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THE INFLUENCE OF ADDING FUNGICIDES AND GROWTH REGULATOR TO L FLAMPROP-ISOPROPYL, FLAMPROP-METHYL AND BENZOYL PROP-ETHYL ON THE GROWTH OF AVENA SPP IN CEREALS

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Summary L flamprop-isopropyl was evaluated in replicated trials in winter barley and in five crops of spring barley for the control of *Avena spp* both alone and in mixtures with triadimefon, carbendazim, and benomyl. L flamprop-isopropyl, flamprop-methyl and benzoyl prop-ethyl were also evaluated with the same fungicides and chlormequat in three winter wheat trials.

Apart from the anticipated effects of the growth regulator, crop effects from the various mixtures were minimal with only slight loss of herbicidal activity in a limited number of sites. Yields of grain showed responses to the various mixtures but these were confounded by fungical activity which are not reported in the paper.

Résumé Le 1 flamprop-isopropyl a été experimente en 1978 dans les cultures d'orge of hiver et de printemps (5 varietes) pour le controle de la folle avoigne *Avena spp*. Le flamprop-isopropyl a été appliqué seul et en mélange extemporane avec le triadimefon, le benomyl et la carbendazime. Le 1 flamprop-methyl ainsi que le benzoyl prop-ethyl ont été egalement experimentés en melange avec les mémes fongicide et le chlormequat chlorure (ccc) dans les cultures de blé tendre l'hiver (3 essais). En dehors des effets prevus du regulateur de croissance les symptomes provoqués par les différents traitements etaient minimes. Seulement une faible reduction de l'activité herbicide a été abservée dan un nombre limités de cas - les rendements ont été mesurés - les differences entre traitment se confondent avec l'effet fongicide qui n'a pas été mesuré danc ces experimentations.

INTRODUCTION

For the cereal grower, the fewer the number of times he has to pass through his crop in order to meet his pest control programme, the more attractive this becomes. Therefore, over the past few years the practice of 'in tank' mixing has increased, with only rudimentary guidelines on the physical or biological compatibilities of the various mixtures and of equal importance, the lack of universal formal agreement between the manufacturers involved as to methods of apportioning liability for the reduced performance of the components in the mixture.

Often, as in the case of a number of the later applied herbicides, the optimum crop growth stage for application coincides with the application period for broad sprectrum fungicides and/or growth regulants.

While it is comparatively simple to obtain evidence of physical compatability, and evidence does exist of the physical compatibility of many of these compounds with L flamprop-isopropyl in wheat, there was an absence of detailed knowledge of the biological compatabilities. There was also an absence of any formal agreement between manufacturers for the cross recommendation of tank mixes of products from different sources; this combined with the pressure from growers wishing to use pest control programmes based on 'tank' mixtures stimulated the current years work in the U.K.

Although it is accepted that antagonism or enhancement of one component by another is mutual, the work reported in this paper concentrates on the influence of fungicides and growth regulator on the performance of three herbicides for the control of Avena spp.

METHODS AND MATERIALS

The results were obtained from plots measuring $70m^2$ using three replicates in the case of winter and spring wheat and four in barley in randomised block layouts. Agronomic details relevant to each site are given in table 1.

The tank mixtures were made up by firstly adding the herbicide to the partially filled water container, agitating then adding the fungicide and/or growth regulator, and continuing agitation while topping up the tank and during spraying. Application was by Land Rover mounted sprayer at 280-330 litres/ha at 2.8 bars pressure.

Avena infestations were assessed by panicle counts above and below crop level using $0.5m^2$ quadrats. The number of quadrat counts per plot varied with the density of infestation and ranged from 8 per plot to whole plot counts in Scotland where in two trials wild oat infestation was relatively low. Spikelets per panicle were also counted and by assuming two seeds per spikelet the mean number of seeds per m^2 was calculated. The control is expressed as a percentage of the total formed in the untreated control whether they be above or below the crop level.

Crop effects including shortening (S) uniformity (U) and where appropriate lodging (L) were assessed by scoring on the E.W.R.S. scale. Yield was determined by combine harvesting an area of $40m^2$ through each plot with a modified Claas Comet machine and correcting the data where necessary to 15% moisture. The efficacy of the fungicides under the influence of various herbicides was assessed by the manufacturers and is not reported in this paper.

The materials used in the trials were as follows:-

Wild Oat Herbicides	Formulation	g.ai/l	Dose (kg/ha)	Abbreviation
Flamprop-methyl	e.c.(Mataven)	105	0.525	f-m
L flamprop-isopropyl	e.c.(New Barnon)	200	0.60	Lf-i
Benzoylprop-ethyl	e.c.(Suffix)	250	1.125	bp-e

Fungicides	Formulation	g.ai/kg	Dose (kg/ha)	Abbreviation
Triadimefon	w.p.	125	0.125	td
Carbendazim	w.p.	500	0.25	cb
Benomyl	w.p.	500	0.25	bm

Growth Regulator	Formulation	g.ai/l	Dose (kg/ha)	Abbreviation
Chlormequat	a.c.	460	1.61	cm

All the mixtures tested appeared to be physically compatible when made up under laboratory conditions for the duration of the time taken to spray the appropriate number of plots.

RESULTS

Winter and Spring Barley

For the purpose of relating crop scores to commercially acceptable levels, a value up to 5 is taken to be acceptable, although the ultimate criterion of whether an effect is acceptable or not is the standing ability and grain yield and quality.

Generally the addition of triadimefon, carbendazim and benomyl to L flamprop-isopropyl caused only marginal changes to the crop in relation to the untreated control and to the 'Straight' herbicide. In Scotland the effects on the cultivar Golden Promise were minimal despite the inherent difference in vigour between the sites H268 and H269.

In the South of England (H224) the addition of carbendazim to L flamprop-isopropyl marginally shortened the crop but at this site all chemical treatments improved the visual appearance of the crop compared to the untreated control. At site H263 where lodging occurred the mixture of carbendazim with L flamprop-isopropyl marginally increased the effect in relation to the other mixtures.

Yields from the barley sites are presented in table 4.

Few of the differences were significant at the 5% level, one of the exceptions, however being at site H263. Here the mixture of L flamprop-isopropyl in combination with triadimefon significantly outyielded all other treatments and the untreated control.

Because of the responses to disease control from the various mixtures it was not possible to relate yield benefits to removal of *Avena spp*.

Winter Wheat

The addition of triadimefon, carbendazim and benomyl caused no adverse crop effects and when chlormequat was added crop shortening occurred to a level normally associated with this compound. Where lodging was assessed at site H225 an effect equal to chlormequat was achieved with L flamprop-isopropyl in combination with carbendazim or benomyl.

The control of *Avena* seeds (table 5) was generally high at all sites with all three herbicides without undue antagonism from the various fungicides, however, at sites H262 and H264 the addition of triadimefon to L flamprop-isopropyl reduced control from 98% to 91% and 84% respectively. In the 'dwarf' wheat cultivar, Maris Hobbit, (site H264) the addition of triadimefon reduced the performance of benzoyl propethyl from 87% to 73%. The control from the latter was also reduced by the addition of carbendazim (79%). At this site the L flamprop-isopropyl/benomyl mixture which gave 95% control was reduced to 83% in the presence of chlormequat, similarly the flamprop-methyl/carbendazim mixture deteriorated in the presence of chlormequat.

