.4.

To compare the heat outputs of both burners, the average gas exit temperatures at the top of the total air entrainment apparatus (Figure 4) were measured using a type R thermocouple and a CR7X data logger. As the air entrainment per hour and the gas consumption rates for both burners were known, comparative heat output results could be calculated as a % increase in heat output, as a function of average gas exit temperature (^{0}C) per volume of air heated (M^3).

However due to unknown heat losses from the walls of the apparatus, no direct comparisons could be made in terms of overall efficiency, as the heat losses through the walls could be markedly different due to the difference in air flow through the system according to the burner used.

Figure 10: Modified Lincoln University burner.



To compensate for this, both burners were run again in the apparatus, this time ensuring that the conditions for both burners were the same. Excess air for the theoretical air/fuel ratio of both burners was supplied by a fan, providing an air flow of 63.5 M^3/Hour, attached to the intake side of the system.

As both burners were now heating the same quantity of air, at the same initial temperature of 15^0 Celsius, flowing through the system at the same rate of 63.5 M^3/Hr, and because the total wall area, through which the heat losses occur, remained the same, the difference in average gas exit temperatures out of the system could be directly related to the differences in the heat outputs between both burners.

The comparative heat output results of both burners can be found in section 6.4 as a % increase in heat output, as a function of average gas exit temperatures (^{0}C). Furthermore the heat output of both burners could be related back to the amount of LPG used per hour, to produce a % increase in heat output, as a function of average gas exit temperature (^{0}C) per quantity of gas used (Kg). These results are also shown in Table 1, section 6.4.

6.4 Results.

TABLE 1 : Burner test results.

	HOFFMANN BURNER	MODIFIED LINCOLN UNIVERSITY BURNER
Fuel consumption at 2 Bar gas Pressure (Kg/Hr)	4.30	3.50
Theoretical air/fuel ratio. Volume of air/volume of fuel.	26.40	26.40
Theoretical air requirement for complete LPG combustion (M^3/Hr)	52	42
Amount of Primary air entrained (M^3/Hr)	10	22
Amount of Primary air entrained as a % of theoretical requirement	20	52
Total amount of air entrained (Primary and Secondary) (M^3/Hr)	38	42
Total amount of air entrained as a % of theoretical requirement	72.8	100.0
Comparative Heat Output (% increase in average gas exit temperature) *	–	+ 5% over the Hoffmann burner
Comparative Heat Output per Kg of LPG (% increase in avg. gas exit temp./Kg LPG used) *	–	+ 22.7% over the Hoffmann burner
Avg. flame temperature from flame temp. profile (^{0} Celsius)	524	530

* Note: These figures are based on tests in which both burners were run in the same apparatus, at a Gas Pressure of 2 Bar, and were supplied with 63.5 M^3 of air/Hr to be heated.
The Comparative Heat Output could therefore be calculated directly from the average gas exit temperatures.

Figure 11: Flame temperature profile (degrees Celsius) of the Hoffmann burner (right half) at 2 Bar gas pressure.

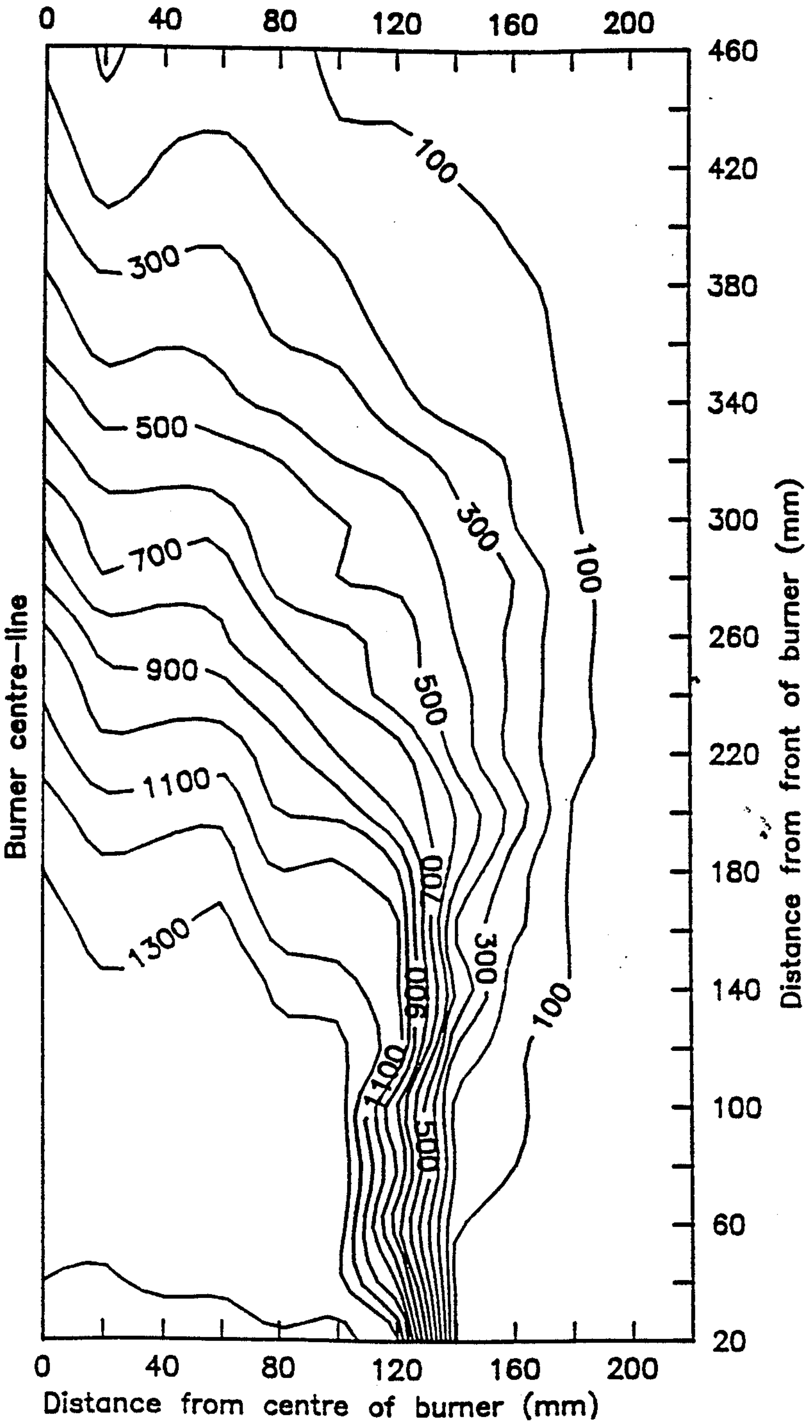


Figure 12: Flame temperature profile (degrees Celsius) of the Lincoln University burner (right half) at 2 Bar gas pressure.

