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Br. Crop Prot. Counc. Monogr. No 18 (1976)

REVIEW OF GRANULAR PESTICIDES AND THEIR USE

W. F. Jepson

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Summary A short history of the changes over the past 20 years in granule application to a selection of major world pest problems is followed by a technician's and consumer's-eye view of salient aspects together with an appeal for an integrated and interdisciplinary approach to the promotion of granule technology.

Resume Un bref aperçu des changements de méthodes et de produits dans l'emploi des pesticides formulés comme granules, en ce qui concerne certaine groupes de problèmes d'importance mondiale est suivi par une revue des critères physico-chimiques et un appel pour l'intégration des efforts multi-disciplinairesdans la promotion de la technologie granulaire.

INTRODUCTION

The reasons which have inspired the British Crop Protection Council to call this first Symposium on Granular Pesticides will become apparent in the remarkable diversity in the range of topics to be dealt with in the programme. Granule technology has always been beset with problems which in the past have tended to be considered and solved in isolation, without benefit of well formulated principles involving a consensus amongst chemists, biologists, chemical and machinery manufacturers, agriculturists and the user public, the latter now well informed as to the economics and environmental issues of pesticide usage. I think it will be the task of the Symposium to lay the foundations for a set of inter-related standards which define the position of granular pesticides in the agricultural market place, the broad specification of granule carriers, sizes, hardnesses, absorptive and release capacities, behaviour and safety in transport and use, and biological efficacy in the various fields in which they provide a substitute or a supplement to the well established spray methods. We may start with a short review of the history of granule development, and then proceed to consider, under the headings which I have suggested, the present state of the art, pointing hopefully to lines of convergence or co-ordination of effort in planning for the future.

HISTORY OF GRANULE USAGE

1. Granules in soil pest and aphid control

The value of dry granular materials was already well recognised in the 1930's in the use of calcium cyanide granulars in soil disinfestation, in citrus tree fumigation, and the protection of stored grain. During the Second World War, the ploughing up of pastures for crop growing had created serious problems in wireworm, millipedes flea beetles etc. and with the invention of DDT and lindane, mixtures with starter fertilisers were developed, which led in due course to aldrinated granular fertilisers for use in many arable crops, especially potatoes. These were all contact or repellent insecticides, used at about 2% of active ingredient, to which were added on the Continent in the early 1950's, granular parathion, and diazinon.

The first systemic granulars to be developed were disulfoton and phorate, highly basically toxic materials (L.D.50 less than 10 mg./kg). These were liquid technical products absorbed into pumice and Attapulgite respectively, and when applied at planting gave several weeks protection against aphids, leafhoppers and red spider mites when applied at seeding or in over-the-row banding in sugar beet, potato, cotton and other rather long season crops. The main technical problem to be overcome was the necessary reduction in application rate from the conventional fertiliser range from 40 to 200 kilos/ha down to 10 - 20 kg/ha. We shall see how this has been achieved by a number of well known manufacturers, some of whom can now supply equipment to apply as little as 5kg/ha. into the planting furrow. It is probably true to say that the introduction of granules in the potato crop (Lindley 1961) was a major factor in the suppression of virus leaf roll in the early 1960's.

During the past decade, a number of more versatile and in some cases less toxic compounds have been introduced into the range of pesticidal granulars. The majority of these have been concerned with the longer-lasting control of soil pests such as the American Corn Rootworm (Diabrotica spp.) with carbofuran, chlormephos and trichloronate, and with the protection of crops in their early stages from attack by Dipterous larvae living at or just above soil level. The successors to Dieldrin on cabbage root fly and diazinon on carrot and onion flies have been typically chlorfenvinphos carbofenthion, phoxim and fonofos. Of the many granulars tested at Broom's Barn for early protection of sugar beet against soil pests, combined with a degree of control of Aphids aldicarb, a systemic with considerable nematicidal action and formulated as a 5% coated granule stands out both in effectiveness and versatility in spite of its high mammalian toxicity. Pirimicarb offers a good control of aphids. In France even more recently the phorate analogue terbufos (2% granule) has been successfully established in sugar beet as a combined soil and systemic treatment for the more extended list of early pests, which include millipedes Pegomyia and white grubs (Melolonthidae). The dosage levels have been steadily reduced in response to the general demand for lower chemical contamination from 2 kilos or more (aldicarb and chlorfenvinphos) to 180 grams active substance per hectáre (Terbufos), a reduction which also lessens the danger of phytotoxicity. These tendencies have increased the demand for greater precision in dosage and placement, especially in France and Germany, where granule attachments are built into beet, maize and potato seeders for application of doses down to 5 kg per hectare. (Migrasol, Cramer, Stoll) These machines are, however, much more expensive than the traditional American and British design of granule applicator (Gandy, Noble, Horstine Farmery), and their cost has to be spread over a large acreage (or can one say now 'hectareage' ?), in view of the limited versatility of such equipment

2. Granules in the control of Lepidopterous & Dipterous Stem borers of Graminaceous Crops

The second major field for granule development in the past decade has been in the control of Pyralid and Noctuid stem borers in rice in Eastern Asia, and in maize in Africa and with the great explosion in maize culture (2 million ha. from less than 1 million hectares), in France. The species concerned are the rice stem borer Chilo suppressalis and its allies, the maize stalk borers Busseola fusca and Sesamia spp in Africa, and the European corn borer Ostrinia nubilalis in France and Eastern Europe.

The insecticides used began with DDT in maize, Lindane and parathion in rice, and to these have been added carbaryl, tetrachlorvinphos, mephosfolan and endosulphan, a typical range of caterpillar insecticides, all applied to the earlier vegetative stages of the plant, or on the irrigation water surface. Application methods range from the directed "pinch", to sophisticated air-assisted granule blowers and aerial equipment.

3. Granulars in Herbicides

The necessity for uniformity in broadcast distribution and for maximum points of impact (Degez et al 1975) has led to the development, chiefly in Germany of micro-granules (80/140 mesh), for the application of the triazines in maize and in perennial crops. The special air-assisted equipment required for wide swath distribution has been derived from their great experience in the design and manufacture of mist and dust blowers. The early results have evidently been disappointing and this was accentuated in the viewing by many European toxicologists of microgranules as dusts.
In extensive crops in Europe generally, only triallate formulated as conventional granules is increasingly used for wild oat control in cereals, though the appearance of a number of highly selective and effective spray materials presents strong competition with any granule method. With the latest extension of the technique of Ultra Low Volume in the herbicide field, a serious challenge to the microgranule technology may only be retarded by the resistance of many European registration authorities to the potential danger of releasing more highly concentrated pesticides into the environment.

4. Granulars in Public Health Insect Control

In public health work, the relative cleanliness and precision of granule usage have encouraged the introduction of DDT, lindane, fenthion, chlorpyriphos and temephos in warm climates to control flies in latrines and other domestic situations, and mosquitos, blackflies and chironomids in casual waters, marshes, ricefields and rivers. Application methods vary from the simple but quite efficient horn seeder, to aerial distribution of light formulations, according to the scale of operations and the social and economic level in the biocoenose.

The main technical probl ems in granule usage in public health have been subject to much research and the whole weight of the Vector Control Division of the World Health Organisation and related national bodies has been thrown behind the field testing of commercial products, and of the framing of recommendations and specifications for the treatment of vector sites and refuges. In the United States, Mulla (1963) reviewed the crucial factors associated with the release of toxicants and breakdown of granules in the great variety of unfavourable media in which they are required to give good persistent control of nuisance and vector species.

Much research remains to be done in the development of robust and efficient machinery for the application of granules for vector control in large scale campaigns such as the control of Simulium in West Africa and of nuisance mosquitos in the French Mediterranean littorale.

5. Toxicology and Registration of Granular Pesticides

The increase in public concern for the protection of the environment and the user against the misuse of pesticides has been reflected very clearly in the setting of criteria for registration, especially in the U.S.A. and Europe. Of necessity, any registration code is built up over the years by piecemeal accretion. Demands formulated by national registration authorities over the past fifteen years, apart from the universal desire for firm, dust-free low concentration granules have included dyeing to warn children in Denmark, bird searches to validate bird safety in England, tests on eels, trout and other local food animals, tests for leaching into streams in Italy, and demands for the coating of all toxic granules in Italy. On the other hand, a more enlightened view of the intrinsic toxicity of granules as measured by the dermal LD 50 instead of rejection out of hand on a threshold figure of acute oral LD 50 of the active ingredient. Insistence on extended tests may well be the result of over zeal, and contributes to the ever increasing cost of launching any pesticide or drug on to the market, a cost which is inevitably borne by the consumer.

Present State of Granule Development

The present state of granule development may perhaps best be illustrated by the figures of granular formulations available in the market in France, Great Britain, Germany and Yugoslavia. In the case of France, we have a veritable Bible of Plant Protection in the "Index des Produits Phytosanitaire", from which the following figures are derived.