Yields of grain from the three wheat sites are presented in table 6. Comparing the performance of L flamprop-isopropyl, flamprop methyl and benzoyl prop-ethyl alone at sites H225 and H265 the ranked order of yield was similar with the greatest yield response from plots treated with benzoyl prop-ethyl and the lowest from L flamprop-isopropyl whereas at site H262 the order was reversed. This was probably attributable to the greater activity of L flamprop-isopropyl (98% and 100% control) over benzoyl prop-ethyl (88% and 99%) in eliminating Avena spp. Grain yields from plots treated with flamprop-methyl improved at sites H262 and H225 with the addition of all three mildewicides whereas with the dwarf wheat Maris Hobbit the reverse was true.

DISCUSSION

Due to the complex interactions that occurred with the mixtures in both barley and wheat, especially when the growth regulator was introduced into the system only tentative conclusions could be drawn from this series of experiments. However, the absence of any deleterious crop effects from the various combinations is encouraging.

In barley, Avena infestation levels were not universally high but at the sites where 4600-5600 seeds per m^2 were recorded the effects of adding the mildewicides varied from no effect to slight enhancement of herbicide activity from the addition of benomyl (site H224). This result was confirmed at site H268 where the control of Avena plants below crop canopy was marginally increased by the addition of benomyl. In wheat the slight loss of herbicidal efficacy in the variety Maris Hobbit and where very high populations of Avena occurred (H262) indicated the need for a further evaluation before herbicide/mildewicide/growth regulator mixtures could be recommended.

The need for treating dwarf wheat cultivars with growth regulators may be questionable and in view of the fact that a competitive crop is a pre-requisite for the efficacy of all three herbicides tested, the case for combining herbicide, mildewicide and growth regulator must be clearly examined.

It is interesting that yield responses were obtained from the three 'straight' herbicides in relation to their activity on Avena spp but the confounding of yield response with varying levels of disease control make it difficult to apportion the level of yield benefit attributable to the removal of Avena spp.

As a general conclusion this work suggests that whilst observing certain constraints of cultivar, crop competitiveness, and Avena infestation levels, mixtures of L flamprop-isopropyl, flamprop-methyl and benzoyl prop ethyl with specific mildewicides may be considered for use in a programme of pest control.

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Table 1

Site Details For 1978 Cereal Trials

Crop	Ref	Location	Drilling Date	Variety	Crop (Vigour)	Pre treatment	Mixture Spray Date	Crop Growth Stage (Zadoks)	Avena Growth Stage	Wild Oat Seeds m^2
W Wheat	H225	Witney (Oxon)	19.10.77	Maris Huntsman	Moderate	Liquid N	11.5.78	30-31	11-30	2522
W Wheat	H262	Grunsburgh (Sfk)	7.11.77	Bouquet	Good	MCPA/CMPP	9.5.78	32	30	21276
W Wheat	H264	Cockfield Grn (Sfk)	19.10.77	Maris Hobbit	Moderate	Cyanazine MCPA/CMPP	18.5.78	32	22	14888
W Barley	H224	Newbury (Berks)	19.10.77	Astrix	Poor	Cyanazine/CMPP	18.5.78	32-33	20-31	5656
S Barley	H263	Cockfield Grn (Sfk)	3.4.78	Ark Royal	Good	Cyanazine/MCPA	10.6.78	31	22	155
S Barley	H226	Coleshill (Wilts)	15.4.78	Aramir	Good	Cyanazine/MCPA	6.6.78	31	23-30	309
S Barley	H268	Leitholm (Brds)*	17.4.78	Golden Promise	Poor	Cyanazine/MCPA	31.5.78	30	22	4649
S Barley	H269	Kincardine Br* (Cent)	12.4.78	Golden Promise	Good	CMPP	2.6.78	31	15	257
S Barley	H270	Nairn (Highland)*	18.4.78	Midas	Good	Cyanazine/MCPA	10.6.78	31	22	64

* Scotland

Table 2

Winter and Spring Barley Sites - Crop Effects (E.W.R.S. Scale)

Treatments	Dose (gms ai/ha)	H224		H263		H226			H268	H269	H270
		S	U	S	L	S	M	U	S+U	S+U	S+U
Lf-i	600	1.4	1.8	1.0	4.3	1.3	1.3	1.3	1.5	1.0	1.0
Lf-i + td	600 + 125	1.9	2.8	1.0	5.3	1.5	1.8	1.5	1.5	1.0	1.0
Lf-i + cb	600 + 250	2.3	2.8	1.0	6.8	1.3	1.8	1.3	1.0	1.0	1.0
Lf-i + bm	600 + 250	1.1	2.3	1.0	5.5	1.0	2.3	1.0	1.3	1.0	1.0
Untreated Control		1.0	3.3	1.3	4.3	1.3	1.8	1.3	1.3	1.0	1.0

S = Shortening (1 = no shortening 9 = escessive dwarfing)
U = Uniformity (1 = uniform 9 = excessive raggedness)
M = Maturity (1 = mature 9 = green and under mature)
L = Lodging (1 = no lodging 9 = completely lodged)

Table 3

Control of Avena Seeds in Winter and Spring Barley

Treatments	Dose (gms. ai/ha)	H224 A	H224 B	H226 A	H226 B	H263 A	H263 B	H268 A	H268 B	H269 A	H269 B	H270 A	H270 B
Lf-i	600	100	90	100	96	100	100	89	90	99	100	100	100
Lf-i + td	600 + 125	100	90	100	99	100	100	85	91	99	100	100	100
Lf-i + cb	600 + 250	100	90	100	97	100	100	95	91	100	100	100	100
Lf-i + bm	600 + 250	100	95	100	98	100	100	85	95	100	100	100	100
Untreated Control (no. of seeds/m^2)		5656		309		155		4649		257		64	

A = Panicles above and level with crop canopy B = Panicles below crop canopy

Table 4

Grain Yield From 6 Barley Sites

Treatments	Dose (gms. ai/ha)	H224 (t/ha)	H226 (t/ha)	H263 (t/ha)	H268 (t/ha)	H269 (t/ha)	H270 (t/ha)
Lf-i	600	3.91	6.13	5.01	4.29	5.38	5.03
Lf-i + td	600 + 125	4.17	6.41	5.35	4.58	5.65	5.08
Lf-i + cb	600 + 250	4.39	6.50	4.88	4.50	5.38	5.03
Lf-i + bn	600 + 250	4.44	6.36	4.86	4.45	5.45	5.10
U.T.C.		4.77	6.28	4.93	4.27	4.83	4.83
Sig Diff (P = 0.05)		0.67	0.40	0.27	0.53	0.33	0.44