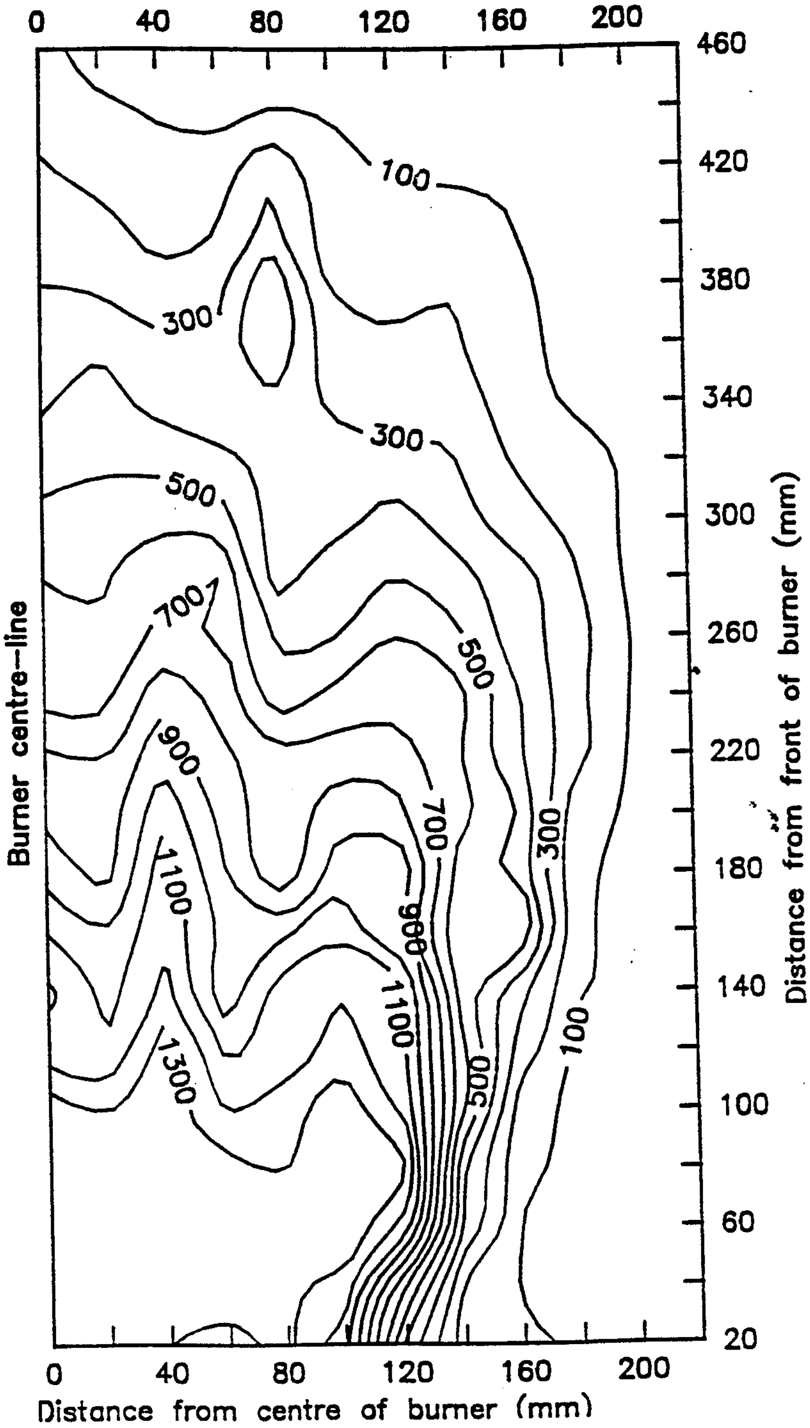


Figure 13: Flame temperature profile (degrees Celsius) of the Modified Lincoln University burner (right half) at 2 Bar gas pressure.

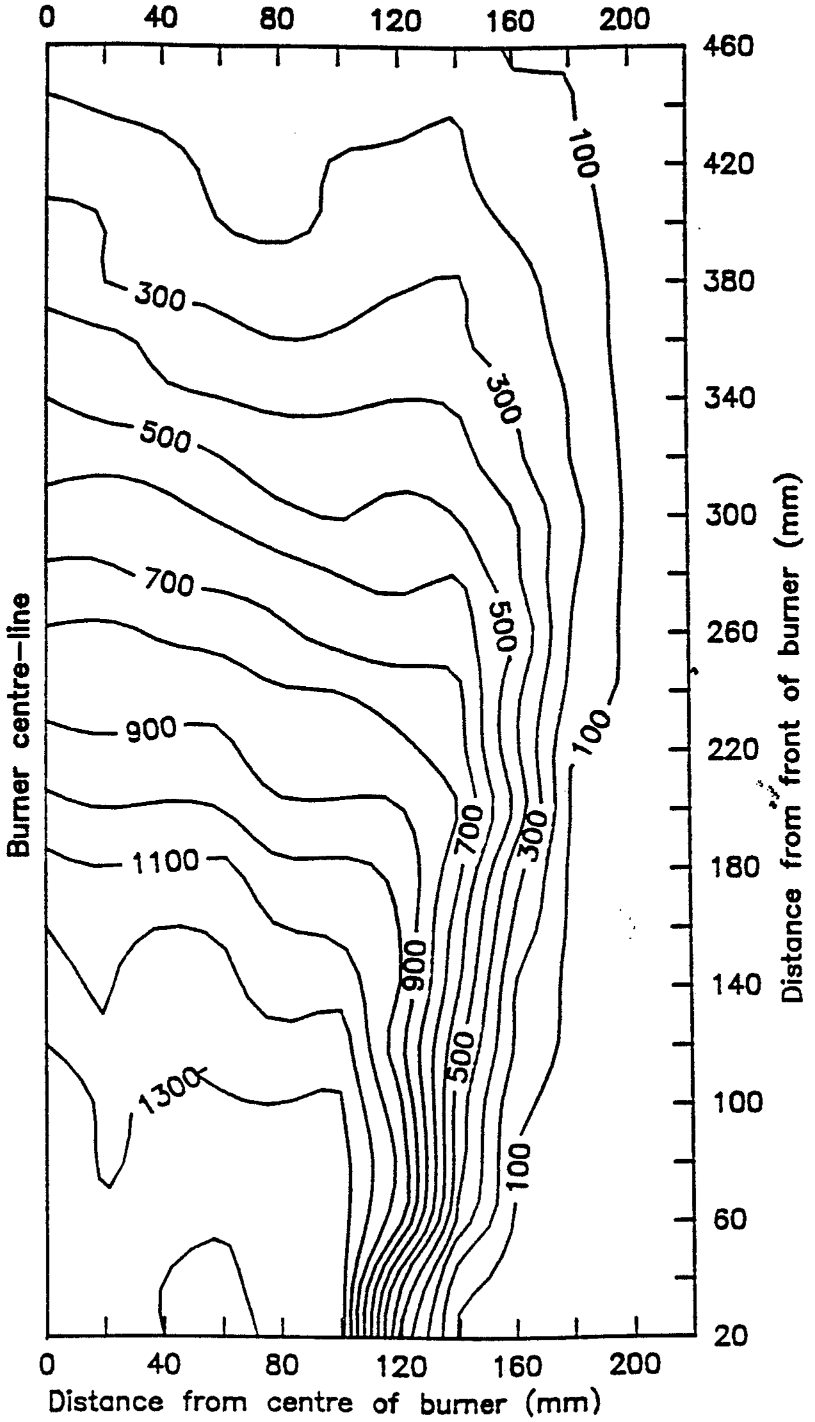


Figure 14: Photo showing the flame of the Modified Lincoln University burner.

