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# Non-chemical weed control-trends in European practice-with special reference to electrical weed control

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## ABSTRACT

For many years the use of chemical herbicides has dominated weed control practice. Chemicals are relatively inexpensive, convenient to handle and apply, versatile and effective. There is increasing concern, however, about their use and their effect on health and the environment. This concern has led to a rising interest in non-chemical methods. Legislation has been passed in Sweden placing restrictions on herbicide use and more regulations are expected in that country and also in Europe.

Chemical techniques can be hard to replace and investigations into various substitutes are taking place. Mechanical weeding, flaming and hoeing are amongst methods being examined, as well as re-stating the benefits of good husbandry from the beginning. Electrical weed control was investigated throughout the 1970's and 1980's and may have a role to play. There are various techniques :- electrical fields and associated air ions, high voltage pulses, direct contact electric shocks and the use of microwave radiation. The techniques are described and the varying merits and disadvantages discussed. The most likely systems to find use in the near future are direct contact electric shocks and, in limited circumstances, microwave radiation.

## INTRODUCTION

In Northern Europe there is a definite trend towards using non-chemical methods of weed control. Concern for the environment, coupled with national and international legislation, has led to an increasing number of restrictions on the range of chemicals that can be used and the circumstances in which they can be applied.

Swedish weed control practice is in the vanguard of change. During the 1980's there was a growing awareness of the disadvantages of herbicides. Herbicide residues were found in streams and in some cases even in well water. This was probably caused by negligence of tractor drivers, nevertheless it focused public attention on the possible environmental and health hazards connected with herbicide use.

During the same time there was a growing consciousness about environmental issues in general and this led to more restrictions on herbicide use in Sweden. The authorities giving permission for companies to sell herbicides made a re-appraisal and now many of the herbicides previously used are no longer permitted.

Political decisions minimised the use of herbicides in urban areas. In 1991, 220 of Sweden's 284 municipalities had legislated against chemical weed control on hard surfaces such as tarmac, pavements, kerbs and gravel paths. At the moment there is only one chemical registered for use on hard surfaces in urban areas (glyphosate) [Svenson & Schroeder, 1992].

There is therefore, a great demand for non-chemical weed control methods and designs of pavements, gravel paths etc, that will prevent weed growth.

Opinion is still divided however, since some of the farmers, fruit and vegetable growers complain about not having enough effective herbicides to resort to. Yet another group of farmers, especially organic growers, would prefer effective non-chemical weed control methods. They are aware of the possible dangers of handling herbicides. In response, research on non-chemical weed control methods at the Swedish University of Agricultural Science has expanded since the 1980's in order to provide more information and to assess the viability of various techniques e.g. the study by Andersson [1993] examining non-chemical methods of disinfection of glass houses in commercial horticulture.

The reduced use of chemicals has not only occurred in agriculture and horticulture. Railways throughout Europe cover tens of thousands of kilometres of track and this must be kept weed free. This is not just for aesthetic reasons, but principally for safety since the rail track must not be disturbed or displaced by plant growth.

Research is in progress in Stuttgart, Germany [Höschle et al, 1981, Kunisch et al, 1992] on the use of railroad weed control by microwaves and also in Switzerland [Matzler, 1991] where a range of frequencies are being investigated. In Sweden there are some tracks where herbicides are banned and adverse publicity often is incurred when the press describe the weed control trains as "the poison trains". It is expected that the railway authorities throughout Europe will turn to alternative non-chemical methods if techniques become available that are both effective and economic.

## CURRENT NON-CHEMICAL METHODS

It is not that alternatives to chemicals are unknown - it is finding other methods which are as effective, easy to apply and economic. Hand weeding, for example, is a very effective way of keeping down weeds. The resources required, however, to regularly tend the millions of hectares under cultivation would be prohibitive. Between 100 and 300 man hours $ha^{-1}$ would be required for hand weeding carrots [Ascard, 1990].

Thermal weed control using liquified petroleum gas (LPG) was used before herbicides were invented. The method has a renaissance. Weed plants are heated in order to destroy the cells which make the plants dry out. This means, however, that only the leaves are harmed, not the roots. Some weed plants are capable of regrowth which makes it necessary to repeat the flaming treatment. Root-propagated weeds are very difficult to control with flaming and if possible a more effective method should be used.

The design of suitable equipment is generally rather simple from a technical point of view. Although improvements have been made in order to lower the energy consumption and to improve the performance, safety aspects have to be carefully considered since fire and heat could be hazardous.