Table 5

Crop Effects and Avena Seed Control at 3 Winter Wheat Sites

Treatments	Dosage (gm.ai/ha)	Crop Effects (EWRS) Site 225 S	Site 225 U	Site 225 L	Site 262 S	Site 262 U	Site 264 S 2	Site 264 U 2	Site 264 L 2	% Avena Seed Control H225 Above	H225 Below	H262 Above	H262 Below	H264 Above	H264 Below
Lf-i	600	2.0	2.3	2.6	2.0	2.3	1.0	1.7	1.0	100	97	98	100	98	99
Lf-i + td	600 + 125	1.7	1.3	2.6	1.0	1.6	1.0	1.3	1.0	99	97	91	100	84	90
Lf-i + cb	600 + 250	1.0	2.3	1.3	1.3	2.0	1.7	1.3	1.0	100	95	98	99	89	98
Lf-i + bm	600 + 250	1.0	2.6	1.3	1.3	1.6	1.0	1.0	1.0	99	93	98	99	95	98
f-m	525	1.0	4.0	3.3	1.3	1.0	2.3	1.0	1.0	99	98	99	99	91	99
f-m + td	525 + 125	2.3	3.0	4.0	1.3	1.3	2.0	1.7	1.0	100	99	99	99	92	96
f-m + cb	525 + 250	1.6	1.7	3.0	1.3	1.6	2.7	1.7	1.0	100	98	99	100	94	98
f-m + bm	525 + 250	1.0	4.7	4.7	1.0	1.0	1.3	2.7	1.0	100	99	97	100	94	99
bp-e	1125	1.3	3.3	4.0	1.6	1.6	2.0	2.0	2.0	98	96	88	99	87	99
bp-e + td	1125 + 125	1.0	4.0	4.3	1.3	1.6	1.3	1.7	1.0	100	91	92	100	73	95
bp-e + cb	1125 + 250	1.3	2.0	3.0	1.0	1.6	1.7	1.0	1.0	100	96	87	99	79	97
bp-e + bm	1125 + 250	1.3	2.3	3.3	1.0	1.3	1.3	1.2	1.0	100	95	85	98	85	98
Lf-i + td + cm	600 + 125 + 1610	4.0	1.6	1.3	4.7	4.3	2.7	1.7	1.0	100	94	96	99	87	98
Lf-i + cb + cm	600 + 250 + 1610	4.7	2.0	1.0	5.0	4.7	2.7	1.3	1.0	100	98	97	99	89	99
Lf-i + bm + cm	600 + 250 + 1610	3.0	1.6	1.0	5.3	5.3	4.7	2.0	1.0	93	96	94	99	95	100
f-m + td + cm	600 + 125 + 1610	4.3	3.7	1.3	4.3	3.0	4.0	1.7	1.0	100	99	94	99	95	100
f-m + cb + cm	600 + 250 + 1610	4.0	2.3	1.0	4.0	3.0	4.0	2.3	1.0	90	94	97	100	88	97
f-m + bm + cm	600 + 250 + 1610	4.3	2.6	1.0	4.0	3.7	4.3	1.3	1.0	99	98	98	99	93	99
Untreated control (Avena seeds/m^2)		1.0	2.0	2.0	1.0	1.0	1.0	3.3	3.2	2522		21276		14888	

Table 6

Grain Yield From 3 W. Wheat Sites (t/ha)

Treatments	Dosage	H262 Bouquet	H225 Huntsman	H264 Hobbit
Lf-i	600	6.21	5.83	4.10
Lf-i + td	600 + 125	6.55	6.68	4.94
Lf-i + cb	600 + 250	6.15	5.32	4.10
Lf-i + bm	600 + 250	6.11	5.84	4.30
f-m	525	6.15	5.92	4.63
f-m + td	525 + 125	6.61	6.02	3.89
f-m + cb	525 + 250	6.29	6.40	3.99
f-m + bm	525 + 250	6.55	6.20	2.70
bp-e	1125	5.95	6.16	4.94
bp-e + td	1125 + 125	6.61	6.16	3.99
bp-e + cb	1125 + 250	6.09	5.70	3.89
bp-e + bm	1125 + 250	6.09	6.44	5.26
Lf-i + td + cm	600 + 125 + 1610	6.75	6.20	3.99
Lf-i + cb + cm	600 + 250 + 1610	6.49	6.68	3.99
Lf-i + bm + cm	600 + 250 + 1610	6.41	6.44	4.94
f-m + td + cm	600 + 125 + 1610	6.55	6.62	4.73
f-m + cb + cm	600 + 250 + 1610	6.55	6.30	3.58
f-m + bm + cm	600 + 250 + 1610	6.35	6.58	4.42
Untreated control		5.56	6.34	4.10
L.S.D. (P.0.05)		0.2	0.74	1.37

PHYSICAL METHODS OF WEED CONTROL

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Summary The use of electromagnetic radiation and electricity in weed control is defined as "physical weed control". Research results in the development of techniques utilizing different parts of the electromagnetic spectrum and electric fields are discussed briefly: - γ-radiation seems to incorporate too many risks for being paractically useable to kill weed seeds, and for soil sterilization; - laser radiation has been tried in only one experimental series with little success, but further investigations should be stimulated; - the application of heat radiation by burning or flaming is being sophisticated by the development of new equipment; - the use of UHF energy has been developed to an advaned stage already. Several self-propelled prototypes are used for intensive field trials, and promising long-time effects have been completed yet, but field experiments have been successful. A comparison of the energy quantities acting directly on the weeds was worked out for flaming, UHF, and chemical control methods. For one single application, amounts of 3.6×10^{10} J/ha, 3×10^9 J/ha, and 4.5×10^8 J/ha are used for UHF, flaming, and chemical weed control, respectively.

Résumé L'usage de la radiation électromagnétique et de l'electricité pour la lutte contre les mauvaises herbes est définée comme "contrôle physicale". Les résultats de recherche en développer techniques prâticables sont discutés brèvement: - la γ-radiation est probablement trop dangereux pour l'appliquer à la stérilisation du sol ou pour amortir les graines des mauvaises herbes; - il y a seulement une série des experiments sur l'effêt de la radiation des lasers sur plantes, mais il serait intéressant de conduire d'autres experiments; - l'application du rayonnement de la chaleur par brûler ou jeter des flammes est améliorée par le développement des matériels nouveaux; - l'énergie UHF est déjà bien développée. Plusieurs prototypes des machines étaient construits, et les expériments dans les champs ont pris un cours promettant; - les recherches fondamentales sur la mode dáction des champs électriques sur plantes ne sont pas encore complets, mais les expériments en plein air étaient avec succes.

Une comparaison des quantités d'énergie qui agissent sur les mauvaises herbes fut élaborée pour les méthodes de contrôle de brûler, UHF, et chimiques. Pour une seule application, 3.6×10^{10} J/ha resp. 3.0×10^9 J/ha resp. 4.5×10^8 J/ha est employé avec UHF resp. brûler resp. contrôle chimique.

INTRODUCTION

Weed control is usually practiced by mechanical or chemical means. Both of them have experienced a rapid development in the course of this century: mechanical methods by progress in the production of technical farm equipment, such as tractor-mounted and/or propeller-shaft driven aggregates, chemical methods by the discovery and synthetization of phytotoxic organic substances acting selectively or non-selectively. The progress of both of these groups, however, has come to a halt. There have been no new tools for weeding during the past ten or twenty years, and new herbicides only seem to generate new problems by their selectivity and to confuse farmers, thereby making their use more and more questionable from ecological and economical points of view. This means, that in spite of all technical achievements in the field of weed science we are still far from being able to help mankind rid itself of this biblical plague.