Number of Commercial Formulations (1975)

	Insecticides	Fungicides	Herbicides	Nematicides	Total
France	72	1	25	8	106
Great Britain	21	11	-	-	32
Germany	-	-	-	-	ca. 15
Yugoslavia	16	1	7	1	25

Granule sales are properly a closely guarded trade secret, but it is estimated from tonnages of industrial minerals sold as pesticide granule bases, that a total of 30,000 to 50,000 tons of formulated granules are marketed in Europe annually.

Advantages of Granules

A masterly statement of the many and varied advantageous features of granular pesticides was given by Sumner (1974) in a paper to the 1st International Congress of Industrial Mineral, the first time that the pesticide usage of minerals had been introduced to mineral producers. A good granular treatment should do the work of two sprays, with precise and economical placement using safe and non-contaminating equipment, without the hazards of mixing toxic concentrates, of poisoning the operator, and of drift of fine particles in windy conditions so commonly encountered in Northern Europe. The metering of the dose, from the package to the crop is greatly simplified by using a ready mixed diluted product, which lends itself to simultaneous application with other operations, seeding, cultivation or fertilising. With the modern selection of granule carriers, and easy attainment of any specification which may be demanded by national registration authorities combined with safely enclosed precision machinery for application, most of the purely technical problems of granule usage seem to be within range of solution. And yet the explosion so confidently predicted on many occasions during the past twenty years by granule protagonists has failed to be realised and once more we are faced with an economic situation which actively discourages rapid changes in traditional methods. The use of granulars must clearly succeed in its own right in straight confrontation with other chemical methods of control of pests diseases and weeds. As Professor Mellanby pointed out in a recent article, the champions of doom and danger from the environment have seen their priorities upset by the economic, social and political stresses, resulting in an ever increasing demand for maximum immediate benefits from the cheapest and most readily available inputs. In the pesticide field, the professional user is by now fully aware of the dangers of the weapon he wields, but he is unlikely to pay from his own pocket any premium in the shape of heavy capital investment in new machines or more expensive formulations, unless it is reflected in the returns he can obtain from the market place in the short term.

We may then turn to the requirements relevant to the granule method, with which the many contributors to this Symposium will be concerned in all phases of their preparation and field use. It is with the latter phase that we shall start.

1. Biological Requirements for Granules

The niche filled by the granule method has been broadly stated in the foregoing historical review, and this is unlikely to be dramatically diversified in the near future. For soil and near-soil applications, a heavy dense free-running granule of specific density of about 0.9 gm/ml, absorbant and retentive for the more volatile insecticides, will probably meet most needs. Diffusion of the active ingredients into the soil/crop biosphere may be realised by the size of the granule and the number of points of impact per unit of area or volume (Degez et al 1975) which will be largely regulated by the dosage rate and efficient uniform distribution of granules at the appropriate level. Solubility of the chemical as well as the physico-chemical properties of the soil will also play an important role. For insects such as wireworms millipedes and white grubs, an element of repellency is probably involved, but the main requirement is certainly to kill the invading population over a critical period, which may not necessarily extend over the whole season of the crop. The protection afforded to the potato crop by disulfoton or phorate extends for more than three months, although the products will have been almost completely metabolised during the period, and only in exceptionally late aphid attack will further spray treatment be necessary. The same may be said about aldicarb in the sugar beet crop. Whilst many individual studies have been done on the fate of granules applied in the routine commercial manner, there seem to be no acceptably comparative methods by which the spatial distribution of particles in the soil can be mapped, and the chemical action whether by direct contact or by diffusion into the infested sites demonstrated and quantified on the pest species and on their natural enemies. Studies conducted on soils of recognised pedological groups should not be considered academic in that any resulting general principles should be of immediate benefit to manufacturers of granular formulations. Similar reasoning can be applied to granules for application to aerial parts of crops, whether to field beans for aphid control or to maize and sorghum for the control of stem borers, or again to water surfaces for insect or weed control. Retention of angular particles by leaf surfaces or axils, fumigation effects on aphids quick break-up of a softer granule (e.g. bentonite) whether on the plant or in water, are topics which require further investigation, so that a body of basic knowledge and rationalisation of the many fragmented observations on granule action may be built up. The whole subject has been well reviewed by Walker (1972).

2. Sources of Granular Materials

The following substrate materials, which may be broadly classified into sorptive and non-sorptive types, are in widest use in the manufacture of agricultural and public health granules:

Clays: Attapulgite/Polygorskyite, Montmorillonite, Sepiolite, Bentonite, Kaolin

Silica: Diatomite, Perlite, Pumice, Volcanic cinder, Graded Low angular sand

Low-sorptive: Talc, Calcite, Gypsum, Anthracite, Graded brick

The structure and classification of the hormite clays was discussed by Robertson (1974).

Since the major tonnages of many of these minerals are used in the realm of absorptive floor litter in oil refineries, in oil filtration, in cat litter and in building insulation, the higher priced but lower volume pesticide market is of necessity a spin-off from these other uses. The manufacture of the modern granule to very narrow specifications calls for heavy investment in mining of a steady supply of uniform raw materials, and in the grinding, extrusion sizing and drying, often with calcining, of a homogeneous mixture of these materials. We shall be hearing more on the mining and production aspects of granules from later speakers, but it must be said that the relative cost of these granules, ranging from £70. per ton for many of the clays down to £25. and less for graded low angular sands imposes important decisions as to the advantages and disadvantages of a commercial choice of carrier, for the market in which it is to be sold.

Formulation, Characteristics and Testing of Granules

Details of the various methods of formulating and preparing pesticide granules for the market are given by Whitehead (1976) in this Symposium.

In the early days of DDT, granules were commonly of 10% concentration, and were applied at 15 to 30 kg per hectare. The tendency in Europe with the acceptance of more basically toxic products has been to bring concentrations down to 5% and latterly to 2%. Unless the active substance is inherently more effective, the higher rate of application will obviously make granule treatments less economic, and in the U.S.A., the tendency has been to increase concentrations to 15%. This is only practicable where extensive crops in rural areas are to be treated with sophisticated equipment, as in the case of the Corn Rootworm in the Mid-West.

The hardness of granules can in the case of clay carriers be adjusted to the wishes of the user by calcination of the blank granules at about 450°C.

Such granules will of course be drier with about 1% of moisture, and less absorptive. Many organic pesticides, especially organophosphorics, may be relatively unstable on carriers with high pH or with many active sites within the lattice structure of the mineral. This may be corrected by the addition of 4 - 6 percent of a stabiliser such as a glycol, which involves the loading of the granule with extra liquid, and may cause problems with stickiness in granules of 10% and upwards. Shelf life of granular formulations should be at least two years under local ambient conditions, with a limit of degradation of 10% at the end of this period. The abrasion of granules during manufacture, transport and application, resulting in dustiness, is one of the major obstacles to registration of a product, as well as to acceptance by the worker in the field. A further result of using a dusty granule is to increase the wear and tear on the metering gear of the applicator, especially when silica or calcitic carriers are involved. The Dust Specification of the British Pesticide Safety Precaution Scheme (B.S.P.S.) lays down the limits, details of which are fully dealt with by Crozier (1976).

Methods of Testing Granules

Methods of testing granules, both by manufacturers for adherence to specification, and by public bodies for safety and efficacy before and after delivery to the consumer will be dealt with in detail during the Symposium, and clearly some agreed international standard should be the aim. F.H.Smith (Cyanamid International, in a personal communication) sets out the following headings under which inert granular carriers should be tested:

1. Sorptivity - if non-sorptive, the firmness of bonding of the active ingredient will be subject to test
2. Hardness
3. Particle size
4. Inertness
5. Wet breakdown of sorptive granules
6. Chemical/Physical Stability

A blueprint for these tests, which are all relatively simple, should be drawn up in consultation with those who will be required to conduct them in the field, both technical and commercial. The prescribing of branded items of equipment and reagents, often only obtainable from suppliers in far-off countries should be studiously avoided. Much research still needs to be done in the field of stability and release, and the relation of pH to PKa, and the role of hydrogen bonding as criteria for predicting the behaviour of granules when they are exposed to storage or to soil moisture. The exact role of stabilisers such as the glycols in pre-empting active sites in the lattice structure of clays and other complex minerals should be expounded so that it becomes intelligible to the non-specialist granule technologist.

Methods of Application of Granules

Since the use of pesticidal granules is clearly descended from fertiliser practice or from techniques of dusting, the development of equipment for spreading or accurate placing of expensive pesticidal formulations at greatly reduced rates of application has followed a predictable course. If we pass by the hand spreaders such as the horn seeder, and the chest-mounted rotaries without disdain, for they are widely used in the tropics, our main concern will be for the tractor or implement-mounted furrow and banding applicator.