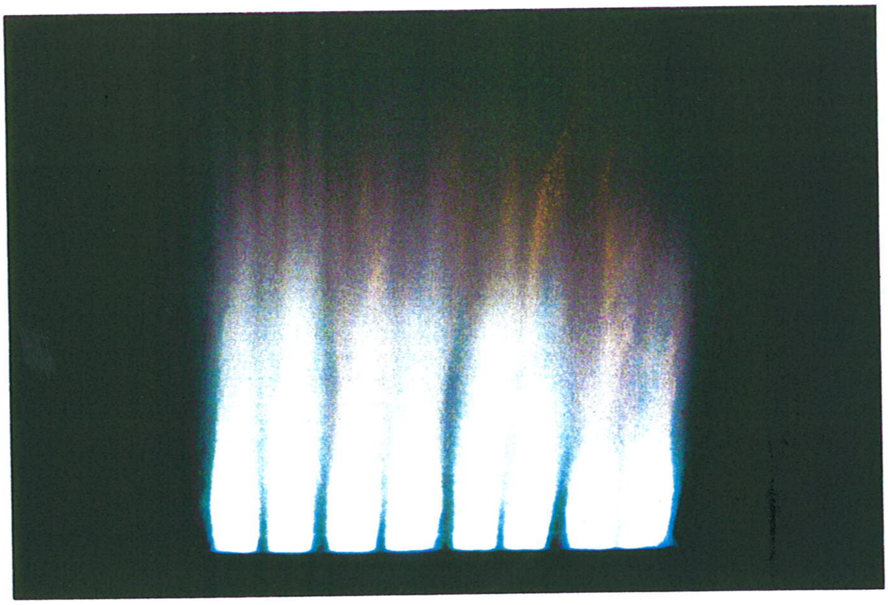


Figure 15: Photo showing the flame of the Hoffmann burner.

6.5 Discussion.

As Figure 12 shows, the Lincoln University burner without the modified burner front has a very uneven flame temperature profile. The Modified Lincoln University on the other hand, through the simple addition of a burner front to even out the gas flow, has an almost constant flame temperature at any distance from the burner along the entire width of the burner (see Figures 13 and 14).

The Modified Lincoln University burner is therefore an ideal burner in applications where precise temperature control is needed, for example post-emergence weed control. By setting the burner at the required height, an even temperature will be applied to the base of the crop plant along the entire width of the burner, ensuring an even weed kill, not distinct green bands of weeds at the sides of the treated area due to a drop in temperature along the sides of the burner.

Although the flame of the Hoffmann burner appears very even and stable (see Figure 15) the Hoffmann burner's flame temperature profile shows a drop in temperature along the burner's edges (see Figure 11). It therefore concentrates its heat more to the centre of the burner while at the edges of the flame the temperatures are much lower. An uneven weed kill along the width of the burner can therefore result, if weeds exposed to the flame's edges do not receive enough heat to damage the cells of the weed.

A burner with a relatively even temperature profile, like the Modified Lincoln University burner is therefore a more likely burner to produce an even weed kill during flame weeding.

Looking at the theoretical air requirement of the Hoffmann burner and the amount of air actually entrained into the burner (see Table 1), it is clearly shown that this is the point where the Hoffmann burner looses a lot of its potential heat output. By not entraining enough air for complete combustion of the LPG it uses, the Hoffmann burner effectively wastes any LPG not combusted.

The efficiency of the Hoffmann burner is therefore by theory lower than that of the Modified Lincoln University burner, which entrains more air into the burner than the Hoffmann, and due to its lower LPG consumption, draws in enough air to theoretically combust all of the LPG used (see Table 1).

In practise however, for the Modified Lincoln University burner to completely burn all of the LPG, the air must be mixed perfectly and completely with the LPG. Although the flame temperature profile of the Modified Lincoln University burner suggests that good mixing of the air and the gas takes place, due to the even temperatures achieved, the author doubts that all of the LPG used is completely combusted.

Any further studies may involve a closer look at the actual mixing and combustion of the air and fuel and may involve exhaust gas analysis to determine whether all of the LPG is combusted. At present however, this lies outside the scope of this thesis.

To compare the heat outputs between the Hoffmann and the Modified Lincoln University burners, both burners were supplied with 63.5 M^3 of air/Hr, the Hoffmann burner was heating up only 11.21 M^3 of air/Hr surplus to its requirement, compared to the Modified Lincoln University which had to heat up an extra 20.94 M^3 of air/Hr above its theoretical requirement.

Even with these conditions the Modified Lincoln University achieved a 5% higher heat output compared to the Hoffmann burner. As the Modified Lincoln University burner uses 18.6 % less gas to achieve this higher heat output, when the heat outputs between the two burners are compared on a per Kg of LPG used, we see that the Modified Lincoln University burner has an even greater advantage over the Hoffmann burner of 22.7% (see Table 1).

The results clearly show that the increased air entrainment, and a possible better mixing of the air and fuel, of the Modified Lincoln University burner, has resulted in a burner with a higher average flame temperature, a more even flame temperature profile, and a higher comparative heat output per Kg of LPG used as compared to the Hoffmann burner.

7) SHIELD DESIGN.

Previous studies (DE ROOY, 1989), concluded that a longer shield results in better weed control due to an increase in exposure time. This thesis will use shields of 800, 1000, and 1200 mm in length, and compares their effectiveness, by establishing the % of weeds killed using each shield, and by determining the temperature profile underneath the shields.

Shield designs used are of the same type used in previous experiments (DE ROOY, 1989), being an insulated, double skinned shield. The shields are open at the front, where the burner is attached, and have a trap door at the rear to prevent excess heat loss while still allowing rocks and other debris to pass through unhindered. At the top of the trap door is an air gap to allow burned gases to flow through freely. (see Figure 16 for the shield design).

For experimental purposes the shields are 300 mm wide and have one 250 mm burner attached to the front at a 45^0 angle in relation to the ground. This allows three shields to be carried on the flame weeder for experimental purposes. Shield height is 150 mm, mainly to keep the heat as close to the soil surface as possible, while allowing plenty of room for any debris to pass through.

For commercial purposes, a full width model would be better suited to allow complete coverage of the planted area, while decreasing the amount of soil disturbance created by the skids of the present flame weeder set up.

Some European flame weeders have a stainless steel mesh attached on the inside of the shield, to reflect the heat to the soil and hereby increasing the efficiency of the flame weeder (NUYTEN, 1990).

It was decided for the purpose of this trial, use would be made of the shields already available, and therefore the effectiveness of the stainless steel mesh cannot be commented on in this thesis.

Figure 16: Lincoln University experimental shield.