It is therefore suggested that we leave the trodden paths, and take a closer look at other methods of approach, some of which are completely new, others of which have been known for many years but have not drawn much attention. All of them have in common that they use electromagnetic radiation or electricity for weed control. To distinguish them clearly from the other processes, they have been defined as "physical" weed control measures. The others are known as "mechanical", "chemical", or "biological" methods. Although mechanical (and, from a basic point of view, chemical) methods are physical as well, during the years they have been looked at as complexes of their own.

Electromagnetic radiation is a form of energy propagation generated on the atomic level, that consists of waves as well as of particles. Thereby, for its distribution it does not need any substantial medium, i.e. it is to be distinguished clearly from sound waves, which posses wave characteristics only, and need some carrier substance for their propagation, such as air, water or solids. The use of sonar waves, like those emitted by ultra-sonic generators for weed control purposes is therefore by definition included under the heading of mechanical methods, as these waves are generated by mechanical excitations on a non-atomic level, and act as a mechanical pressure wave.

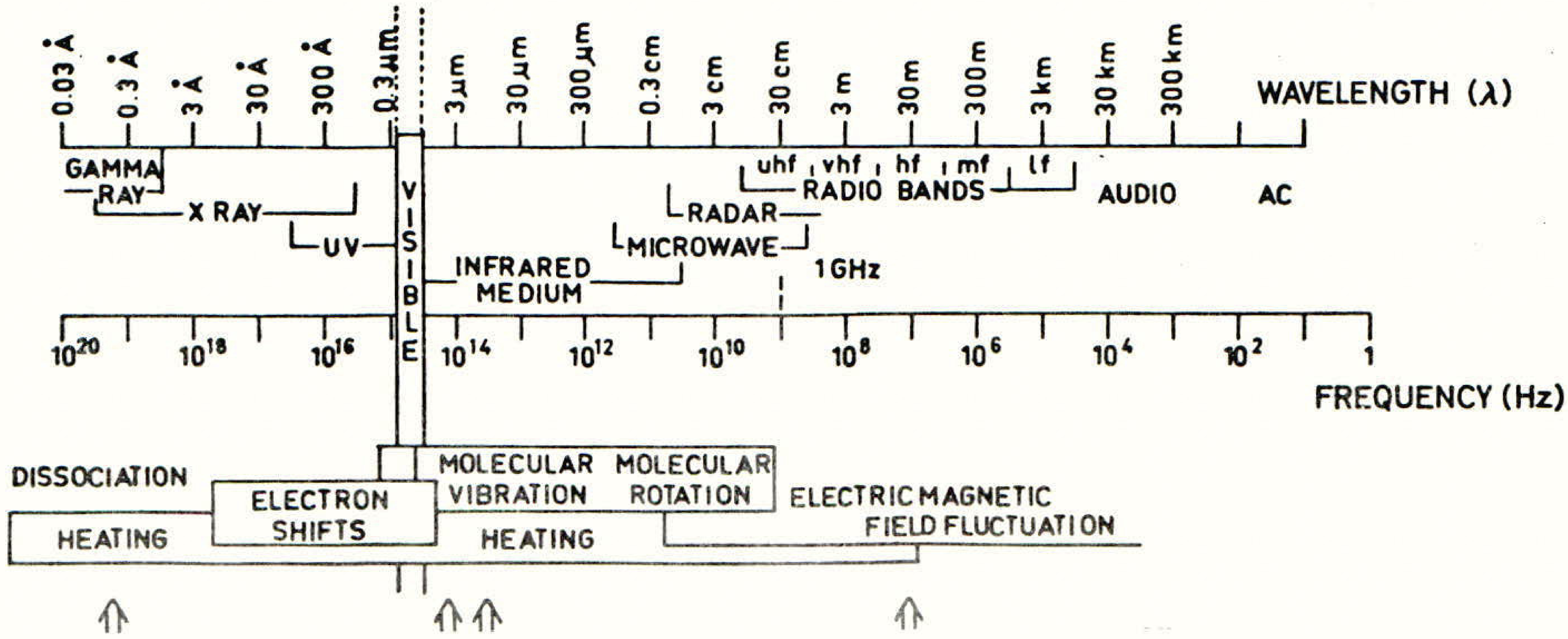
The electromagnetic spectrum is the entity of all kinds of radiation, which are specified by wavelength or frequency (see Fig. 1). These two characteristics are connected by the general wave formula

$$\nu\,(\text{frequency}) = \frac{c\ (\text{Light travel speed})}{\lambda\,(\text{wavelength})}$$

The energy content of electromagnetic radiation is determined by Planck's law: $E = H \times \nu$, where $h = 6.625 \times 10^{-34}$ Js; 1 J = 1 Nm = 1 Kg x m^2 x s^2 = 1 Ws. It follows that shortwave (high frequency) radiation contains more energy than longwave (low frequency) radiation.

Figure 1

The electromagnetic spectrum. Arrows indicate the wavebands used for weed control techniques



Radiation encountering matter is either reflected and/or transmitted and/or absorbed. With respect to our problem, absorption is the most important characteristic , because cellular life can be damaged or killed by absorbing radiation as a result of disturbances at an atomic or molecular level. In the following sections, different kinds of radiation with potential use in weed control are described and discussed.

γ - RADIATION

The use of γ-radiation for killing weed seeds and vegetative plant in the soil as well as in for soil sterilization has been studied in laboratory experiments (SÜSS and BACHTHALER 1968, SÜSS et al. 1977). Different radiation doses were applied to kill non-dormant seeds of different weed species. Energy quantities of 20 to 50 krad killed all seeds ready for germination, with Avena fatua and Apera spica - venti being more susceptible than Alopecurus myosuroides and Sinapis arvensis seeds. No data are available for dormant seeds. Small radiation quantities of 2 to 5 krad seem to stimulate germination, as was shown for Avena fatua.

Radiation doses of about 500 krad are necessary for soil sterilization. As it seems impossible to act selectively on plant seeds and soil-borne pathogens, harmless or indifferent members of the soil microflora will suffer equally from such treatments.

Because of technical problems (construction of application equipment, radiation protection etc.), and of possible mutagenic effects of an unforeseeable extent, weed control methods based upon γ-radiation seem to be of scientific interest only, and any practical use in the future seems quite improbable.

LASER RADIATION

Little is known about the possibilities of high-energetic, coherent laser radiation in weed control. Experiments conducted by COUCH and GANGSTAD (1974), and LONG and SMITH (1975) irradiating water hyacinth (Eichhornia crassipes) plants with a CO_2-N_2-He-Laser at 10.6 μ wavelength and different energy levels (.2 to 100 J/cm^2) indicated that the plant parts hit by the laser beam were damaged. These effects, however, where of short duration and did not kill the plants. No lasting effects on vegetative propagation, inflorescences, biomass production, height, number, percent coverage, and photosynthesis could be found.

It seems probable that in future trials, other kinds of lasers, e.g. solid matter lasers of other emittance wavelengths and of a smaller size will be tested (the equipment used for the above mentioned trials is more than 30 m in length). Trials will show if there can be some possibility of using them in practice.

HEAT RADIATION

Temperatures of more than 42°C denature proteins in the cells of living organisms. Thus heat can kill plants partially or totally. In weed control, this principle is used for heat sterilization, soil damping, and burning of flaming techniques. As sterilization and damping are well known and largely used in horticulture, they shall not be discussed further in this paper.