No apology is needed for singling out one of our later speakers, Mr. Horstine Farmery for his pioneering work over the past fifteen years in developing a versatile extensibl e and economic system for delivering granules to extensive agricultural crops with precision of dosage rate and placement. The system is versatile because the farmer can use the same piece of equipment for furrow treatment, banding along the row ('Bow-wave'), side dressing, or high clearance application to brassicae, beet or beans. The metering rotor is original and accurate, and is so installed in its housing that minimal leakage and grinding of the granules occurs. Eliminated also was the sliding dose regulator, the bugbear of all users of earlier equipment. The independant field drive to the rotors reduces errors due to uneven ground by means of its large spider wheel, but this is not universally popul ar owing to the vul nerability to buckling on the headlands, and during the long periods of winter storage so often in the traditional back of the barn, or even under the hedge. These machines, of which there are several well known and successful makes (Gandy, Noble, John Deere, (U.S.A.) Tank (Belgium), Migrasol, Stanhay-Herriau (France), Stoll, Cramer (Germany), Zorka (Yugoslavia), might well be further developed in the direction of reducing the number of hoppers, and of various detachable items which are easily lost in the field. Reduction of chances of corrosion by using lighter non-rusting materials would also be the answer to the layman's prayer. A built-in quick calibration meter would perhaps meet the present trend to put labour-saving before capital expense.

Air-assisted granule equipment is indicated in uses such as the control of aphids on beans, of the rice stem borer in rice paddies, and in the whole field of granular herbicide application, e.g. simazine and atrazine on Maize, triallate on cereals. Particle sizes range from 30/60 for the insecticides to 80/140 for herbicides ('microgranules'), and swath widths up to 10 metres on either side of the tractor. At present the added capital expense of buying and operating such specialised machinery would tend to restrict the development of the method in Western Europe to large scale enterprises. It would seem well adapted to the Kombinats in Yugoslavia, the State Farms in Hungary, kibbutzim in Israel and similar institutions.

The use of conventional knapsack mist blowing equipment for applying weedkillers in forest nurseries, young plantations etc., has prompted several German firms to install hopper-shaped tanks and optional wide tube feed to their knapsack sprayers. If granule weed killing should be more widely accepted, such machinery should claim an increas_ed share in an expanding market.

Aerial application of granules for the control of aphids in full grown crops, is practised over several thousand acres of cereals and field beans in the U.K., a contractor's operation well suited to unforseeabl e outbreaks of sporadic pests. In Yugoslavia, many thousands of tons of DDT and Lindane granules were spread over sugar beet fields in spring for control of the large bl ack Curculionid, Bothrynoderes (Cleonus), and later in the season in maize for control of the European Corn Borer Ostrinia nubilalis. For these purposes a lighter, softer, quick acting granule is preferred, and both pumice and bentonites are suitable carriers.

Conclusions

From this review of many of the aspects of the granule story, we may conclude that this is no novel technique, but has been steadily if unspectacularly developed over the past twenty years in agro-ecological niches where it is at least as effective, longer lasting, cleaner for operator and environment, and commensurate in cost with traditional spraying or drenching methods. Without anticipating our closing Session 5 it is right to stress that the great upswing in granule usage in France, right across to Roumania which has occurred during the past 5 years will provide a launching platform from which scientists and technologists from this country and from the United States can provide a radiating burst of new ideas and new applications of this fascinating branch of agricultural development.

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CHLORPYRIFOS GRANULES FOR THE CONTROL OF SOIL PESTS IN BRASSICA AND OTHER CROPS

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Summary Trials carried out from 1973 have shown chlorpyrifos 5% granules to be active against a valuable range of soil pests. In the principal use against cabbage root fly (Erioischia brassicae), at a rate of 4.4 kg a.i./treated ha, chlorpyrifos granules gave control always at least equal and frequently superior to that of the standard products.

Other trials showed good results against wheat bulb fly (Leptohylemyia coarctata) at 0.8-1.0 kg a.i./ha and leatherjackets (Tipula spp) at 0.6-0.8 kg a.i./ha, chlorpyrifos granules again frequently showing superior activity to that of the standards.

Chlorpyrifos granules have satisfactory physical properties and can therefore be used through all appropriate application equipment.

Phytotoxicity and taint tests have shown the granules to possess a high level of crop safety at all stages of plant development and to be free from flavour taints.

INTRODUCTION

Chlorpyrifos, a broad spectrum organophosphorus insecticide of moderate mammalian toxicity (WHO 1975) was introduced under the trade name 'Dursban' (R) by the Dow Chemical Company and has been used for many years in the U.S.A. for cockroach control. Evaluation against United Kingdom pests was started at Lenton Research Station in 1967 but it was not until 1973 that the economics of use justified full scale development of a granular formulation, initially against cabbage root fly (Erioischia brassicae) and more recently for the control of wheat bulb fly (Leptohylemyia coarctata) and leatherjackets (Tipula spp). The field work carried out to prove the efficacy of chlorpyrifos granules against these pests is described in this paper.

(R) Dursban is the registered Trade Mark of the Dow Chemical Company.

PROPERTIES

The properties of chlorpyrifos have been fully described by Sparrow et al (1973); details relevant to its formulation as a granule are listed below.

Chlorpyrifos

Vapour pressure: 1.87×10^{-5} mm Hg at 25°C

8.15×10^{-5} mm Hg at 35°C

Solubility: Extremely low in water

Toxicity to earthworms: No long term effect at rates up to 4.4 kg a.i./ha (Sparrow 1973, King 1969)

Granules

Formulation: Chlorpyrifos as a free flowing 5% a.i. w/w granular product is formulated on a sepiolite base. This is a non-abrasive clay compound less dense than either Fuller's earth or pumice. The granules of which there are 10,000 per gram are formed through a 30/60 mesh. This formulation, used in all the trials is the current commercial product.

Mode of action

Chlorpyrifos, active by contact, stomach and vapour action (Sparrow 1973) is not systemic in plants. Because of its low water solubility chlorpyrifos is not leached and remains active in the soil for at least two months after application, with a half-life of about 90 days. Thus it is very suitable for application in granule form.

METHODS

Thirty-six trials were carried out from 1973-75 on brassica crops against cabbage root fly. Applications were made primarily using Horstine Farmery Microband applicators. Application to transplanted crops was by sub-surface placement using a Leeds coulter at the time of transplanting. In this technique the granules are delivered into the upper 5 cm of the soil through the small hollow coulter which is fitted in front of and in line with the planter share.

Bow-wave treatments were used on direct drilled brussels sprouts and in seed-beds where the granules were applied as a band through a fish-tail outlet and the seed drilled through this band. Broadcast applications were also made in some seed-bed trials. This technique is the same as that used in the cereal trials described below. A Fisons Pest Control hand applicator or a pepper-pot applicator were also used for applications by hand in some small scale trials.

The rate of use, based on preliminary field work carried out by Dow Chemicals, was the same in all trials irrespective of the application technique used. This was 4.4 kg a.i./treated ha (60g per 43m crop row) and all applicators were calibrated to deliver this rate.

Assessments were made on at least 20 randomly sampled roots per plot by grading the roots according to the amount of damage and then converting this to a percentage (Wright 1953).

In 1974-75 on cereals, nine trials were carried out against wheat bulb fly and eleven against leatherjackets. Broadcast applications were made using Horstine Farmery TMA2 or TMA4 applicators or a Vicon Varispreader fitted with a long delivery spout. The Horstine Farmery machines were originally used for granular herbicide application but after fitting with different sized rotors were found to be very suitable for this work. The Vicon Varispreader used for fertilizer applications was suitably modified by fitting a blanking disc to the base plate. Rates of use in the trials ranged from 0.6 to 2.0 kg a.i./ha based on data from preliminary tests.

Wheat bulb fly damage was assessed by collecting random samples of at least fifty plants from each plot and recording damage and larvae in the main tiller of each plant. Leatherjackets were assessed in 10cm x 10cm cylindrical cores, 10-40 of which were taken per plot depending on plot size. The leatherjackets were extracted dry by hand or by the technique described by Rayner (1975).

A further series of trials has been planned for 1976 to confirm the results so far obtained on wheat bulb fly and on cabbage root fly in swedes and turnips.

RESULTS

Cabbage root fly (*Erioischia brassicae*)

The following tables of results are representative of those obtained in the trials. All the methods of application described above were studied and all applications were made at the recommended rate of 4.4 kg a.i./treated ha.

Table 1

Root damage assessments on transplanted cabbages and cauliflowers

Treatment	Rate	% damage at each site						
	kg a.i./treated ha	Scotland	Salop	Surrey	Lincs	Yorks	Yorks	Yorks
		1973	1973	1973	1973	1975	1973	1973
Chlorpyrifos 5% granule	4.4	12.6	17.5	24.8	27.5	10.0	19.0	25.0
Carbofuran 5% granule	4.1					27.0		
Chlorfenvinphos 10% granule	4.4	12.0			44.0		33.0	
Fonofos 10% granule	4.4			29.0				
Phorate 10% granule	4.4		27.5					
Dieldrin 15% e.c.	0.3							33.0
Control	-	54.6	71.0	55.3	57.0	-	70.0	50.0
Date treated and transplanted		28 May	2 July	16 July	2 Aug	11 July	18 June	3 May
Date assessed		29 Nov	18 Oct	19 Nov	18 Jan	12 Dec	4 Sept	21 June
Crop		Calabrese	Cauliflower	Cauliflower	Cauliflower	Cauliflower	Cabbage	Cabbage
Variety		Rex	Boomerang	Symbol	June Market	White Chief	Winter Monarch	June Star
Application		Bow-wave	Sub-surface	Sub-surface	Sub-surface	Hand	Sub-surface	Sub-surface

These results demonstrate the high activity and persistancy of chlorpyrifos granules when used at different planting dates and in different localities.