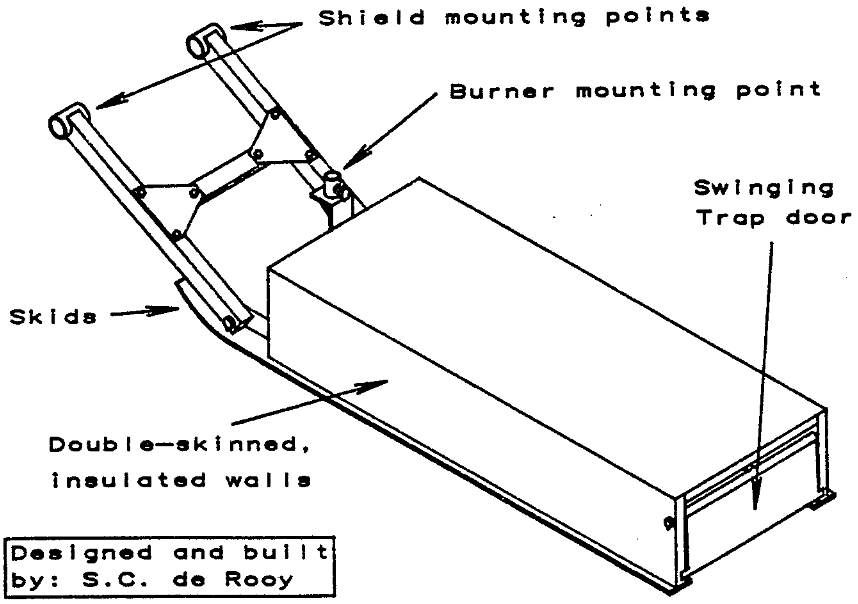
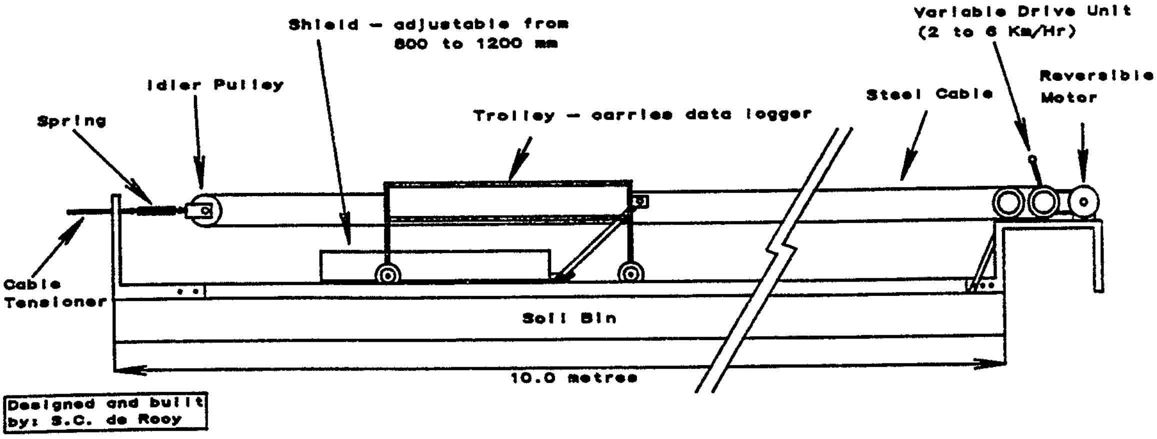


Figure 17: Laboratory trial apparatus.



8) TEMPERATURE X TIME EXPOSURE CONSTANTS REQUIRED FOR WEED CONTROL.

8.1 Introduction.

The principle aim of this part of the thesis is to establish some guidelines as to the temperature x time exposure required to kill weeds. (ie. what temperature does a weed need to be exposed to and for how long, to ensure that the weed is killed.) THOMAS (1964) mentions the need for the knowledge of, " the energy required to disrupt the functions of certain metabolizing cells of plants resulting in a plant kill, expressed as a time-temperature exposure factor", his paper however, does not establish any such factor. Following an extensive literature search, no other papers studying or providing information on temperature x time exposure for weed kill were found.

It is hoped that if temperature x time exposure constants are known, they might be able to be used to evaluate flame weeders, and for the calculation of the maximum travel speed a flame weeder can be used at, while still maintaining a 100% weed kill.

Establishing the temperature x time exposure constants, which result in a 100% weed kill, involves two basic steps. Firstly, several different combinations of travel speeds and shield lengths have to be trialled on weeds. The combinations that result in a 100% weed kill, have to then be identified for further investigation. Secondly, the average temperature underneath the shield, and the time of exposure, of the combinations that resulted in a 100% weed kill, have to be established. By combining these temperature x time exposures, an average temperature x time exposure constant, required to give a 100% weed kill can then be calculated for each weed size trialled. The trial will use three weed sizes, three shield lengths, two burners, and six travel speeds as variables in establishing temperature x time exposure constants for three weed sizes.

8.2 Materials and Methods.

To establish temperature x time exposure constants required to kill weeds, a trial was set up to investigate several different exposure time and temperature combinations, resulting in a 100% weed kill for three different weed sizes. The trial consists of two main parts: 1) Field trial, and 2) Laboratory trial.

8.2.1 Field trial.

The trial was conducted at the Horticultural Unit at Lincoln University, Canterbury, New Zealand. It consisted of a cultivated area on which young weed seedlings had started to emerge. Due to the size of the area, 60 x 100 metres, a diversity of weed species and sizes were available for the trial.

This enabled three different weed sizes to be used as variables, to establish the difference in temperature x time exposure constants needed for smaller as compared to larger weeds.

The three different weed sizes were as follows:

- 0 to 15 mm in length
- 15 to 30 mm in length
- 30 to 45 mm in length

Note: length is used in preference to height as some weeds grow along the surface of the soil rather than straight up, the length is measured as the length of the main stem, whether along the ground or straight up.

Four weed species were present in the trial plot, and although they are identified, the results will not distinguish between the different species.

The weeds present were:

- Twincress	(*Coronopus didymus*)
- Dandelion	(*Taraxacum officinali*)
- Scarlett Pimpernel	(*Anargallis avensis*)
- Scrambling Speedwell	(*Veronica Persica*)

Sampling grids (100 x 100 mm) were placed randomly within the trial area. Each grid was identified and the number and size of weeds present were identified. These grids were then subjected to their treatments, which consisted of three variables.

2 burners

- Hoffmann burner
- Modified Lincoln University burner

3 shield lengths - 800 mm
- 1000 mm
- 1200 mm

and 6 travel speeds - 2 Km/hr
- 3 Km/hr
- 4 Km/hr
- 5 Km/hr
- 6 Km/hr
- 7 Km/hr

As the aim of the trial was to find the minimum temperature x time exposure combinations required to give a 100% weed kill, the treatments which gave a 100% weed kill at the highest travel speed possible, needed to be identified.

Therefore, through experience, some of the lower travel speeds were not trialled with the smaller weed sizes and the longer shields, as it was known that the higher travel speeds would still result in a 100% weed kill.

Each one of the three weed sizes were exposed to a total of 2 burners x 3 shield lengths x 4 travel speeds. This resulted in 24 different treatments being applied to each of the three weed sizes. Each treatment was replicated ten times.

Grids were treated using the Lincoln University flame weeder, which enables three different shields to be carried on the machine (DE ROOY, 1989), mounted behind a tractor. Travel speeds were monitored using a radar mounted on the tractor, and the gas pressure was set at 2 bar for all treatments. At the time of treatment the soil moisture content was 20.3% and the soil temperature was 7.3^0 Celsius. After treating the plots, they were left for three days before results were gathered.

As every grid could be identified individually, as to the number and sizes of weeds present before and after the treatments, the results could be expressed directly as a % weed kill for each weed size and treatment combination. No significant difference between the replications was found at the 5% level, using the Analysis of Variance F test. (Snedecore and Cochrane, 1982) The results of all ten replications for each treatment were therefore added together and averaged. For results see Tables 2, 3, and 4 in section 8.3.

From these results, the treatments with the highest travel speeds for each burner, shield length and weed size, resulting in a 100% weed kill were identified for further investigation (see Table 5 in section 8.3). These treatments were then repeated in the laboratory using the apparatus shown in Figure 17. The variable speed drive mechanism allowed speeds between 1.5 and 7 Km/hr to be achieved. Similar apparatus for trialling in a controlled environment was used by PARISH (1989) and BUTTIGLIERI, HARRIS, and MARCHELLO (1967).

8.2.2 Laboratory trial.

The aim of using the apparatus was to find the temperature profiles underneath the shields, using the same travel speed, shield length, and burner combination that gave 100% weed kills during the field trials.

In the first attempt to establish the temperature profiles, a type R thermocouple, connected to a CR7X data logger, was placed in the soil bin with the measuring junction 5 mm above the soil level and precisely along the centre-line of the shield when the shield was run along the tracks. The remainder of the thermocouple was placed underneath the soil level to keep its thermal mass to be heated to a minimum. It was hoped that the thermocouple would measure the temperature profile, that a weed passing underneath the shield, would be exposed to.