In flaming or burning, a hot flame, supplied by oil or gas, is directed at undesired plant growth by burners mounted onto a tractor in a way that is relevant to the task in hand. Depending on the area to be treated, the time of treatment, and crop conditions, methods of flaming can be separated into different groups, whose characteristics shall be summarized briefly (HOFFMANN 1975 and 1977):

(a) Non-Selective Flaming (areal burning) - treatment of the whole area by the flames, with the burners being directed parallel. For complete plant kill, further treatments may be necessary, or a combination with a preceding herbicide (MATTHEWS et al. 1976, STRITZKE et al., und.), or mechanical treatment (DODD and HOLTZ 1975). This method is largely used on fallow, rangeland, pastures, railways and the like. It is also useful in most crops as a pre-sowing treatment, and up to a few days before emergence, as increases in temperature only occur to a depth of max. 0.6 cm in soil (KOCH 1969).

(b) Band (or Row) Flaming - treatment of standing crops by selectively flaming the space between the crop rows, with burners directed parallel but confined to the inter-row space. The crops are protected by metal plates attached to the equipment. Successfully used in combination with mechanical weeding in cotton (CARDOZIER 1957), tree and shrub nurseries, and carrots (MERZ 1975).

(c) Selective Flaming - selectivity based upon a higher heat tolerance of the crop as compared with the less advanced weeds between the rows. Burners arranged in an opposite-alternating fashion. Applicable in tree nurseries and crops with woody stems (cotton, corn, etc.).

(d) Pre-Harvest Flaming - usually conducted as row-or selective flaming. Used for facilitating harvesting, or preventing infestations of the ripening crop by pathogens associated with weeds.

(e) Post-Harvest Flaming - for removing crop residues, pathogenic organisms, and weed seeds. Applied as areal burning. Its use is dependent on subsequent field management practices.

Only part of the weed seeds present on a flamed area are destroyed. Those lying on the soil surface or below, may survive the heat impact unharmed, while most of those still attached to the plants are killed because of the stronger heat impact.

Susceptibility of weed seeds to flaming depends largely on the amount of heat present, and on plant species. Therefore, seeds of some species can be destroyed to a large extent, while others survive (KLINGMAN 1961). Little is known about the heat tolerance of weed seeds. The results of HOPKINS (1936) indicate that dry seeds of *Avena fatua* are killed effectively only after being exposed to a temperature of 105 °C for 15 minutes. Seeds of many other weed species are destroyed by 15 minutes exposure to temperatures of 80 to 100 °C, which is unlikely to be achieved under field conditions.

In general, flaming in agricultural crops is only successful when weeds are not more than 5 cm high. In most cases, repetition of the treatment, or combination with chemical or mechanical methods are necessary. Despite rising costs for oil and gas it can be a promising alternative, or at least a supplement to chemical methods, especially as there are no toxic residues. A useful side-effect is the destruction of phytopathogenic or phytopagous organisms (fungi, insects) which live in or on the weeds, or on the soil surface. On the other hand, however, harmless organisms are similarly affected.

UHF - RADIATION

The energy of electromagnetic waves belonging to the UHF (i.e. FM- or TV-broadcasting frequencies) can cause molecules to vibrate, thus generating heat. With high energy densities of certain wavelength bands, living organisms exposed to the radiation source can suffer local damage, or death.

At the beginning of this decade, a group of American scientists attempted to make use of this fact (DAVIS et al. 1971). In the beginning, they tried to kill seeds of different plant species in a cavity by 2 450 MHz radiation. Later on, experiments were carried out under greenhouse (WAYLAND et al. 1973) and field conditions (MENGES and WAYLAND 1974 a), extending the trials to weeds of different species and growth stages.

Up to now, the following basic correlations between seed characteristics and their susceptibility to UHF-radiation have been found (DAVIS et al. 1973, PICE and PUTNAM 1977):

- the content of ether-soluble substances in seeds is negatively correlated to susceptibility

- water-imbibed seeds are more susceptible than dry seeds, what can be explained by the pronounced dipole characteristic of H_2O molecules

- mass and volume of seeds are positively correlated to susceptibility

- no correlation exists between specific weight, nucleic acid content, specific heat, and susceptibility

- seeds in moist soil are more susceptible than seeds in dry soil.

A trailer-mounted prototype was constructed for the field trials in 1973, and its application gave good results in controlling weeds (*Sorghum halepense*, *Sisymbrium irio*, *Amaranthus retroflexus*, and others), and nematodes (*Pyrenochaeta terrestris*, *Rotylenchulus reniformis*, cyst-forming nematodes) (MENGES and WAYLAND 1974 b). Further research is being conducted, and self-propelled application equipment which has already been produced - in still very small numbers - by a commercial company (BODY 1973) is being steadily improved.

Energy amounts necessary for soil penetration to a depth of 5 to 10 cm are in the region of 360 J/cm^2, which is quite a lot. No side-effects were caused by energy densities of 40 000 J/cm^2 on soil microflora, as bacteria, fungi, and actinomycetes (VELA et al. 1976), the energy required for weed control being only a hundredth of this. It must be assumed, however, that harmless or useful animals living in the soil are affected seriously. Residual effects of microwave treatments could not be found yet.

ELECTRICITY

Because of recent developments, electricity had to be included in the original definition of physical weed control made by SANWALD (1977).

Plants grow in the natural electric field of 100 - 130 V/m existing at the earth's surface. As this electric field belongs to the plant's natural environment, any change in its capacity can be expected to cause positive or negative changes in the life mechanisms of plants. Experiments conducted by NEACHEV (1975) indicated that plants are killed by electricity when the field capacity acting on them surpasses their physiological tolerance, this being between .001 and 100 V/m. He also described plant stems and roots as three -layered (epidermis - cells - conducting tissue) electrical conductors of finite length in order to facilitate a basic understanding of their various relationships. SVITALKA (1976) found that damage to vegetation by field breakdown is either due to electric currents flowing in the plant tissue and causing electrobiochemical and structural changes on a molecular basis, or, in spark discharge, to the pressure wave preceding the spark. Thermal and magnetic influences do not seem to be of any significance.

In further research, the technical problems of applying destructive high-voltage fields to plants were investigated by BAEV and SAVCHUK (1976) who were able to develop suitable electrodes. In the United States, DYKES (1977) obtained excellent results in killing weeds up to 120 cm high by using a high-voltage electric discharge system.

KNIEVEL and McKEE (1977) studied the effect of high-voltage electric fields on different plant species. Damage to plant parts was dependent on voltage and exposure time as well as on plant species, morphology, and age.

In a first serie of own experiments we exposed seeds of Lepidium sativum as well as wheat seeds to high frequency-high voltage (30 kV) electric fields for different periods of time (0.5 to 500 sec.), and determined their germination rate and shoot lengths. At the present stage we cannot yet draw any final conclusions; further experiments are underway.

As a conclusion to this section we can say that as experiments have only been started recently, progress is to be expected during the next few years. Results obtained hitherto look promising, and the future will show if an economically and biologically practicable system can be worked out.