Soils high in organic matter are known to reduce the action of granular products but chlorpyrifos gave very satisfactory control when compared with other commercial products on such a soil (Lancs, Table 2).

Table 2

Root damage assessment on direct drilled brussels sprouts and in broccoli and cabbage seed beds (1973)

Treatment	Rate	% damage at each site			
	kg a.i. per treated ha	Lancs	Kent	Yorks	Yorks
Chlorpyrifos 5% granule	4.4	10.0	11.5	0.0	25.0
Chlorfenvinphos 10% granule	4.4	10.0			
Dimethoate 10% granule	4.4		18.3		
Dieldrin 15% e.c.	0.3			17.0	42.0
Control	-	41.5	100.0	42.0	50.0
Date treated and drilled		28 May	29 June	3 May	3 May
Date assessed		28 Nov	19 Nov	21 June*	21 June*
Crop		B. sprouts	B. sprouts	Broccoli	Cabbage
Variety		Peer Gynt	Gravendeel	White Early	January King
Application		Bow-wave	Bow-wave	Hand	Broadcast

*Seed bed trials assessed just before transplanting.

The table shows chlorpyrifos applied at drilling to give the same high level of control as when it is applied at the time of transplanting.

Trials have also been carried out on swedes and turnips, Table 3 illustrating the results obtained.

Table 3

Root damage assessment on turnips 1974

Treatment	Rate	% damage	
	kg a.i./treated ha	21st June	24th September
Chlorpyrifos 5% granule	4.4	25.0	65.0
Control	-	66.0	70.0

Date sown	12th April
Date treated	20th May
Variety	Golden Ball
Application	Broadcast

Because of their long growing period, swedes and turnips are very susceptible to attack from all generations of cabbage root fly. Control at this site was considered to be satisfactory by the grower. Trimming losses were very much less in the treated than in the control plots.

Wheat bulb fly (*Leptohylemyia coarctata*)

Trials carried out from 1974 demonstrate chlorpyrifos granules to be very active against wheat bulb fly.

Table 4 shows that when used at a rate of 0.8 kg a.i./ha the granules either equalled or were superior to the standards and gave good control of larvae in the soil. Larvae already in the plants were not controlled until they returned into the soil.

Table 4

Wheat bulb fly assessments

% damaged plants and, in brackets, % plants containing live larvae

Treatments	Rate	Trial Sites				
		Yorks	Yorks	Ely*	Yorks	Yield+
	kg a.i./ha	1974	1975(a)	1975(b)	1976	% of control
Chlorpyrifos 5% granule	0.6	22.1	15.3(4.3)			103.1(a)
	0.8	23.6	8.8(1.6)		13.7(5.8)	103.9(a)
	1.0			17.3(5.4)		115.9(b)
	1.2	14.3				
	1.7		7.3(0.5)		8.5(3.9)	105.5(a)
	2.0			10.7(4.0)		118.4(b)
Omethoate 57.5% e.c.	0.6		15.4(4.9)	28.9(3.5)	13.8(8.2)	100.8(a)
						92.1(b)
Dimethoate 40% e.c.	0.7	25.0	13.0(8.3)	33.2(5.6)		99.5(a)
						106.6(b)
Chlorpyrifos 48% e.c.	0.8		10.3(2.0)	25.6(4.1)		103.6(a)
						115.8(b)
Control	-	34.8	30.9(9.1)	31.1(11.2)	17.3(8.6)	
Date treated (crop tillering)		19 March	21 Feb	7 Jan	6 Jan	
Date assessed (leaf sheaths strong)		13 May	24 April	14 March	10 March	
Variety		C. Desprez	Templar	Chalk	M. Freeman	
Application		TMA2	TMA2	Hand	TMA2	

*Murphy Chemicals trial.

+Yield (a) and (b) refers to the two 1975 trials.

Good control of wheat bulb fly, as shown in the table, has been achieved in all trials. Yield increases, although moderate, have more than covered the cost of chemical and application. Farm scale trials are also being carried out in 1976 with a view to making a recommendation for commercial use.

Leatherjackets (*Tipula spp*)

Trials have been carried out successfully by Boots and Regional Entomologists of the Ministry of Agriculture (A.D.A.S. J. Rayner 1975). Good control of leatherjackets up to two months after application is demonstrated in Table 5.

Table 5

Leatherjacket control in winter wheat, Derbyshire 1974

Treatments	Rate	% control		
	kg a.i./ha	18 March	1 April	19 April
Chlorpyrifos 5% granule	0.6	66.7	85.7	91.7
	0.8	77.8	71.4	83.3
BHC 5% pellets	0.3	88.9	14.3	25.0
Control population/ha		449,000	349,000	599,000

Date treated	22 February
Population/ha at treatment	700,000
Application	Broadcast using TMA2 applicator

Rayner (1975) observed an effect of low temperatures on the activity of chemicals and concluded that consistent control can only be expected if the mean air temperature after treatment exceeds 6°C. This is demonstrated in Table 6.

Table 6

The effect of temperature on leatherjacket control in winter barley, Northumberland 1975

Treatments	Rate	Date	24 March	5 May
	kg a.i./ha	Air temperature	2.4°C	8.3°C
			% control	
Chlorpyrifos 5% granule	0.75		23.0	85.0
Carbofuran 5% granule	0.75		45.0	66.0
HCB 1.8% pellets	0.3		0.0	62.0
Triazophos 40% e.c.	1.1		36.0	81.0
Control population/ha			479,000	324,000

Date treated	7 March
Population/ha at treatment	1,235,000
Application	Broadcast by hand

Activity was inhibited at the low temperatures on 24th March but improved as the temperature rose, only chlorpyrifos and triazophos giving an acceptable level of control. The fact that a similar effect was observed with spray and granular treatments demonstrates that the temperature effect is not directly attributable to the release of chemical from the granule. It is not clear however whether this low temperature effect is related to activity of the chemical or of the leatherjackets.

Taint testing

Taint tests have been carried out from 1973-75 at the Campden Food Preservation Research Association (Reports 1973-76) on samples of brussels sprouts, cabbages, cauliflowers and calabrese treated with chlorpyrifos granules. No taints were found in any of the samples submitted for the full series of tests either with twice normal application rates at planting or with normal rates applied six weeks before harvest. This is the minimum harvest interval allowed under the Pesticides Safety Precautions Scheme.

Phytotoxicity

The maximum rates of chlorpyrifos granules used were 9 kg a.i./ha for cabbage, cauliflower, brussels sprouts (2 applications); 4.5 for calabrese and 2.0 for winter wheat (2 applications) and winter barley. At these rates no phytotoxicity was observed.

DISCUSSION

The Dow choice of sepiolite as the base for chlorpyrifos granules is an important factor in the success of the product. The granules flow freely, do not 'bridge' in the applicators and the soft, non-abrasive qualities of the base makes for minimum wear of rotors. When compared with granules based on Fuller's earth or pumice the lower density and smaller size of the sepiolite granules, combined with the fact that they are formulated with 5% active ingredient as distinct from 10% means that more than twice the number of granules are applied per unit area for the same amount of active ingredient. This is an aid to even distribution in the soil.

Good activity with adequate persistence has been demonstrated against cabbage root fly in transplanted and direct drilled brassica crops. Control has always equalled and frequently exceeded that of the commercial standards against which the product has been compared. Taint and phytotoxicity tests with cabbages, cauliflowers and brussels sprouts have been completely satisfactory.

In the wheat bulb fly trials good control of larvae in the soil substantially prevented invasion into the crop plants. Larvae already in the plants were not controlled and this implies that applications must be made before damage is easily seen at the time of egg hatch. Wheat yields in infested fields after application of chlorpyrifos granules were satisfactorily increased.

Leatherjacket control was good in all trials showing chlorpyrifos to be at least as effective as the commercial standards under low temperature conditions. Phytotoxicity observations on cereals showed chlorpyrifos granules to have a high level of crop safety.

From the trials reported in this paper which are representative of the results obtained from all the work carried out from 1973-76 it can be seen that chlorpyrifos granules, active against three major soil pests, safe on the relevant range of crops and convenient to use, make a significant contribution to modern crop protection requirements.