After one run using this set up, the temperature readings were much lower than expected and it was decided to investigate the possible reason for this. That is the inability of the thermocouple to respond fast enough.

To test the extent of the temperature measurement and time lag of the thermocouple, due to its thermal mass, the thermocouple was exposed to a 1200^0 Celsius LPG flame for 0.1 seconds. The result was a much lower temperature reading than the thermocouple was exposed to, along with a considerable delay in time (see Figure 18).

To compensate for this temperature and time delay, a small trial was set up to investigate the possibility of fitting the thermocouple with a correction equation, to provide a true indication of the temperature profile underneath the shield.

The 1200 mm shield and the Hoffmann burner were run at 5 Km/hr over the stationary thermocouple and the measured temperature profile was recorded. The same run was then repeated several times but this time the thermocouple was inserted through a series of holes, 100 mm apart, through the top of the shield. The measuring junction was again 5 mm above the soil level and along the centre-line of the shield. As the thermocouple was now run inside the shield for the entire run, the thermocouple had enough time to reach its temperature equilibrium. Only one measurement at a particular point along the length of the shield was taken per run.

These temperature measurements were then plotted on a graph, showing the measured temperature profile with the thermocouple stationary, alongside the measured temperature profile when the thermocouple was run inside the shield (see Figure 19).

Figure 18: Thermocouple Temperature Response Profile (Type R thermocouple exposed to 1200 degrees Celsius for 0.1 Seconds).

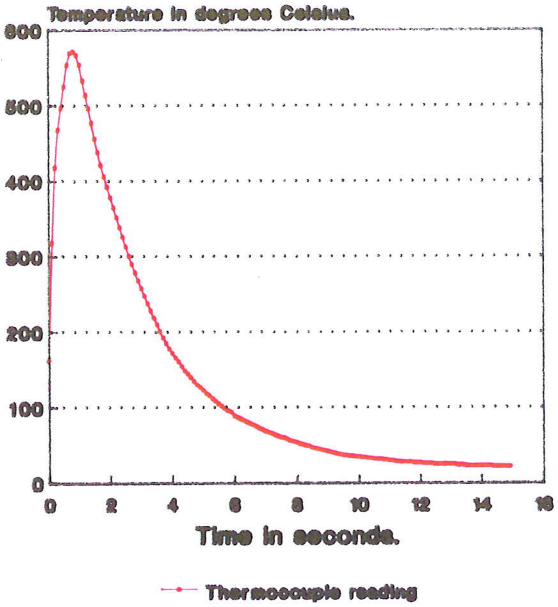
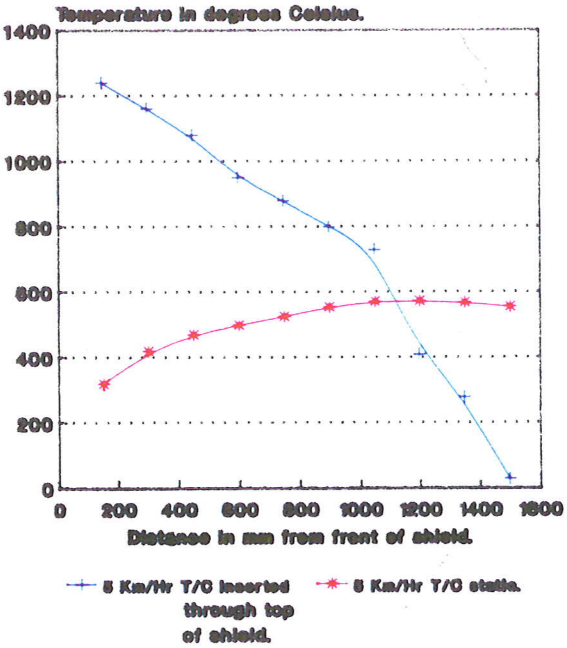


Figure 19: Temperature Profiles, 1200 mm shield, at 5 Km/hr, showing the difference between the two methods of measuring temperature



Several books and papers, BAILEY; 1931, HORNFECK; 1949, COON; 1957, LOONEY and ROCHESTER; 1957, MOFFAT; 1957, MURDOCK, FOLTZ and GREGORY; 1963, MOFFAT; 1968, ASTM Special Technical Publication 470b; 1981, and McGEE; 1988, concerned with thermocouple lag corrections, were consulted in an attempt to establish a correction equation to compensate for the response lag of the thermocouple.

After spending a considerable period of time applying all of the different correction methods, a decision was made not to pursue this avenue any further, as no correction method came even remotely close to the actual temperature profile.

Unlike similar procedures carried out by PARISH (1989) and BUTTIGLIERI, HARRIS, and MARCHELLO (1967), the temperature measurements achieved with the stationary thermocouple did not fulfil the requirements for this thesis. There is some doubt that the maximum temperature measured by Parish, of 350^0 Celsius, is in fact the actual temperature the plant is exposed to, as even a simple LPG burner should achieve flame temperatures well above 350^0 Celsius.

In order to utilize the equipment available, a decision was made to measure the temperature profiles underneath the shield using the more time consuming, but more accurate method of inserting the thermocouple through the top of the shield at 100 mm intervals. The measured temperature profiles can be seen in section 8.3, Figures 20 to 31.

From these temperature profiles, the average temperatures underneath the shields could be derived. These in turn, combined with the exposure time, a simple function of shield length and speed of travel, were used to calculate the temperature x time exposures for each treatment.

Each weed size now had six different temperature x time combinations resulting in a 100% weed kill. Some variation between the temperature x time exposures was present, due to the large intervals between travel speeds trialled. However only three from the eighteen temperature x time exposures, varied greater than 10% from the average temperature x time exposure for each weed size. A more extensive travel speed variation, with intervals as low as .25 Km/hr, would result in a reduced variation between the temperature x time exposures giving a 100% weed kill.

However as this thesis aims to give an insight into the typical temperature x time exposures needed for three weed sizes and to provide a sound method of establishing these, the average of the temperature x time exposures, which result in a 100% weed kill, and the methods by which these are established, can be used as general guidelines in further research of flame weeders.

Therefore the temperature x time exposure constants, giving 100% weed kill for each of the different weed sizes, were added together and averaged. The results (see Table 6 in section 8.3), therefore indicate the temperature x time exposure constant required to kill a weed of a certain size.

8.3 Results.

TABLE 2 : Percentage of weeds killed, average from ten replications, using the 1200 mm shield.

Burner type	Speed Km/hr	Weed sizes 0 - 15 mm	 15 - 30 mm	 30 - 45 mm
Hoffmann	4	100	100	100
	5	100	95	69
	6	88	86	27
	7	63	0	0
Modified Lincoln University	4	100	100	100
	5	100	92	82
	6	87	63	29
	7	66	29	25

TABLE 3 : Percentage of weeds killed, average from ten replications, using the 1000 mm shield.

Burner type	Speed Km/hr	Weed sizes 0 - 15 mm	 15 - 30 mm	 30 - 45 mm
Hoffmann	3	100	100	100
	4	100	100	92
	5	93	75	70
	6	82	69	60
Modified Lincoln University	3	100	100	100
	4	100	100	90
	5	94	81	73
	6	86	67	67

TABLE 4 : Percentage of weeds killed, average from ten replications, using the 800 mm shield.