ENERGY CONSIDERATIONS

Under the impact of the energy crisis, and with the prospect of rising energy costs, PIMENTEL et al. (1973) have considered the problem of energy and plant production. They could show that in industrialized countries, energy input is often higher than the energy produced by the plant through the conversion of the energy into combustible material. Even though the energy input share of plant protection as a whole amounts to about two per cent only (for USA agriculture) it seems justified to consider even only a part of this aspect, as it will be ever increasing importance (see also PRICE JONES 1975 and DIAS 1976). Therefore it seems advisable to check newly developed or suggested methods for alternative use not only for their effectiveness but also for their energy requirements. This is a rather complicated task, as many different components have to be taken into consideration, e.g. for chemicals: synthesis of the compounds up to the formulated product, transport and application; for flaming: production of liquid propane gas, application and equipment, etc.. Each single point consists of many sub-aspects, and for many of them the energy requirements are unknown.

After several different approaches and calculations, we decided to consider just the energy acting on the plant, as this is at present the only possibility for making any sort of comparison, even if certain partial aspects have to be omitted. That means, that for herbicides, the energy used for synthesis of chemicals which are later applied to a given area was taken, and for flaming resp. UHF-treatment the energy amounts leaving the burner resp. transmitter. The calculations are summed up in Tab. 1. The figures of the herbicide section have been calculated from LEACH and SLESSOR (1973), and GREEN (1975). Mean values were taken for application amounts (kg formulated product /ha) from commonly used herbicides (HEDDERGOTT 1977). The comparison shows that chemical weed control uses 10^1 resp. 10^2 times less energy than flaming or UHF-treatments. On the other hand, these numbers were calculated for one single application of either treatment. Considering the fact that two or more chemical treatments may be necessary during one year, while two flaming sessions and one UHF-treatment are sufficient, the energy requirements are not so very different. More precise studies will be possible only when further progress has been made in the practical use of physical methods, and the subsequent gathering of information.

Table 1

Comparison of energy amounts needed for chemical and physical weed control techniques

	Application rate (average)	Mean energy content per kg(J)	Control energy per ha(J)
Herbicides	3 kg/ha formulated product (calculated from HEDDERGOTT 1976)	1.5×10^{8} (GREEN 1975)	4.5×10^{8}
UHF-Radiation	$360\ J/cm^2$ (DAVIS et al. 1973)		3.6×10^{10}
Flaming	65 kg/ha (MERZ 1975)	4.6×10^{7}	2.96×10^{9}

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WEED CONTROL BY SOIL PARTIAL STERILANT CHEMICALS: A REVIEW

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Summary Complete control of weeds in seedbeds or whole fields can be achieved by application of methyl bromide at 20 g/m^2 and higher, and a treatment time of more than 6 h. Combinations of methyl bromide and chloropicrin applied for control of soil-borne fungi also give complete weed control. All such treatments are dependent on soil sealing with polyethylene sheeting, and are therefore expensive and can only be justified on high-value crops where the climate would normally permit successful cropping. Attempts to reduce treatment costs by eliminating sheeting and sealing the soil by rolling or application of water have in all cases given incomplete weed control.

There have been no detailed studies of the long-term effects on field populations of whole-field treatments giving complete or partial weed control.

INTRODUCTION

In 1869, in response to the devastation by the rootlet-sucking aphid (*Phylloxera vastatrix*) of the vineyards of Europe, Baron Paul Thenard conceived and developed the technique of soil fumigation. Carbon disulphide was applied to holes in the soil around vines, and although some vines showed evidence of chemical injury, complete control of the aphid was achieved (Tietz, 1970). The basic principle involved was diffusion through the soil of carbon disulphide vapour, with retention of the vapour in the soil for sufficient time to kill the aphids. Dosage of soil fumigants is a product of concentration and time.

An unexpected bonus from the treatment was improved vine growth beyond that which could be related to removal of the aphids. Later when resistant rootstocks were available, and even in some areas where *Phylloxera* was not a problem, soil fumigation with carbon disulphide continued to be practised because of the resultant yield increase (Wilhelm, 1966). In spite of numerous investigations, this growth response has still not been fully explained.

Since 1869 soil fumigation, or more correctly partial sterilisation (since some organisms survive all treatments), has been developed and accepted worldwide, with the greatest progress having been made since 1940. Based on the availability of relatively few suitable chemicals which have become commercially significant (Table 1), technological advances have nevertheless extended the control possibilities of soil partial sterilisation from insects, to weed and nematode control, and the control of soil-borne fungi; simultaneously the scale of operations was extended from treatment of bins of soil or small plots, to whole-field treatments. Such developments were undoubtedly aided by the introduction of polyethylene film which could be used to seal the surface of soil during treatment.

Aside from considerations of safety and cost, the requirements of a soil partial sterilisation treatment are that the method of application and total treatment time, including the time taken to remove phytotoxic vapour from the soil, should be acceptable to the grower, and that the treatment should leave the soil free of the target pest, weed or disease. While many chemicals have been tested as soil partial sterilants few have become commercially important. Of the true soil fumigants listed in Table 1 only chloropicrin, methyl bromide and 1,3-dichloropropene have significant usage today.

Table 1

Soil fumigants and chemicals with fumigant-like behaviour

True soil fumigants

- Carbon disulphide
- Chloropicrin
- Ethylene dibromide
- Methyl bromide
- 1,3-dichloropropene
- 1,2-dibromo-3-chloropropane

Chemicals with fumigant-like behaviour

- Sodium N-methyl dithiocarbamate (metham sodium)
- Tetrahydro-3,5-dimethyl-2H-1,3,5,-thiadiazine-2-thione (dazomet)

Methyl bromide has become particularly important since it combines activity across a wide biological spectrum (Table 2); it is a heavy gas with powers of deep penetration, and yet easy release from soil. Commercial applications involve 1-4 day treatment periods with planting after airing the soil for 7 days or less. Attempts to synthesise new products for soil partial sterilisation have failed to approach the efficiency of methyl bromide. Metham sodium and dazomet, which break down in soil to methyl isothiocyanate, are dependent for their distribution on mechanical incorporation which in most circumstances limits the depth of soil treated to between 15 and 20 cm. Treatments often comprise 3 wk for production and diffusion of methyl isothiocyanate, followed by cultivation to open the soil and a 3 wk airing period.

Techniques for the application of soil partial sterilants have varied with treatment requirements. In general, liquids (chloropicrin, 1,3-dichloropropene, metham sodium) have been injected into soil from point or line sources, granules (dazomet) have been spread and mechanically incorporated, and methyl bromide has been injected as liquid or vapourised onto the surface of soil previously covered with polyethylene film.

Table 2

Relative number of units of chemical required for direct control of indicated pests

Chemical	Nematodes	Fungi	Seeds	Soil insects
Carbon disulphide	> 100	> 200	> 200	> 100
Chloropicrin	12	25	50	10
Methyl bromide	15	40	25	10
1,3-dichloropropene	8	100	75	15

(After Goring, 1962)

Methods for sealing the soil surface to prevent loss of vapour (≡ loss of degree of control) have included rolling the soil after treatment, application of large volumes of water to flood the surface temporarily and finally, sealing whole fields with polyethylene sheet. It is significant that there are only occasional references to weed control by soil partial sterilisation where 'sealing by rolling' has been used. That Kingston (1939) was able to control Chenopodium album and Spergula arvensis with an application of 22.5 g/m^2 chloropicrin applied to planting holes was an indicator of what might be achieved with chloropicrin efficiently applied and sealed.