Acknowledgements

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THE PROPERTIES OF CARBOFURAN IN RELATION TO FIELD PERFORMANCE

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INTRODUCTION

Since the restrictions placed on the use of persistent organochlorine compounds in the U.K. in 1963 and the widespread occurrence of resistance to aldrin and dieldrin by cabbage root fly in commercial brassica production, the organophosphorus insecticide alternatives in use have been subject to several disadvantages in terms of persistence, level of efficiency, spectrum of pest control, and inconsistency of performance. As a result, the search has continued for a more suitable alternative to aldrin and dieldrin for pest control in brassicas in order to provide a control treatment which satisfied the following requirements:-

(a) High level of efficiency in preventing pest damage in the ever-increasing demand for quality, blemish-free produce in brassica crop production.

(b) Activity against cabbage root fly and also other brassica pests which have become increasingly important since the cessation of widespread usage of organochlorines.

(c) A consistent and reliable performance under the variable soil and climatic conditions experienced in the various brassica growing regions of the U.K.

(d) Adequate persistence to provide the desired crop protection against pests without the danger of toxic residues in either the produce or the environment after cropping.

(e) No undesirable effects on crop growth and vigour caused by chemical phytotoxicity to balance against the benefits of chemical pest control.

With this in mind, this paper discusses the special chemical and physical properties of carbofuran granules (U.K. trade name ® YALTOX)* in relation to its biological activity and development in the U.K. as a broad spectrum, soil applied insecticide for use on brassica crops.

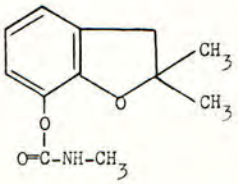
THE PROPERTIES OF CARBOFURAN

Chemical and physical characteristics of the active ingredient

Chemically carbofuran is 2,3-Dihydro-2,2-dimethyl-7-benzofuranyl-N-methyl-carbamat.

* Registered trade mark of Bayer AG, Germany

Structural formula:



Empirical formula: $C_{12}H_{15}NO_3$

This carbamate was registered simultaneously by the FMC Corporation under the code number NIA 10242 and by Bayer AG under the internal identification D1221 and Bay 70143. The active ingredient and its crop protection uses are protected by the Patent DBP 1493646 and the U.S. Patent 3474171 (Homeyer, 1975).

Appearance: White crystalline solid

Molecular weight: 221.3

Melting point: 150-152°C

Vapour pressure: 2×10^{-5} mm Hg at 33°C
1.1×10^{-4} mm Hg at 50°C

Stability: Stable in acid to neutral conditions but slightly hydrolysed in alkaline pH range

Solubility: at 25°C

250-700 ppm in water
1% in Xylol
9% in Cyclohexanon
12% in Methylenechloride
15% in Acetone
27% in Dimethyl formamide

Toxicology: The acute oral LD_{50} for rats is 8-14 mg/kg (in corn oil), for dogs 19 mg/kg (as dry powder); the acute dermal LD_{50} for rabbits is 3,400 mg, 75% w.p./kg. In long-term tests on rats, diets containing 25 ppm had no effect over two years; neither did 10 ppm over three generations. With dogs, diets containing either 20 ppm over three years, or 50 ppm over one generation produced no effects. The ten-day LC_{50} for pheasants was 960 ppm; the four-day LC_{50} for trout was 0.28 ppm (Martin, 1972).

Direct Contact Activity

Metcalf et al (1968) using topical application techniques demonstrated carbofuran to be highly active as a direct contact insecticide. Contact toxicity was shown against a wide range of test insects including Dipteran larvae and adults and Coleoptera. Earlier, Harris and Mazurek (1966) showed that carbofuran was ten times more toxic to crickets, Acheta pennsylvanicus (Burmeister) than aldrin and equally toxic to flies.

Indirect Contact Activity

Indirect contact activity in treated soil was also investigated by Harris and Mazurek (1966) and subsequently by several workers. The former discovered that although somewhat less toxic in soil than aldrin to their test insects, the activity of carbofuran was less affected by soil organic matter compared with aldrin and several organophosphorus compounds (Table 1).

Table 1

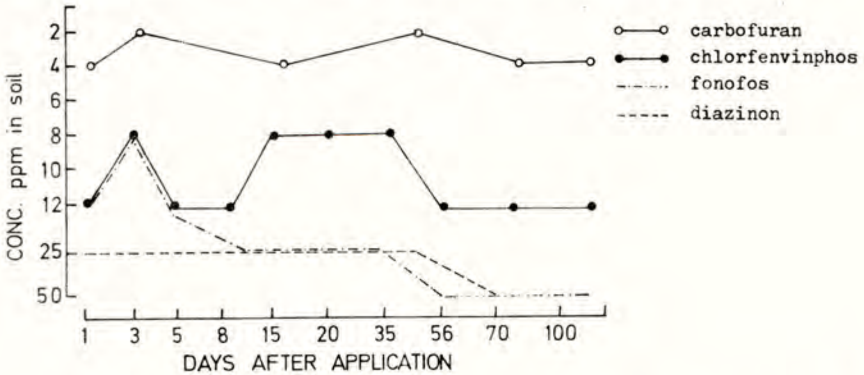
Lethal Dosage Ratios in Varying Soil Conditions (Harris and Mazurek (1966))

Treatment	Dosage Factor Dry/Moist Soil	Dosage Factor Organic/Mineral Soil
carbofuran	x 10	x 10
aldrin	x 10	x 50
diazinon	x 100	x 100
lindane	x 10	x 100
phorate	x 10	x 20

In relation to cabbage root fly, Read (1969) demonstrated that the indirect contact toxicity of carbofuran in soil was activated more rapidly and had greater effect at lower concentrations than other compounds tried.

Figure 1

Soil Concentrations Achieving >90% Mortality of Root Fly Larvae (Read 1969)



This high degree of early activity was continued in effective persistence for longer than other materials. Read (1971b) confirmed these earlier conclusions using equal concentrations (100 ppm) of various granular insecticides applied in the soil at 3/4 in depth. The treated soil was then removed at various times after application and diluted to desired concentrations with untreated soil and used to grow rutabagas. These were subject to known numbers of cabbage root fly larvae and the toxicity assessed on pupae formation. The results confirmed the more rapid activation at lower dosages than other test materials and continuation of this activity for a longer period. In this experiment carbofuran was biologically active within two days of application, achieved its peak of toxicity after 30 days and declined only gradually afterwards. In contrast, fonofos and chlorfenvinphos were only slowly bioactivated and exhibited low initial toxicity, effective mortality not being recorded until 30 days after application.

In these tests granules were used rather than putting the active ingredient directly into the soil in a volatile diluent. Read hypothesized that the biological activity of the compounds depended largely on the oxidizing organisms per unit volume of soil capable of oxidizing the parent compound into its various toxic metabolites. The use of an inert granule carrier reduced immediate exposure and perhaps accounted for the initial lack of bioactivity of sub-surface bands of granules with some materials, although improving overall efficiency and performance when compared with soil treatment, as liquid formulations. Carbofuran however became as rapidly active in the soil from use of a granule formulation as with liquid treatment.

Persistence

In examining the effective persistence of soil insecticides Harris (1969) described 3 groups and compared on mineral and organic soils.

	Mineral Soils	Organic Soils
1. Highly residual	dieldrin, DDT 48 weeks	dieldrin, DDT 48 weeks
2. Moderately residual	aldrin, carbofuran 16 weeks	carbofuran - 25 weeks aldrin - 16 weeks
3. Slightly residual	diazinon, phorate, chlorpyrifos 4 weeks	diazinon, phorate, chlorpyrifos 4 weeks

Carbofuran displayed moderate residual activity up to 16 weeks on mineral soil and this persistence of effective activity increased on organic soil up to 25 weeks. This confirmed in biological effect, the results of chemical residue sampling for persistence of carbofuran in soils. Stanovick (1968) had shown the half-life of carbofuran to vary from 7 weeks in sandy loam, to 10-15 weeks in silt loam, and up to 40 weeks in organic soil. Getzin (1973) showed a similar persistence of 7-17 weeks, persistence increasing with in-soil application, lower pH and lower temperatures. Getzin also defined the soil factors more closely. The half-life of carbofuran was shown to extend up to one year and was most significantly affected by soil pH. In soils of pH greater than 7.8, degradation was rapid, 10 times greater than in acid and neutral soils (pH 4.3-6.8).

Systemic Activity

In common with many carbamates, carbofuran was found to exhibit an efficient plant systemic activity against pests. Early work by Abdellatif et al (1967) demonstrated the systemic efficacy of carbofuran against Aphis gossypii on cotton plants using soil applied granules. Uptake in different soils was governed in these experiments by soil clay content, with organic matter less important. Clay reduced the concentration available in free soil water. Both clay and organic matter content directly affected the persistence of carbofuran in the plant as measured by the duration of kill. The higher the clay and organic fractions in the soil, the shorter the duration of kill.

Investigating the systemic uptake and translocation of carbofuran in tobacco, Ashworth and Sheets (1970) demonstrated that uptake by roots from soil water was rapid. Within one day of being made available in soil water, carbofuran was already absorbed and translocated to all parts of the test plants. In the plant, carbofuran accumulated in between the lateral veins of larger and older leaves rather than terminal buds, and indicated a possible differential efficacy against pests feeding on terminal buds compared to those feeding more generally.