Flame cultivation can be used before emergence in crops such as carrots and onions. Some cultivated crops like maize and onion, are rather more heat resistant. Selective flaming is possible when weed plants are more sensitive to heat than the cropped plants. Flaming is also used where no vegetation is wanted, that is to say mainly in urban areas. Equipment for LPG flame treatment is available although not very widespread. Size varies from small, wheel barrow units to tractor mounted units covering 4.5m widths carrying up to 250 kg of LPG [Ascard, 1988].

Consumption of gas varies from 25-50 kg $ha^{-1}$ at vehicle speeds of 3-6 km $hr^{-1}$ whilst some new Danish equipment is reported to travel at 6-9 km $hr^{-1}$ using 50-60 kg $ha^{-1}$ of gas. Restricting the technique to strip flaming, consumption can be reduced to 10-20 kg $ha^{-1}$ [Ascard, 1988; Ascard, 1989; Hoffman, 1989; Vester, 1986].

Another thermal weed control method has been tested in Sweden. Two different media were used - freezing liquid nitrogen and carbon dioxide snow. Technically the method worked well but unfortunately did not work well economically. The weed control effect was similar to that achieved by flaming but the cost was much higher [Fergedal, 1992].

In the future other thermal methods, for instance spraying boiling water might be used [Berling, 1993].

Mechanical weed control can be performed in many different ways. Weed harrowing and inter row cultivation are two examples. Mechanical weed control is generally performed beside the cultivated plants. When not using herbicides, however, the worst weed competition is caused by the weed plants growing right by the cultivated plants [Mattsson et al, 1990] - difficult to treat effectively mechanically, without damaging the crop.

A Swedish manufacturer has developed a weed brush machine for intra row weed control in crops. This machine is new on the market but it has been put through testing by the Swedish University of Agricultural Sciences and seems very promising.

Harrowing on gravel paths in urban areas has proved to be a very effective method. The cost is in the same range as that of using herbicides [Svensson & Schroeder, 1992].

Mechanical weed control seems attractive in the respect that the energy requirement is low and residual pollution negligible. Diesel exhaust products are the same for one mechanical pass as in one chemical pass but, in general, one spraying has to be replaced by more than one mechanical weeding. Although the exact effect on weed plants has not yet been studied very carefully, research on plant sensitivity towards mechanical damage has recently started in Sweden.

Ascard [1990] re-iterates the importance of good husbandry in weed control. Well planned crop rotation (including perennial crops), the inclusion of fallow land in the cycle, maintaining efforts at reducing the weed seeds entering the soil, good seed bed preparation, (including transplanting it appropriate), mulching, harrowing and sometimes inter-row cultivation are all techniques which reduce the need for weed control The ease of use and versatility of herbicides has, perhaps, encouraged some farmers to neglect established practice and rely upon the application of chemicals to control the ever increasing weed problems. Environmental concerns and the rise in interest of consumers in "organic" foods may encourage the return to good husbandry.

## ELECTRICAL WEED CONTROL

The concept of using electricity for weed control is not a new one. In 1893 Sharp [Sharp, 1893] patented a "vegetation exterminator" followed in 1895 [Scheible, 1895] by a patent on an "Apparatus for exterminating vegetation". Both systems used steam plant to drive generators which applied the electricity to the weeds via a variety of electrode shapes and sizes. Various systems were invented and tried throughout the next 70 years, but it was in the USA throughout the 1970's and early 1980's that electrical methods and microwave methods were extensively researched.

In the 1980's, European interest was in direct contact, high voltage weed control and systems were tested in the UK, Belgium and France. It had little commercial use but recently there has been a resurgence of the interest in this technique and also in the use of microwaves for limited purposes.

Although electrical weed control was first proposed last century, the concept is appropriately up to date. Electrical methods are quick and environmentally "clean" in that they leave no residues in the soils or in or on plants. Once the equipment has passed through an area, then it is perfectly safe for a human or animal to enter that area. Birds can eat the berries from treated plants with no possibility of ill effects and animals can move amongst the plant tissue or eat treated vegetation without fear of skin contamination or poisoning. It is not entirely pollution free since the electrical energy has to be generated. This is usually by a diesel engine coupled to an alternator or by a tractor engine using the power take off (p.t.o.) shaft to drive a generator mounted on the rear of the machine. The waste products of the diesel engine enter the atmosphere, but usually the fuel consumption is not that much greater than when the tractor is moving through a field on its own.