Burner type	Speed Km/hr	Weed sizes 0 - 15 mm	15 - 30 mm	30 - 45 mm
Hoffmann	2	100	100	100
	3	100	100	100
	4	100	90	85
	5	93	73	60
Modified Lincoln University	2	100	100	100
	3	100	100	100
	4	100	100	90
	5	96	80	70

TABLE 5 : Maximum travel speed resulting in a 100% weed kill.

Burner type	Shield Length (mm)	Weed sizes 0 - 15 mm	15 - 30 mm	30 - 45 mm
Hoffmann	1200	5	4	4
	1000	4	4	3
	800	4	3	3
Modified Lincoln University	1200	5	4	4
	1000	4	4	3
	800	4	4	3

Figure 20: Temperature profile underneath the 1200 mm shield, at 4 Km/hr, using the Hoffmann burner.

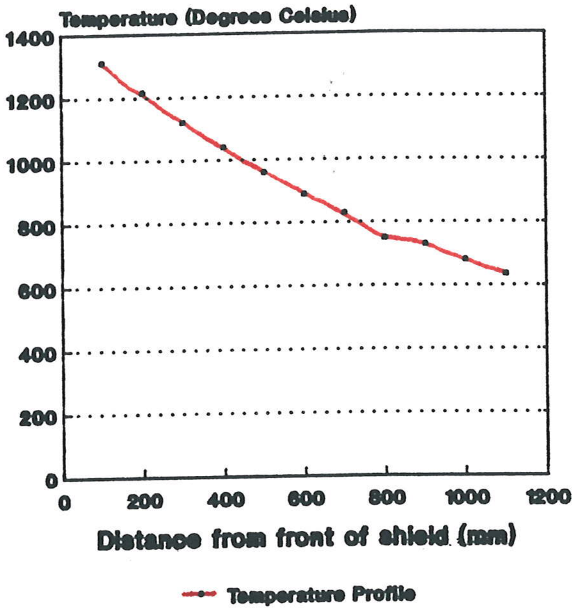


Figure 21: Temperature profile underneath the 1200 mm shield, at 4 Km/hr, using the Modified Lincoln University burner.

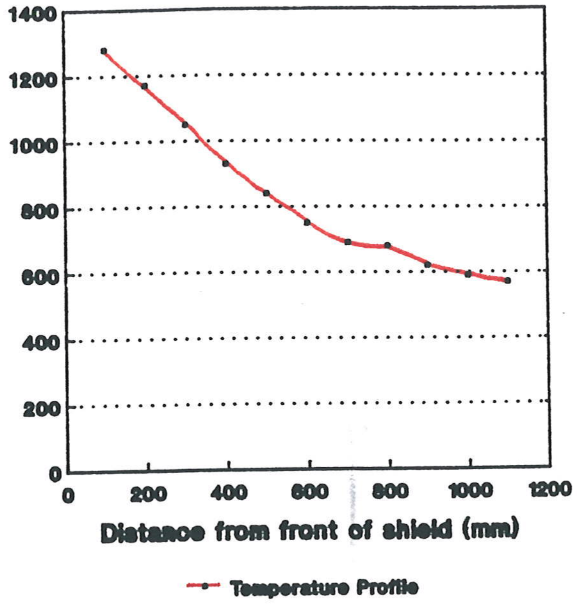


Figure 22: Temperature profile underneath the 1200 mm shield, at 5 Km/hr, using the Hoffmann burner.

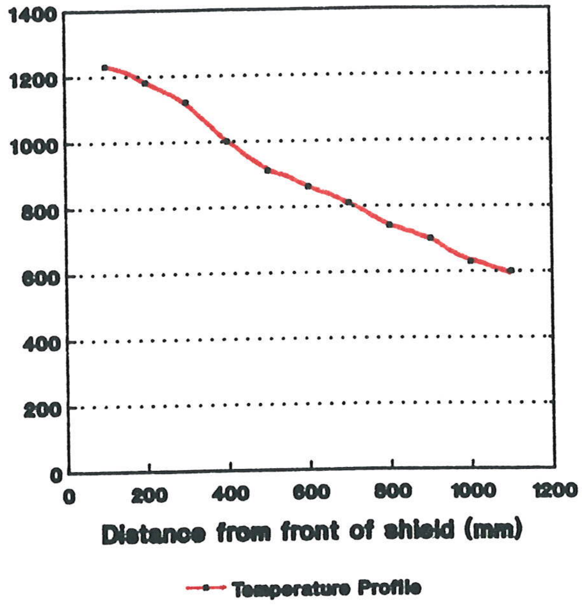


Figure 23: Temperature profile underneath the 1200 mm shield, at 5 Km/hr, using the Modified Lincoln University burner.

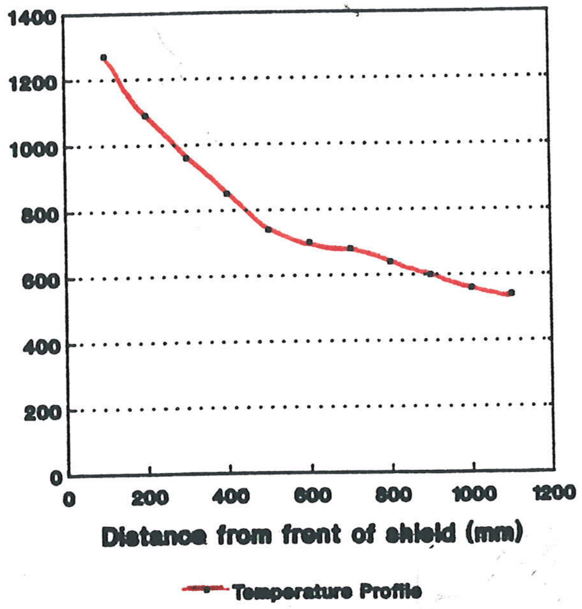


Figure 24: Temperature profile underneath the 1000 mm shield, at 3 Km/hr, using the Hoffmann burner.

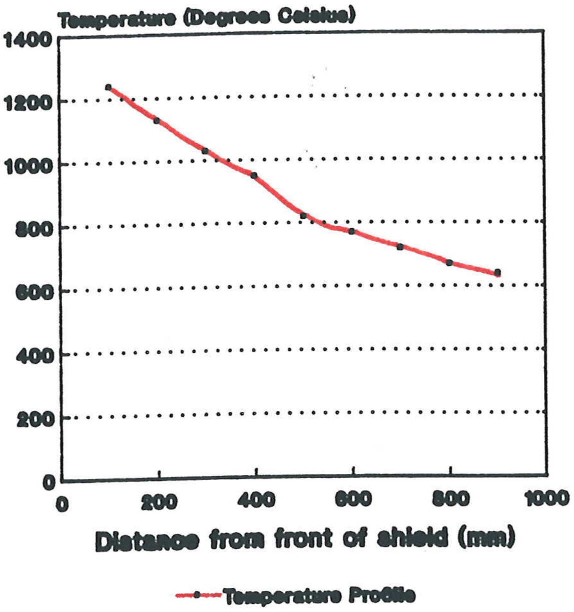


Figure 25: Temperature profile underneath the 1000 mm shield, at 3 Km/hr, using the Modified Lincoln University burner.