In foliar uptake studies, carbofuran was not readily absorbed through leaves and that which was absorbed was not translocated out to other parts. Carbofuran was considerably more persistent in plants however from foliar uptake than from root uptake.

Mistric and Smith (1973) working with 3 different pests of tobacco, and using soil applications of carbofuran confirmed the systemic activity and plant distribution by measuring the effective persistence against the different types of pests:-

Flea beetle (older leaves)	- 10 weeks
Tobacco Hornworm (younger leaves)	- 7 weeks
Tobacco Budworm (terminal buds)	- 5 weeks

Read (1971a) investigated the mechanisms of absorption of carbofuran into root brassicas sown in treated soil. The plants were then transplanted to sterile soil and subjected to root fly larvae at intervals. Toxic residues were present in roots sufficient to kill larvae even at harvest. Once removed from soil, root residues disappeared rapidly, confirming the earlier conclusion that transport and degradation of carbofuran from roots is rapid compared to organochlorine and organophosphorus soil insecticides.

The persistence of carbofuran in brassica foliage was demonstrated biologically by McEwan et al (1970) when, in testing 9 sprays, carbofuran was one of only 2 compounds to provide a high degree of control of mealy cabbage aphid. This of course was a foliar uptake study. Hale and Shorey (1972) using granular formulations and thus relying on root to leaf translocation, proved carbofuran one of the best materials under test in controlling cabbage looper on broccoli and cabbage. Persistence however was inadequate.

Effect on Plant Growth and Vigour

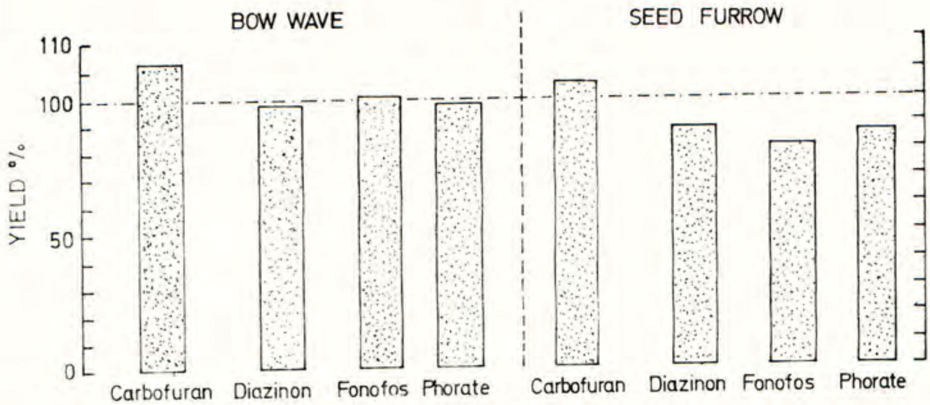
In testing 8 granular insecticides for phytotoxicity against dent corn in the absence of pests, Apple (1971) showed carbofuran and others to have no adverse effect when applied as a bow-wave band application. When applied in the seed furrow however, all materials except carbofuran had a detrimental effect on plant stand and growth. Even at 4 lb a.i./acre, carbofuran had a positive effect on growth and vigour both visually and as measured by yield. In the absence of pests, carbofuran was the only material to demonstrate a total lack of plant injury and in addition consistently exhibited a vigour response which reflected in final yield (Figure 2).

Physical Properties of Formulation

Carbofuran was formulated for U.K. development by Bayer AG, Leverkusen, as a 5% granule on a quartz sand carrier of particle size range 0.4-0.8 mm. The active ingredient was coated on the carrier and retained within a water permeable polymer. The formulation as a 5% granule coupled with a relatively small particle size meant an average number of 70 granules per cm. length of treatment band at recommended field dosage. This increased the number of particles containing active ingredient by a factor of 2-3 compared to other standard granular formulations of insecticides in commercial use. In this way, the potency and rapid activation of the chemical was ensured in formulation by creating greater contact and more thorough distribution of the chemical within the soil.

Figure 2

Yield Response of Dent Corn to Granular Insecticides (Apple, 1971)



FIELD PERFORMANCE IN THE U.K.

Carbofuran granules were developed for protection of brassica crops against cabbage root fly and other major brassica pests in the United Kingdom and much of the results of field experiments was reported by Martin (1973) and Martin and Morris (1975). An examination of these results and those of a commercial usage survey reported by Kelly (1976) demonstrated how the properties of carbofuran granules already described made this material particularly suitable for brassica pest control. The following information consists of greatly summarised results in an attempt to indicate trends; for detailed results of the many field experiments conducted in the U.K. the references quoted above should be consulted.

The control of root damage caused by cabbage root fly larvae (Table 2) indicates the greater degree of activity of carbofuran in soil compared to a similar rate of chlorfenvinphos, a standard organophosphorus material used for cabbage root fly control.

Table 2

Percentage Reduction in Cabbage Root Fly Damage (R.D.I.)

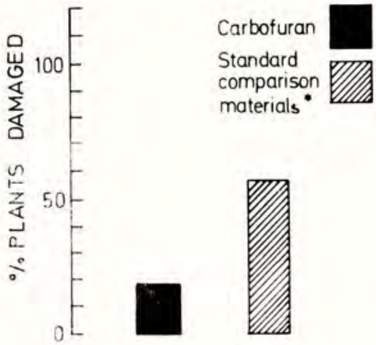
(Means of 27 trials 1972-1974)

Treatment	carbofuran (0.62g/10m row)		chlorfenvinphos (0.7g/10m row)	
Application:	Sub-surface	Surface	Sub-surface	Surface
% Reduction in Root Damage Index	66.6	55.4	50.3	37.4

In the field survey of commercial use in 1975, when general soil conditions were extremely dry, an examination of 74 brassica crops during July and August measured the efficacy of carbofuran against E. brassicae by recording the proportion of damaged plants in relation to the grower's standard material (Figure 3).

Figure 3

Cabbage Root Fly Control - Field Usage Survey 1975



The superior root damage control provided by carbofuran granules under varying conditions is a measure of its good contact effect both in the soil and in brassica roots, related to its rapid activation from the granule formulation.

The 1975 results also reflected the advantages of these properties, together with high water solubility enabling a good insecticidal effect from carbofuran in dry soil conditions which reduced the efficacy of standard comparison materials. The greater activity of the carbofuran formulation under varying conditions was shown by the higher level of protection against root damage from the different methods of granule placement, compared to chlorfenvinphos. In common with other materials such as chlorfenvinphos, as demonstrated by Bevan and Kelly (1975), the incorporation of carbofuran granules within the soil gave superior results compared with surface band applications.

The persistence of carbofuran was indicated earlier in the paper as being moderately residual, of the order of 16 weeks for field dosages on medium soils extending considerably in organic and acid soils. The results above have shown this persistence to be adequate in providing protection to harvest in most brassicas, but in longer term crops such as Brussels sprouts, the persistence of carbofuran was examined by measuring the control of both root damage and larval and pupal numbers on roots in the autumn treated by single and double applications of granules. In 5 trials a single carbofuran application gave a superior kill of E. brassicae populations as recorded by final pupal survivors after 2 generations compared with a single application of the more persistent but less active chlorfenvinphos. This level of control was greatly increased by a second application of both materials, there being little difference between either chemical from two applications. A greater initial effect from the single application was therefore suggested, whereas the more slowly activated but more persistent chlorfenvinphos benefited more by a second application.

* Composite of results with more than one standard chemical

Table 3

Percentage Control of E. brassicae Larvae and Pupae on Brussels Sprouts Roots in August-October

(Means of 5 trials)

Treatment and Rate (a.i.)	Single Application	Double Application
carbofuran @ 0.62g/10m row	49.7	84.9
chlorfenvinphos @ 0.7g/10m row	39.6	82.2

The degree of root damage in the autumn as assessed by Root Damage Indices after the method described by Rolfe (1969) further confirmed the effective persistence of carbofuran against root fly on long term brassica crops such as Brussels sprouts.

Table 4

Percentage Reduction in R.D.I. on Brussels Sprouts Roots in August-October

(Means of 5 trials)

Treatment and Rate (a.i.)	Single Application	Double Application
carbofuran @ 0.62g/10m row	56.4	59.5
chlorfenvinphos @ 0.7g/10m row	58.3	59.5

Effective persistence of single applications of carbofuran on Brussels sprouts compared with double applications was also quantified in final yield (Table 5). It can be seen that there was no substantial difference in yield between a single application at sowing or planting and a second treatment later in the growing season indicating that the effective persistence of carbofuran was sufficient on a long term crop such as Brussels sprouts to provide optimum yields. The performance

Table 5

Pest Control on Brussels Sprouts - Relative Yields in Trials 1972-74

Yields expressed as a percentage of untreated (Means of 8 trials)

Treatment	All Crops	Transplants	Direct-Drilled
Untreated	100	100	100
carbofuran - single application	112	106	117
carbofuran - double application	112	97	120
chlorfenvinphos - single application	102	94.4	109.5
chlorfenvinphos - double application	109	-	109.5

of carbofuran on organic soils in comparison with other materials confirms the greater efficiency of this compound both in activity and persistence in organic media as suggested previously. There was little difference in control obtained by different placement techniques with carbofuran whereas the comparison material again performed better when incorporated in the soil.