There have been four principal methods investigated for using electricity to control weeds - or for that matter unwanted crop plants, e.g. thinning seedlings. They are - high voltage electric fields, spark discharges, high voltage direct contact equipment and the use of high power microwaves.

The history of this type of weed control, descriptions of the techniques and the results of the research work have been extensively reviewed elsewhere [Diprose et al, 1984; Diprose and Benson, 1984] and so only a basic description of the methods will follow.

a) High voltage electric fields

Early this century it was believed that if an electric field was applied to plants, then it could affect their growth - this was called electrotropism. An electric field is a region in which an electric charge or electric dipole would experience a force. Electric fields can be generated by applying a voltage between two electrodes.

If the electrodes consist of two plates separated by a distance d and connected to a voltage V, then the electric field E is given by :

$$E = \frac{V}{d} \text{ volts } m^{-1}$$

and it is uniform.

This is the simplest form. In practice the fields are generated by multi-various electrodes, e.g. a rod, sphere or a wire mesh could be above a plant whose leaves and stem would constitute the second electrode. The resulting electric fields would be highly non-uniform and would actually change as the plants and leaves moved about - as they might in a breeze or wind.

From 1918 to 1937 in the UK, the Board of Agriculture and Fisheries formed a sub-committee of Electroculture which financed much work trying to establish whether or not crop yield increases could occur when electric fields were used. The final report [Board of Agriculture and Fisheries, 1937] declared that the 18 years of research had been inconclusive; although sometimes yield increases had been demonstrated of up to 30% [Blackman, 1924], it was not possible to predict what a yield increase might be - or even if there could be one at all. Experience during this period in the USA was also disappointing and no further work was carried out until the 1960's, when Murr [Murr, 1963(a)] and Sidaway [Sidaway, 1969] began a series of experiments on "lethal electrotropism - a term suggested by Murr. Although some interesting phenomena were reported once again the work was inconclusive since it was not possible to definitely state whether or not very high electric fields could damage plants - or even enhance their growth.

The equipment used to generate electric fields as used by Blackman and others in the 1920's was very cumbersome indeed. In a field of crops a number of tall posts were erected and between these was strung an array of wires between 2 and 3m above the ground. A voltage of 20-40kV was connected between the wires and the ground which created strong electric fields in which the crops grew. Apart from being extremely dangerous the wires and posts were very inconvenient.

It is debatable as to whether or not the yield increases as seen by some research workers were due to the electric fields per se. Krueger and others [Krueger at al, 1978; Kotaka and Krueger, 1968] believe that air ions (particles in the air which have a positive or negative electric charge) influence the way plants grow. They showed that increases in air ion density could affect respiration, growth rates, chlorophyll density and A.T.P. metabolism. Plants grown in ion-free atmospheres show retarded growth, lacked rigidity and had soft leaves. When workers experimented with wire arrays charged to high voltages above fields, it is certain that the air ion density and type would have been altered from normal. This fact could have led to the considerable variation in results as air ion conditions changed uncontrollably from one experiment to another as well as variations throughout the season due to climatic conditions, e.g. winds, temperature, humidity etc.

It is unlikely that the use of electric fields to kill weeds or to control growth is practicable. The air ion conditions, however, may well be worthy of further investigation as these could be of considerable benefit to plants grown in greenhouses or where growing conditions are controlled. It is relatively easy, for example, to produce air ion generators to increase the negative ion content in atmospheres.

b) Spark discharges

This method uses equipment which generates a very high voltage, e.g. 60kV - 100kV between two electrodes or between an electrode and the ground. Although only separated by a few cms the electrodes are far enough apart to prevent sparking until an object, e.g. a seedling, comes between them. The object disrupts the electric field to cause a spark to flash over between the electrodes via the object. Most of the work done on discharges has been in what was the USSR [Slesarev et al, 1972; Slesarev, 1973; Bayev and Savchuck, 1974]. The temperature of the spark, radiation from it and its shock wave have all been investigated as reasons for plant destruction. Svitalka [1976] concluded from his work that the shock wave was principally responsible for tissue damage having observed broken cell walls and coagulated cytoplasm in affected plants. It had previously been calculated [Vasilenko and Sakalo, 1971] that 1μs after the beginning of a 30kV, 1J spark discharge the shock wavefront was travelling at 5.0 km/s at a pressure of 15 bar.