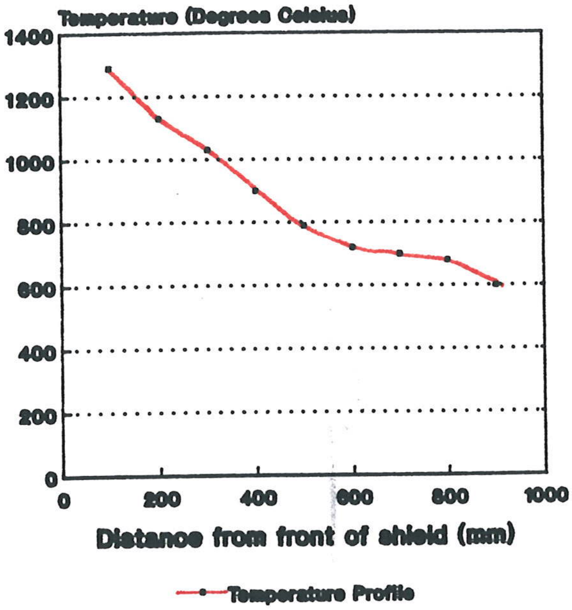


Figure 26: Temperature profile underneath the 1000 mm shield, at 4 Km/hr, using the Hoffmann burner.

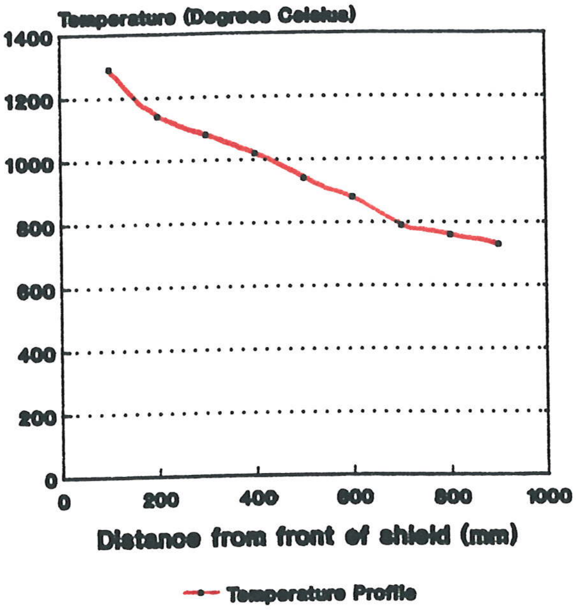


Figure 27: Temperature profile underneath the 1000 mm shield, at 4 Km/hr, using the Modified Lincoln University burner.

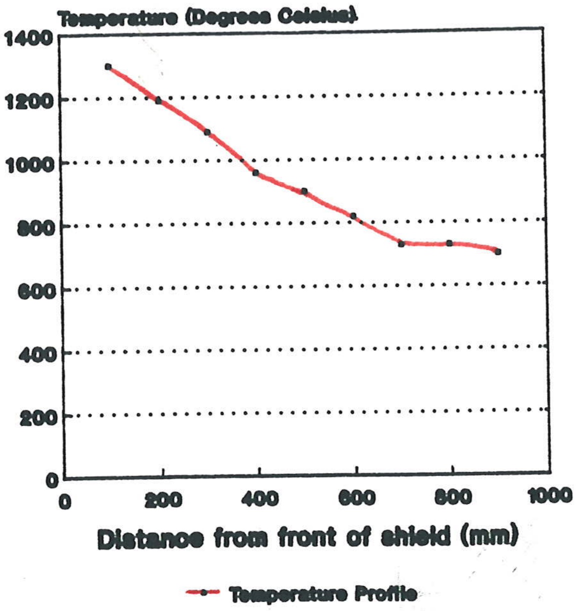


Figure 28: Temperature profile underneath the 800 mm shield, at 3 Km/hr, using the Hoffmann burner.

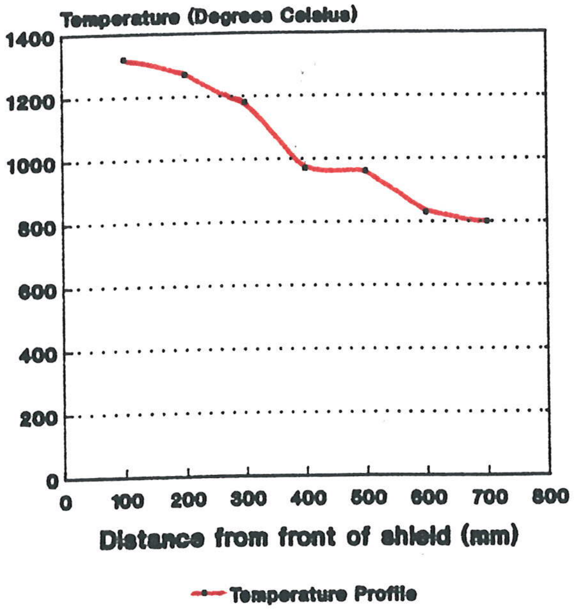


Figure 29: Temperature profile underneath the 800 mm shield, at 3 Km/hr, using the Modified Lincoln University burner.

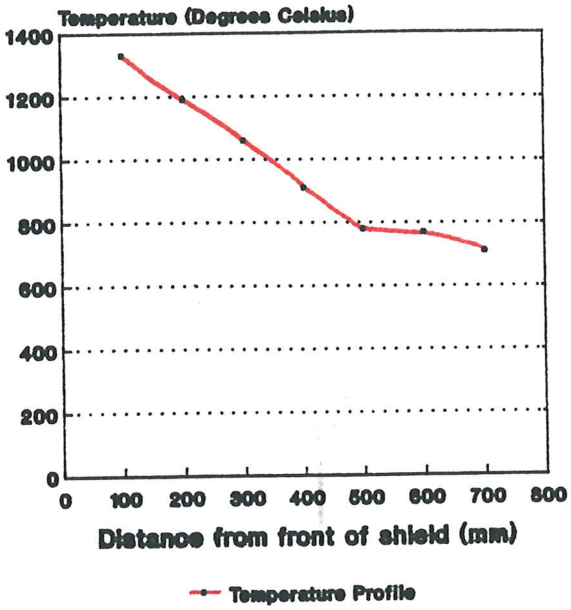


Figure 30: Temperature profile underneath the 800 mm shield, at 4 Km/hr, using the Hoffmann burner.

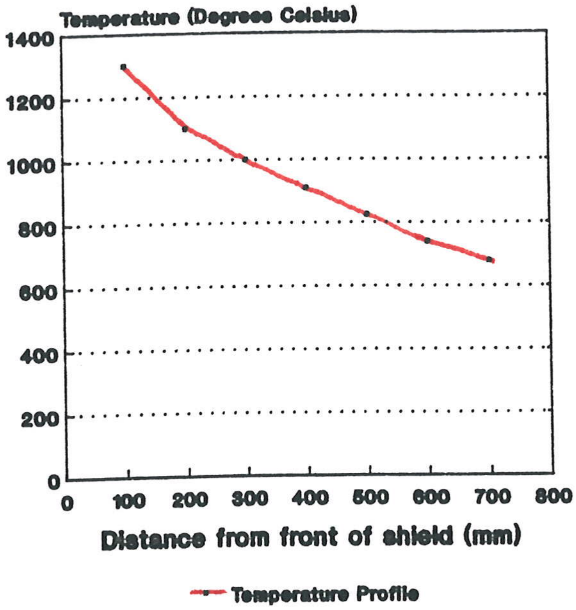


Figure 31: Temperature profile underneath the 800 mm shield, at 4 Km/hr, using the Modified Lincoln University burner.