Table 6

Percentage Reduction in R.D.I. on Organic Soils

(Means of 4 trials)

Treatment and Rate	Surface placement	Sub-surface placement
carbofuran @ 0.62g/10m row	55.3	54.2
chlorfenvinphos @ 0.7g/10m row	8.5	36.2

The upward movement of carbofuran in soil resulting in kill of adult cabbage root flies was also observed by Martin (1973) and Martin and Morris (1975) in the field development of carbofuran granules in the U.K., probably an important additional property in achieving rapid insecticidal activity and early reduction in attack.

In addition, this upward movement of active carbofuran may be one of the properties responsible for the control of flea beetle damage on young brassicas (Table 7).

Table 7

Control of Flea Beetle Damage on Brassica Crops 1973-75

% Plants Damaged

Treatment	Trial 1 - 1973 20 plants Mean of 4 plots	Trial 2 - 1973 25 plants Mean of 4 plots	Trial 3 - 1974 10 plants	Trial 4 - 1974 Means of 10 plants/plot	1975 Grower Usage (Visual Scores) Mean of 27 Crop Comparisons
carbofuran	7.5 (1.3)	1.0	2.0	0	2.2
standard comparison	80 (4.0)	22.0	76.0	100	14.0
Untreated	74.0 (3.9)	100.0		-	-
LSD 5%	(0.7)				
1%	(0.97)				

( ) No. plants damaged transformed to $\sqrt{n + 0.5}$

This additional benefit in providing excellent flea beetle control may be a combination of a contact effect due to upward movement of carbofuran in the soil plus a stomach-poisoning action from feeding on brassica leaves due to the early systemic translocation of carbofuran from roots to leaves.

This dual activity against flea beetle also extends to the control of damage by stem weevil larvae, Ceutorhynchus quadridens (Panz) whose tunnelling damage within stems and along leaf petioles was effectively prevented both in trials and commercial use (Table 8). It is unknown whether the major activity against this pest by carbofuran is against adult weevils in preventing oviposition or the young larvae, contact or systemic effect respectively.

Table 8

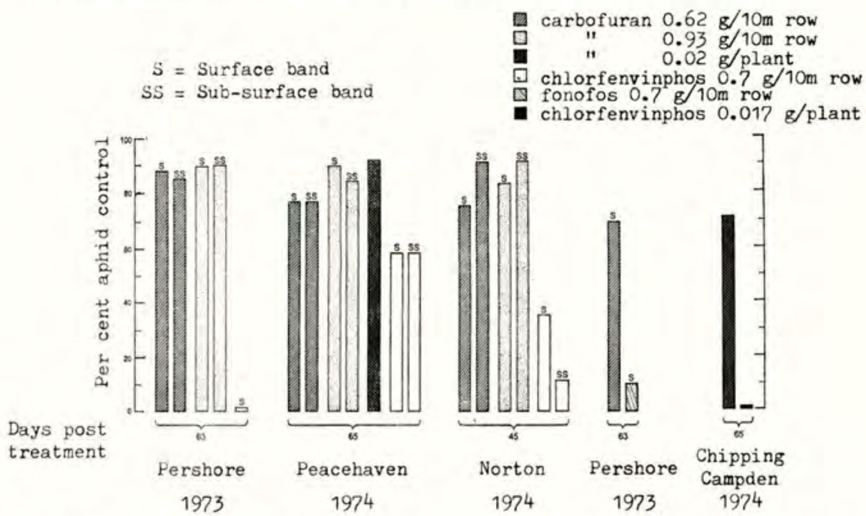
Control of *Ceutorhynchus quadridens* (Panz) on Brassica Crops 1973-75

Treatment	Worcestershire 1973 % plants damaged 20 plants/plot Mean of 4 plots	Gloucester 1974 No. weevils/plot (10 plants)	Grower Survey 1975 % plants damaged (field score) 14 crop comparisons
carbofuran	1.25 (0.83)	0.5	carbofuran 13.0
chlorfenvinphos	55 (3.4)	14.5	grower's standard 42.0
Untreated	75 (3.9)	9.0	
LSD 5%	(0.5)		
1%	(0.7)		

( ) No. of plants transformed to $\sqrt{n + 0.5}$

Figure 4

Aphid Control with Carbofuran Granules in Cabbage Root Fly Trials



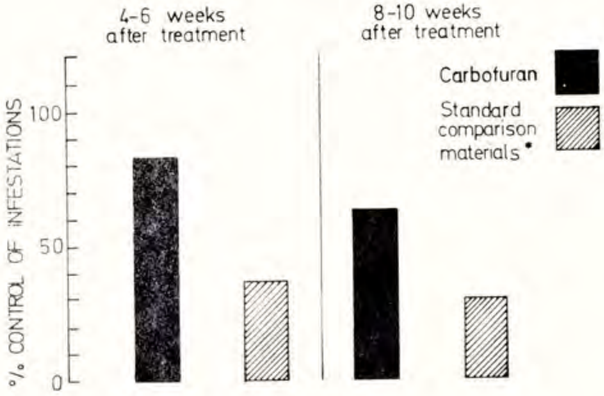
The systemic activity of carbofuran is undoubtedly the reason for the useful effects demonstrated against aphids infesting brassicas including mealy cabbage aphid, *Brevicoryne brassicae* (L), confirming the results of McEwan et al (1970) previously referred to. It is interesting to note from Figures 4 and 5 that the effective persistence of carbofuran against aphid infestation ranged from 4-9 weeks from soil applications primarily for cabbage root fly. This is a considerably shorter period than the known persistence in soil, indicating again the differential distribution of carbofuran toxicants in various parts of plants as described by previous workers and the lack of foliage persistence from root uptake, particularly in the younger parts of plants.

Nevertheless the level of aphid control and persistence indicated by these results were an additional benefit which in many short term brassica crops provided adequate protection. This was of particular significance in the 1975 grower usage survey where soils exhibited a moisture deficit in the hot dry conditions causing reduced translocation and systemic activity; this together with heavy and prolonged aphid infestations resulted in effective persistence being reduced to 4-6 weeks.

Figure 5

Aphid Control with Carbofuran Granules in Commercial Brassicas 1975

(Bayer survey of grower usage)



An outstanding feature of carbofuran treatment in both development and subsequent commercial usage was the resultant increased vigour of the crops, culminating in improved yield and quality, particularly of cauliflowers, in which crop visual appearance of the curds is so readily affected by crop vigour and health (Figures 6 and 7).

In the survey of 1975 commercial usage, yield and quality assessments could not be made but the visual scoring of crop vigour based on plant stand, size and colour was made and expressed as a percentage conversion from a 1-9 BBA scale (Figure 8) against a theoretical total crop failure as the base line.

* Composite of results with more than one standard chemical

Figure 6

Diagram to Show the Effect on Yield and Quality of Cauliflowers Using Surface Applied Granules, Norton, 1973

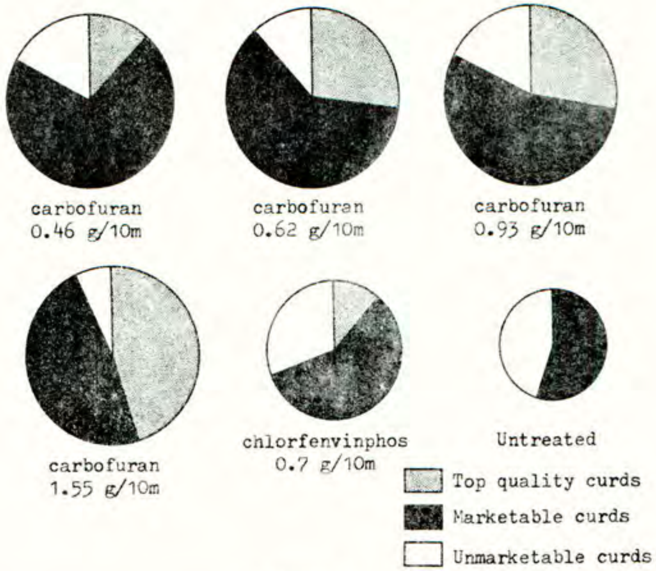


Figure 7

Diagram to Show the Effect on Yield and Quality of Cauliflowers Using Sub-Surface Applied Granules, Peacehaven, 1973