The technique has never been developed in Western Europe and it is not known whether it is still used in the East. It is, in any event, only really suitable for small plants a few cms in height. It could be a very useful technique for thinning where a mechanical cutter might be inappropriate, i.e. for use in a specially prepared seed bed. For general weed control purposes, however, it appears unlikely that it will ever be used.

c) High voltage direct contact weed control

An electric generator driven by a tractor p.t.o. or its own engine supplies a transformer to give an output voltage in the region of 5-15kV rms. This is connected to a metal electrode suspended just above crop height whilst a steel wheel running along the ground acts as a current return. As the system travels along, any plants which touch the electrodes close the circuit and a large electric current flows through them. The current rapidly heats the tissue, water turns to steam and cell integrity is destroyed [Diprose et al, 1980; Diprose et al, 1985]. It is an instantaneous effect and as stated in the introduction, it leaves no residues.

In the UK, the principal weed problem investigated was that of bolting weed beet (*Beta maritima*) in sugar beet crops (*Beta vulgaris*). This was also the weed problem investigated by the French and Belgium teams [Martens and Vigoureux, 1983]. In the USA, a firm called LASCO Inc., marketed electrical weed control machinery and made extensive trials in a wide variety of crops [Dykes, 1977; Wilson and Andersson, 1981; Dykes, 1980]. Usually the machines differentiated between weeds and crops physically, i.e. the weeds were taller than the crops or to one side of them, e.g. between rows. Under various circumstances, however, both the weed and crop could contact the electrodes and only the weeds would die. Dykes demonstrated this in two instances - clearing weeds from a sycamore tree plantation [Dykes, 1977] and in cotton plants [Dykes, 1978].

The equipment is the most straightforward of all out of the four techniques and involves a standard generator, a transformer and control gear. This is all robust with a good service life, tolerant of hard use and widely available. The electrodes depend entirely upon the particular situation and range from pieces of wire 3mm in diameter and 30cm long to sets of 12mm steel rods in three rows, 30cm apart and spanning 6m. Safety shielding required varies from country to country. In the USA simple shielding was attached to the rear of the electrode whilst UK practice required a large fibre glass shield above, behind and to the sides of the electrodes. The shield extended at least 0.5m in front of the most forward electrode [Diprose et al, 1985].

Power requirements vary from situation to situation. Small plants a few cm high will only need 4 or 5kV to destroy them, whilst larger plants will require the higher voltages, e.g. 15kV rms to ensure that destruction is rapid. As a general guideline, the bigger the plants and the more of them mean more kW; the taller the plants the more kV required as is the case the faster the operator wishes to travel. Practical limits for tractor borne equipment are 15kV and 60kW. This enabled weed beet infestations of up to 5000 stems $ha^{-1}$ to be treated at a rate of 2 ha $hr^{-1}$ and a fuel consumption of less than 6l $ha^{-1}$ [Vigoureux, 1981]. Others [Diprose et al, 1985] used the technique to control weed beet and could cover 12 rows (6m width) at 5 km $hr^{-1}$ giving a clearance rate of 2.4 ha $hr^{-1}$ during which fuel consumption was 3.5 *l* ha. Infestations were less than 4000 stems $ha^{-1}$. Higher infestations, e.g. up to 18,000 stems $ha^{-1}$ were not dealt with very well at first with a 15kV, 60kW machine, but could be cleared satisfactorily with two or three passes.

This technique does seem the most promising of them all as it is reasonably economical, has a good work rate, equipment is widely available (or rather the component parts are) and it is an extremely versatile, non-polluting system.

d) High power microwaves

Microwave ovens are a very well known form of domestic tool for heating and cooking. Technically they are described as "dielectric heaters", that is systems which generate a high frequency (typically 2450 MHz) alternating electric field within a cavity. The dielectric property of the medium being heated describes how well it responds to and extracts energy from that alternating electric field. The property is called the loss factor. It is very high for water (e.g. 80) and high enough 0.02-10 for many plastics and biological material to enable them to heat up when placed in an excited cavity. The higher the loss factor then the more energy that material will absorb and turn to heat. Loss factors are very frequency dependent but are quite high for plant materials (especially as they contain water) in the microwave region (915 MHz - 10 GHz). Equipment used in experiments on microwave weed control includes domestic type microwave ovens for laboratory work and field equipment consisting of a mobile carriage, a diesel/alternator set, a microwave generator, associated control switch gear and one or more applicators. The microwaves are beamed towards the ground and are absorbed - thus heating the ground and all the plants, roots and seeds within the heated volume. Penetration depths depend upon soil type, soil moisture content, frequency and time of exposure and can vary in practice from one cm to 10cm. Power outputs range from 650W to 2kW for laboratory microwave ovens and from 1.5kW to 60kW for field machines. A French machine is reported to be under construction at this time which can produce over 80kW. It is intended to be tested in the summer of 1993 [De-Robert, 1993].