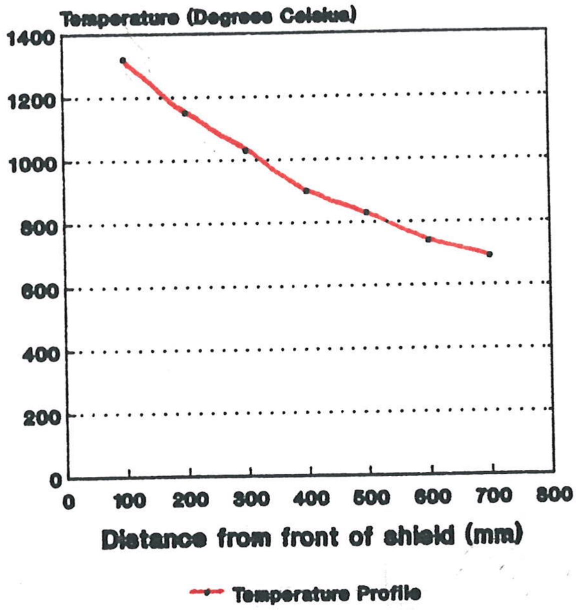


TABLE 6 : Temperature x Time constants required to kill weeds:

Weed size	Temperature x time exposure constant required
0 - 15 mm	750 degrees Celsius.Seconds
125 - 30 mm	882 degrees Celsius.Seconds
30 - 45 mm	989 degrees Celsius.Seconds

8.4 Discussions.

As Tables 2, 3 and 4 show, the longer the length of shield, the faster the travel speed can be, while still maintaining a 100% weed kill.

This is largely due to the fact that the exposure stays relatively even. As the length of the shield increases from say, 800 mm to 1200 mm, the exposure time has been increased by 50%. If the average temperature underneath the shield remained the same, which it doesn't, then it would be expected that the travel speed could be increased by a similar amount. However as the average temperature underneath the shield changes both with respect to changes in shield length and travel speeds, the travel speed can not increase by 50% while maintaining a 100% weed kill. The tables also show that as the weed sizes are increased, the maximum travel speeds to achieve a 100% weed kill are decreased, for every shield and burner combination.

The table also shows that although the heat output from both the Modified Lincoln University burner and the Hoffmann burner are comparable, see Table 1, Section 6.4, the Modified Lincoln University burner has a slight advantage over the Hoffmann burner in the 800 mm shield during treatment of weeds between 15-30 mm.

The Modified Lincoln University burner achieved a 100% weed kill at 4 Km/hr, while the Hoffmann burner achieved this at only 3 Km/hr. Apart from this, both burners gave very similar results and no real distinctions in practical performance, between the two burners, could be made from this trial.

Figures 20 to 31 show that the temperature profiles underneath the shields follow an almost straight line relationship with regards to temperature drop along the length of the shields. The slopes of the graphs are all very similar, the only real difference between the graphs being the height of the slope.

Although some temperature profiles using the Modified Lincoln University burner showed a slight drop in temperatures halfway along the shield, the average temperatures underneath the shields were comparable to those using the Hoffmann burner. This is consistent with the field trial results, where no significant difference in practical performance between the Modified Lincoln University burner and the Hoffmann burner were found.

The graphs also show that the temperatures underneath the shields drop, both when the length of the shield is increased, or when the speed of travel is increased.

Combining all of the data into one table we get temperature x time exposure constants required to kill the three sizes of weeds (Table 6).

As expected, the larger weeds required a higher temperature x time exposure than the smaller ones. Whether the increase in temperature x time exposure, according to the size of the weeds, is a straight line or an exponential curve, cannot be deducted from the data. A larger trial including more classes of weed sizes and travel speeds, may result in a definite relationship between the size of the weeds versus the temperature x time exposure required to kill the weeds.

It is important to note that although theoretically, any temperature x time exposure combination resulting in the temperature x time exposure constant required to kill weeds, should result in a 100% weed kill, there is a limit to the minimum temperature requirements to achieve this. As most papers suggest, cell destruction takes place at 60 to 70 degrees Celsius (KLOOSTER, 1983; VESTER, 1986; PARISH, 1987; and HOFFMANN, 1989), weeds must therefore be exposed to a minimum of 70^0 Celsius to ensure that the weed cells are damaged beyond repair.

The three temperature x time exposure constants can be used, either as a guideline in further research, or to establish the maximum travel speed a flame weeder can be used at while maintaining a 100% weed kill.

The materials and methods described in this thesis can be further used to establish temperature x time exposure constants for individual weed species and sizes. Further trials using these materials and methods, may therefore eventually result in a list of the more common species of weeds in New Zealand, and the appropriate temperature x time exposure constant required to kill them, according to the size of the weeds to be treated.

Such a list can then be used by operators to establish the maximum speed of travel he/she can safely operate at to obtain a 100% weed kill, once the average temperatures underneath the shields, over a range of travel speeds, has been established for the particular flame weeding system used.

The temperature x time exposure constants, required to kill weeds, can also be used to determine the overall cost efficiency of any flame weeder. Simply by calculating the maximum speed of travel and the gas consumption of the flame weeder; the gas, labour and tractor costs can be determined on a per Hectare basis.

9) CONCLUSIONS.

After establishing that the burner initially used in the Lincoln University flame weeder, the Hoffmann burner, does not entrain enough air to burn all of the LPG it uses, a new burner was designed to overcome this problem. The results of this thesis indicate that the new burner design, called the Modified Lincoln University burner, which entrains sufficient air to theoretically allow complete combustion of the LPG used, has an increased heat output per Kg of LPG used of 22.7% over the Hoffmann burner.

The Modified Lincoln University burner also has a more even temperature profile compared to the Hoffmann burner, resulting in a relatively constant flame temperature along the entire width of the burner at any distance from the end of the burner.

Field trials using both burners showed that in all cases the Modified Lincoln University burner equalled or exceeded the weed kill performance of the Hoffmann burner, while consuming 18.6% less LPG. The field trial results were consistent with the results obtained in the laboratory.

The temperature x time exposure constants required to kill weeds between 0 to 45 mm in size, established in this thesis, are as follows:

0 - 15 mm = 750 degrees Celsius.Seconds
15 - 30 mm = 882 degrees Celsius.Seconds
30 - 45 mm = 989 degrees Celsius.Seconds

As no other literature on temperature x time exposure constants was found by the author, the figures above cannot be compared to work done by others.

However, the temperature x time exposure constants above, can be used as guidelines in the evaluation of flame weeders. They can be used either, to establish the maximum speed of travel an operator can use a flame weeder at, while maintaining a 100% weed kill, or to establish the cost efficiency of any flame weeder (in $/Ha), depending on the size of the weeds to be treated.

The materials and methods used in the establishing of the temperature x time exposure constants can be used in further research to eventually provide flame weeder operators with a complete list of the most common weed species present in New Zealand, and the required temperature x time exposure constants to kill them, according to the size of the weeds present.

The Lincoln University flame weeder is now more fuel efficient due to the lower gas consumption of the Modified Lincoln University burner, and it can now be used at its maximum cost efficiency as the maximum travel speed possible can be calculated using the temperature x time exposure constants established in this thesis.

Continued research into shield design can make the Lincoln University flame weeder an even more cost efficient method of non-chemical weed control.

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Two individuals that require special mention for their contribution to this thesis are Mr. G.A. Martin and Mr. R.A. Diehl.

Mr. Martin, my supervisor, has been a great source of support. Academically, he steered me onto every avenue related to my thesis, allowing my own judgement to determine the relative importance of each one. Being stretched to the maximum limit of my academic ability has allowed me to mature academically and mentally. Tedious hours of reading drafts were endured, many of which were outside normal working hours. Again, thanks very much for your support Graeme.

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