Development of methyl bromide as a seedbed herbicide

The first indication of the pesticidal properties of methyl bromide was in the control of insect pests in grain stores (Thompson, 1966). Attempts were made (Taylor & McBeth, 1941) to kill soil-borne nematodes by applying the chemical to soil covered with glue-coated paper. The application consisted of releasing 680 g methyl bromide liquid onto the surface of soil of c. 20 m^2 plots and leaving the paper seal in place for 24 or 48 h. The treatment did result in the death of root knot nematodes (Heterodera marioni ≡ Meloidogyne incognita) and the authors, on the basis of the estimated depth of penetration of vapour of 30 cm, concluded that the effective dose was 2 ml methyl bromide/0.08 m^3.

Methyl bromide was supplied in 1 or 1.5 lb (454 or 680 g) cans which were expended in one operation. Dosage was altered by varying plot size, although 100 ft^2 (9.3 m^2) was commonly adopted. In this way, and by varying the treatment time, the concentration/time product (CTP) could be adjusted.

After the report by Taylor & McBeth there were no major advances until 1951 when Kopitke, writing in the journal 'Down to Earth' described experiments in which polyethylene sheeting was used for sealing methyl bromide into soil. The first experiments involved release under the sheeting of 45 g methyl bromide for every m^2 of seedbed. With a 24 h treatment period, the author found it was safe to plant after airing the soil for only 4 days.

Although the methyl bromide was required to diffuse over a wide area from point sources, treatments resulted in complete control of nematodes, and a reduction in weeds such that losses of crop seedlings through hoeing were reduced. Kopitke was instrumental in the introduction of methyl bromide supplied from large pressurised cylinders and was therefore able, using a weight loss basis, to regulate the dosage. Using similar techniques, Koch (1951) successfully treated bins and heaps of soil sealed by polyethylene. A dose of 2 ml/0.08 m^3 methyl bromide eliminated weeds and controlled the damping-off fungi Rhizoctonia and Pythium. This treatment is regularly used at NVRS in the preparation of soil for potting compost. When a similar treatment was applied to tobacco seedbeds (Hill et al, 1951) complete control of Cynodon dactylon was combined with enhanced seedling stand. In cauliflower seedbeds (Marvel, 1953) weeds including Agropyron repens, were eradicated; in Azalea and pansy plantings (McFaul, 1955) there was complete weed control; and in cabbage seedbeds (Winstead & Garriss, 1960) a weed-free stand of transplants was obtained.

The next advance in application technique was based on the idea that the treatment might be more effective if methyl bromide vapour, instead of liquid, was applied. Sorbtion of the chemical on soil particles would be reduced, and diffusion could be aided by increasing the number of application points. Davidson (1957) introduced the technique of vapourisation of methyl bromide in a heated copper coil, followed by release of the gas through pipes with multiple outlets. With a dose of 68 g/m^2, varying the treatment time from 6-48 h had no effect on weed control. The application of vapourised methyl bromide spawned the work (Hague et al, 1964; James & Hague, 1967) which led to annual fumigation of the soil in the culture of glasshouse tomatoes in the United Kingdom and Holland.

A later, novel application of the technique was that of Goldberg & Uzrad (1976) where methyl bromide vapour was channelled down permanent irrigation pipes in the centre of strips of polyethylene sheet prior to seeding with tomatoes. Some weeds (Malva, Erigeron and some legumes) survived the treatment, but the effectiveness was sufficient to justify its adoption.

Until the mid-1950's, work had been largely empirical and experimenters made no attempt to develop the technique beyond the seedbed situation. An indication of the future potential was given by Adamson (1956) who reported a series of experiments on the control of Convolvulus arvensis in which paper covers were tested and ultimately replaced by polyethylene sheeting. Adamson took the simple step of burying Convolvulus seeds in plots and was thus able to correlate field results with a quantitative assessment of treatment effects. Treatment with 68 g/m^2 methyl bromide gave a complete kill of buried seeds and left field plots free of bindweed.

Progress to whole-field treatment with methyl bromide

In contrast to the Phylloxera experience where the existence of an established crop was threatened, the development in California of field tomato production was prevented by infestations of the introduced parasitic weeds Orobanche ramosa and O. ludoviciana. Where the use of cultural techniques or conventional herbicides failed to control Orobanche, treatment of infected land with methyl bromide succeeded (Wilhelm, Benson & Sagen, 1957). Working from original observations by Benson that methyl bromide killed the minute seeds of Orobanche, these workers demonstrated that 23 or 45 g/m^2 methyl bromide vapourised onto sheeted field plots could reduce the number of seedlings in 1000 m^2 to that previously encountered in 0.1 m^2. It was also noted that C. dactylon and desert annuals were controlled. One year later (Wilhelm et al, 1958) the work had progressed to the successful use of injection of liquid methyl bromide or a 70% solution of the chemical in kerosene (Weedfume). Polyethylene sheets 6 x 400 m were placed in position in the wake of the injection machinery. Applications of 20 g/m^2 methyl bromide, with a one-day treatment period, consistently gave Orobanche-free tomato crops. In two years c. 350 ha were treated in this way. The benefit to growers extended beyond the control of Orobanche, since control of root knot nematode was complete, improved tomato seedling stand reduced the amount of seed required and more uniform crops lead to easier harvesting (Wilhelm, Storkan, Sagen, Carpenter, 1959).

In a review of the history of Orobanche, Wilhelm (1962) signalled the end of the weed (and probably of other weeds) as a problem in high value field crops and introduced the concept of soil injection of chemicals for the control of pathogenic fungi.

In the meantime, J. Wilhelm, the brother of the experimentalist S. Wilhelm, developed a process for the inexpensive production of chloropicrin, and Storkan founded Tri-Cal Inc., a company which produced machinery for the simultaneous injection and sheeting of whole fields.

Later publications concerned the use of chloropicrin-methyl bromide mixtures in controlling Verticillium wilt of strawberry (Wilhelm et al, 1961; Wilhelm, 1962). The basis of this work was the discovery that applications of mixtures such as 57% chloropicrin with 43% methyl bromide were more effective than applications of the same total amount of either chemical (ie the mixture is synergistic). Control of Verticillium wilt was achieved, together with a fourfold increase in yield of berries. Since the treatment was sufficiently stringent to control a persistent fungal pathogen, the weeds must have been killed, and from being a pre-occupation in the early work, weed control was generally accepted. By the mid 1970's adoption of this technique by customers of Tri-Cal alone amounted to annual treatment of 8000 ha in California.

Although the preceding account indicates a steady progression from an original idea to whole-field treatment, many other important factors contributed to this development. Expansion of whole-field treatment in California was greatly benefited by the types of field soil in cultivation, by temperatures suitable for efficient vapour diffusion and also a climate which permitted growing of high-value crops outdoors. Additionally, programmes of land levelling for the introduction of furrow irrigation facilitated secure covering of whole fields with polyethylene. In the Salinas valley where treatments were designed to remove the weed hosts of lettuce viruses, it was necessary to safeguard the field crop by use of conventional herbicides on all headlands and waste areas (A S Greathead, personal communication).