Many experiments have been performed with seeds and seedlings in microwave ovens to see how much energy is required to kill them [Diprose et al, 1984 - review]. Wayland et al [1975] built a mobile unit for field trials after a series of laboratory experiments and this developed into a huge, 60kW, 2450 MHz self-propelled unit. It had a 150kW diesel alternator set for providing the power to the microwave generators and for driving the hydraulic system which drove the machine along. This was financed by the Phytox Corporation who intended it to be the first of many commercial machines.

Although it could kill weeds and weed seeds down to several cm it was large, expensive and slow. It took many hours to treat one acre. It has been [Diprose et al, 1984] calculated that it may take the machine from 92.6 hr $ha^{-1}$ up to 1037 hr $ha^{-1}$ to treat certain weed types. (The calculations were based on data in published literature, not their own experiments). Lal & Reed [1980] calculated that a 30kW machine used to kill wild oats in soil would operate at 0.197 km $hr^{-1}$ and only treat $1.8 \times 10^{-3}$ ha $hr^{-1}$. There is no way round these long times. The machines simply beamed the microwaves into the ground to heat everything up and "cook" the weed seeds and weeds, and this takes a lot of energy.

It is not thought that there is any future in this approach to weed control. It is simply too energy intensive and consequently too slow, although some specialised applications may be found [Mattsson, 1993]. There are also considerable implications for safety in the very high powers involved. The only possible avenue would be to find a non-thermal means of killing the plants. The machines used so far in field and laboratory trials undoubtedly killed by heating. If a system could be found whereby applying an electric field stressed plant tissue electrically but did not heat it, e.g. use a frequency at which the material had an extremely low loss factor, then that might be the basis for a practical system. If the load is not to be heated, then the power requirements diminish and higher field operating speeds become possible. At present, no clearly definable non-thermal methods of killing plants by electric stress alone are in use, although Swedish investigators are considering examining this aspect [Mattsson, 1992].

Other uses of dielectric heaters in horticulture and agriculture have been investigated. Diprose & Evans [1988] patented a system for taking poor quality soils infested with fungi and treating them on a continuous basis to kill the fungi yet leave beneficial bacteria. This enabled used compost and infested soils to be treated and used as casing material in mushroom farming. A 50kW machine at 27.12 MHz could treat up to 2 tons $hr^{-1}$. Benefits included the recycling of used materials, reductions in operating costs as less new materials were purchased and indications of earlier more uniform flushing and increased yield (although the latter was unpredictable, in one instance it was 20% above the control). Thomas et al [1979] demonstrated that tobacco (*Nicotiana*) leaves could be dried very rapidly using microwaves and Diprose et al [1979] showed that biological material could be dried rapidly in 5 or 10 minutes to yield moisture content values very close to those obtained by drying in conventional ovens at around 100°C for several hours. Very interesting measurements by Thomas showed that when dried by microwaves the tobacco lost less of the non-aqueous volatile substances. This technique could be extremely useful in laboratories and especially for growers of herbs or high quality produce that needs to be dried. Process times are reduced considerably and the products could contain more of the natural oils that give the product its value.

## CONCLUSIONS

Chemical methods of weed control are effective in action and cost, are well established and are likely to be used for many years to come. Increasing concern with their affect on the environment and on the produce quality is leading to a resurgence in interest in non-chemical methods and this trend is likely to continue as Western European governments increase restrictions on herbicide use. Electrical weed control is a viable method for use in a variety of crops and situations. Of all the methods the high voltage, direct contact systems are the most likely to be developed and their increasing use is likely during the next decades. At first, one or two "niche" problems will be solved electrically and then once the equipment becomes widely available more and more weed control problems will be tackled electrically.

Microwave weed control machines are unlikely to be used whilst heating is the principal agent killing the plants. If non-thermal techniques are developed then microwaves may be used in the field. There is plenty of scope, however, for development of dielectric heating systems for sterilising, drying and the processing of products.

Electrical weed control has a long history and many investigations have been published but it is not used to any great extent - eclipsed by the versatile chemical herbicides. Changes in legislative and social patterns will mean that this exciting and potentially very useful weed control technique should find its place in modern horticultural and agricultural practice.

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