The basic concept of simultaneous injection and sheeting of soil partial sterilants spread through the United States with only minor changes in specification. Apart from routine applications such as in the large-scale production of woody ornamentals (Haasis & Sasser, 1962) the technique proved valuable in a programme for the eradication of the introduced parasitic weed Striga asiatica in North Carolina (Eplee & Langston, 1972).

In contrast, the introduction into the United Kingdom of simultaneous injection and sheeting of whole fields did not occur until 1976 and was limited to injection of methyl bromide; to date usage has been confined to less than 50 ha. White (1977) suggested that the main reason for this delayed introduction was a climate unsuitable for extensive outdoor production of high value crops. Other contributory factors include the necessity to import at high cost from America or Israel virtually all supplies of methyl bromide and a general lack of interest in the exploitation of this technique.

Other soil partial sterilant treatments

In addition to the successful use of methyl bromide to control Orobanche, Wilhelm et al (1958) reported failure to control the weed with chloropicrin, carbon disulphide, dazomet (Mylone) or metham sodium (Vapam) when soil was not sheeted. Attempts at control with applications of methyl bromide in which split doses were injected on successive days with cultivation and rolling were also unsuccessful. Since the analysis by Goring (1962) of the principles of soil fumigant action it is possible to explain why the treatments failed or were only partially successful. During treatment of sheeted soil vapour diffuses along gradients with the result that a high, even concentration is found in the upper part of the soil. When the soil surface is not covered there is a loss of vapour to the atmosphere, and as the diffusion gradient out of the soil is accentuated, vapour loss accelerates. In this way the upper 2 cm of soil is effectively by-passed. Wilhelm and his co-workers became aware of this, and the use of chloropicrin in combination with methyl bromide, as described earlier, became an important part of their work. The concept of sealing with polyethylene for the low volatility partial sterilants was not exploited further until the work of White & Buczacki (1977). Although 1,3-dichloropropene (Telone) is a nematicide, when sealed into the soil by polyethylene sheeting and left in position for 14 days, the chemical gave control of clubroot (Plasmodiophora brassicae) equal to that achieved by the use of methyl bromide. Weed control was also complete.

There are weed problems in many crops that cannot stand the high cost of methyl bromide/polyethylene treatment. Piglionica (1975) however was able to demonstrate some control of Orobanche crenata on broad bean and pea with ethylene dibromide applied at planting time. Extensive studies showed that treatment with the chemical would give reasonable crops even in fields where, because of the degree of infestation, the predictable crop yield was nil. Nevertheless, whichever way the treatments were manipulated, some broomrape always survived.

Deep-rooted weeds may be controlled by soil partial sterilant treatments applied without polyethylene sheeting. In an investigation of deep placement and split application of 1,3-dichloropropene, ethylene dibromide and chloropicrin, Ogg (1975) demonstrated control of Cirsium arvense with soil sealing by a heavy roller. Unfortunately his experiments were marred by the growth of broadleaf weeds from the upper portion of the soil. A dose of 56 g/m^2 1,3-dichloropropene injected at 46 cm depth gave best thistle control. It is unlikely that the omission of the polyethylene sheeting would result in reduced expenditure since it was necessary to apply a high dosage of 1,3-dichloropropene, employ equipment capable of injecting into the subsoil, apply a heavy roller and still use conventional herbicides.

Some soil partial sterilant treatments which have been shown to be effective, but which have failed to be adopted on a large scale, are nevertheless retained by growers for use on a relatively small scale. Mixtures such as methyl isothiocynanate with dichloropropene and dichloropropane (Trapexide, Ditrapex) which were developed in Germany are used for weed and disease control in the Channel Islands. Usage of allyl alcohol, which was developed for weed control in horticultural crops in Scandinavia and the UK (Roberts & Proctor, 1964), never became significant on a worldwide basis, but the chemical is still used in celery seedbeds in Florida.

Apart from the previous examples of attempts to control weeds without the use of polyethylene sheeting, it is only possible to consider experiments where the primary target of the treatment was a pest or disease, but where weed control was also observed. Wilson (1968) quotes several reports of significant weed control in potatoes resulting from treatments designed to control nematodes or Verticillium infection. Similarly, Cetas (1958) demonstrated some weed control with applications of metham sodium (Vapam) when the primary target was clubroot. Moate & Taylor (1976) comment on significant weed control when dazomet (Basamid) was applied for the control of Phoma root rot and clubroot disease of brassicas, unspecified fungal pathogens of radish and for the preparation of land for cropping with outdoor tomatoes.

Following development work in Holland (Nuyten, 1975), Andrews (1977) and Davison (1978) investigated the possibility of applying low doses of metham sodium (Vond Metam) to the surface of soil prior to cropping the short-lived block lettuce crop. Treatments significantly reduced numbers of weeds, and because of the nature of the application, block lettuces could be planted 2-8 days after application. This unconventional approach could well be extended to other block planted crops, and should overcome the problem of surface weeds germinating after soil cultivation. Since metham sodium is non-selective, the chemical will control some weeds which at present cannot be controlled by conventional herbicides.

Although there are many reports concerning the use of formaldehyde as a soil sterilant, there is little information on its herbicidal properties. In experiments carried out by the author, soil treatments with formaldehyde applied for clubroot control failed to give complete control of weeds. Although numbers of Graminaceous weeds were reduced, populations of Urtica urens and Stellaria media were unaffected (White, unpublished data).

In all cases where applications were made without polyethylene sheeting, the indications were that the numbers of weeds were reduced, but that a portion of the normal field population survived. It is possible that the survivors, presented with reduced competition, would grow vigorously and ultimately return as many seeds to the soil as the original less vigorous populations. In the long run, such reductions in weed stand are unlikely to be significant.

CONCLUSIONS

Complete control of weeds in seedbeds or whole fields can be achieved with soil partial sterilant treatments such as 20 g/m^2 methyl bromide sealed into the soil for 24 h by polyethylene sheeting. Increased dosage, or the use of methyl bromide/ chloropicrin mixtures improve efficacy. Because of the economics of such treatments, it is normal to apply the minimum reasonable dosage which would give control of soil-borne fungi, with weed control accepted as one of the treatment benefits. Clearly the grower having made considerable investment in the treatment of whole fields, must protect that investment by the use of conventional herbicides on weedy areas around fields.

Apparently there is no published information on whether, or how quickly, weed populations return to normal, or whether a whole field treatment giving complete weed control might minimise weed problems for several years. This information could be of value where crop economics prevent annual treatment, but where a treatment that could simplify the work of conventional herbicides might be used every 3 or 5 years.

An area which appears to have received scant attention is the use of low volatility soil partial sterilants in conjunction with polyethylene sheeting. It is possible that chemicals such as 1,3-dichloropropene could give weed control equivalent to that of methyl bromide, but at reduced costs.

Soil partial sterilant treatments applied without sheeting give partial or no control of weeds. There are suggestions that significant weed control has been obtained, but it is likely that this was based on killing of weed seeds below the surface of the soil with dilution by cultivation of viable seeds from the soil surface. Although it is unlikely that the effects of a single application would be of long-term significance, it would be valuable to determine the effects on weed populations of annual applications of soil partial sterilants without sheeting.

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