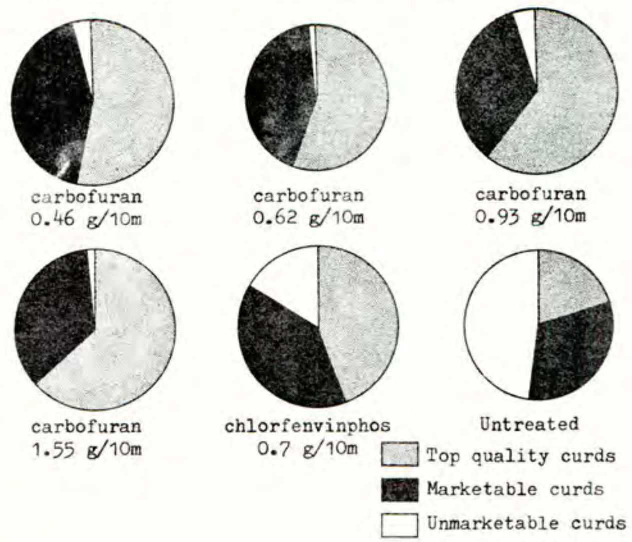
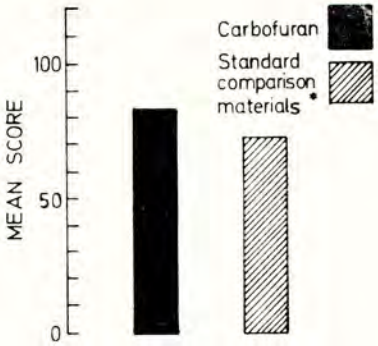


Figure 8

Visual Assessment of Relative Crop Vigour and Growth on Commercial Brassicas, 1975

(Mean of 25 crop comparisons)



CONCLUSIONS

The chemical properties of carbofuran enabled rapid activation as a contact insecticide in soil and also as a plant systemic insecticide; the facility to be mobile in soil especially in upward movement to the soil surface; the relative lack of effect of soil organic matter and adverse climatic conditions; a substantial and biologically adequate persistence. In addition the physical properties of the 5% granular formulation on an evenly distributed and uniform size granule complemented the above chemical properties. This ensured that the commercial use of carbofuran as Yaltox provided a new concept and higher standard of broad-spectrum efficiency against the major pests of cultivated brassicas in the U.K. Increased efficiency against pests has also been accompanied by a marked positive effect on crop growth and vigour, resulting in improved yields, both in terms of overall marketable quantity and also uniform maturity.

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ECONOMICS OF NEMATICIDE USE FOR THE CONTROL OF POTATO CYST NEMATODE IN WARE CROPS

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INTRODUCTION

Trials on land infested with potato cyst nematodes have been carried out over the years 1972-1975 with soil sterilants and granular nematicides on 19 sites with a variety of soil types and eelworm infestation levels in the Yorks/Lancs Region. The main objects of the trials were to obtain information on the levels of eelworm infestation at which the use of chemicals would be economically justifiable in terms of yield improvement and also of final eelworm counts and so to provide a basis or reference system for advice in particular cases.

MATERIALS AND METHODS

In the 1972/1973 trials the soil sterilants dazomet and dichloropropene were compared with the experimental nematicide fenamiphos. In 1974 and 1975 the nematicides oxamyl and aldicarb were used. Plot sizes were standardised at 20 m x 7-9 drills and there were 4 replicates of each treatment. Applications of dichloropropene were made by contractor type injectors during the autumn before planting, while dazomet and the granular nematicides were applied by front mounted applicators and the materials incorporated in the topsoil by rear mounted rotavators during the same operation. Yields were assessed by harvesting 3 centre drills of 15 m length. Estimates of viable eggs per gram of soil were made from pre-treatment and post-harvest soil samples respectively, taken and processed by the usual Fenwick can method.

RESULTS

Results from the first years trials have already been summarised (Jones, 1973) and those from the succeeding trials will be reported in greater detail elsewhere. In the first trials the experimental nematicide fenamiphos was compared as a broadcast autumn application and as a narrow band spring application. The greater effectiveness of the former was considered to be related more to the method of application than to the timing, so that in subsequent trials all granular nematicides were applied broadcast over a wide band except in 1974 where broadcast and narrow band applications immediately before planting were directly compared giving clear evidence in favour of the broadcast method. In 1974, in addition, differing rates of nematicide were compared and in 1975 double rates were tried with depth incorporation by applying standard rates to the plough furrow bottom followed by surface application of a similar quantity. The standard rates were now settled at 3.4 kg/ha ai for aldicarb and 5.6 kg/ha for oxamyl.

Earlier results indicated that yields in all cases except in peat soils were improved by nematicide treatment at moderately high to high eelworm levels but yield levels tended to fall off with increasing densities of eelworm. Dichloropropene gave good yield responses but resulting eelworm infestations after cropping were at a very high level and consequently work with this product was discontinued. Dazomet gave good control and good yield response but costs of treatment in 1972 and 1973 were unrealistically high so that in the concluding series of trials only aldicarb and oxamyl were used. The 1975 costs of treatment at normal commercial rates were of the order of £120/ha. At the 2 sites with initially high eelworm the use of these materials increased yields compared with untreated controls by amounts ranging from 6t-20t/ha and it is estimated that these yield responses would have fully repaid treatment costs with a clear profit. On the site with a lower eelworm count (mean 17 eggs/g) there were slight yield increases but insufficient to repay cost of treatment on some of the plots. From the point of view of the economics of treatment and its profitability, the results from all trials are summarised in Table 1.

Table 1

Profitability from Nematicide Treatments, 1972-1975

Profitability	Advisory Eelworm Levels		
	Low-Mod. Mean Range 16-24 e/g	High Mean Range 35-53 e/g	V. High Mean Range 70-128 e/g
Clear Profit	1	8	1
Costs not Recovered	4	2	3
Totals	5	10	4

In 1974/1975 the Leeds "Blueprint" methods of growing were attempted at 4 out of the 8 sites but the best results on these plots with optimum inputs of nematicide fell short of experimental yields obtained in those years on non-infested soil by some 20 or more t/ha. In effect, therefore, eelworm control under the severely practical conditions in which the trials were conducted was insufficient to prevent damage. Depth sampling (21-45 cm) and surface soil sampling (1-20 cm) comparisons after harvest showed that in no case was there good control at the lower depth. All treatments, however, gave reduction in eelworm levels compared with untreated plots at the 1-20 cm depth with a mean reduction of 60% compared with control. There was little improvement from the double treatments and it appeared that aldicarb applied at furrow depth only affected eelworm above this level.

To summarise, nematicides in these trials were economic at high eelworm levels but did not reduce these levels. At very high eelworm levels total treatment costs were not recovered. At lower eelworm levels there was also no economic gain from the use of nematicides and the only advantage would have been in holding eelworm populations at levels that would enable a shortening of the potato rotation.

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SEED-FURROW APPLICATION OF GRANULAR PESTICIDES AND THEIR BIOLOGICAL EFFICIENCY ON SUGAR BEET

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Summary Experiments testing granular pesticides in the seed furrow for sugar beet pest control started in 1958. The technique was first used commercially in 1973 in England; in 1975 about 25% of the beet area was treated in this way.

The reasons why the pesticide (0.5 - 1 kg a.i./ha) cannot be incorporated in the seed pelleting material - mainly problems of phytotoxicity and unnecessary and possibly harmful use - are discussed. Seed-furrow treatment is more economical and has fewer adverse side effects than overall treatment but many materials are phytotoxic; some studies on effect of granule size, side-placement and bow-wave techniques are discussed.

Seed-furrow treatment proved particularly effective for control of Docking disorder, and commercial usage developed with the advent of aldicarb and oxamyl. Work on control of soil pest damage, and aphids and virus yellows, is reviewed. For certain materials liquid formulations were more effective than granules. Some physical data on commercial granules are recorded, and the current choice of granule size and concentration questioned.

INTRODUCTION

Commercial use of granular pesticides in the seed furrow for sugar beet protection started in 1973 to control Docking disorder (free-living nematode damage on sandy soil); since then the technique has been used increasingly for controlling soil-inhabiting pest damage, aphids and virus yellows (Dunning & Davis, 1975; Cooke, 1975).

In 1975 about 25% of the 202,000 ha of sugar beet grown in England was treated with granular insecticides/nematicides (aldicarb and oxamyl). Trials on seed-furrow application of granular pesticides for controlling Docking disorder started in 1964 (Dunning & Winder, 1969), but were preceded by several year's work testing different formulations of pesticides applied in different ways, principally for the control of aphids and virus yellows. This project developed because the sprays being used (Hull, 1960) were effective against aphids for only one to two weeks. Despite the benefits derived from spraying, control of yellows was at best 50% and often much less; a different approach was needed for longer aphicidal persistence and seed or soil treatment with systemic pesticides seemed the most promising (Ripper, 1957).

WHY NOT SEED TREATMENT?

Seed treatment can be a cheap and convenient method of applying pesticide where it will be most effective against certain pests. The action can be local (e.g. against Onychiurus damaging germinating seeds : Baker & Dunning, 1975) or systemic (e.g. against aphids feeding on the seed leaves of the first-year seed crop in July : Dunning, 1962; Dunning & Winder, 1964). Seed pelleting ensures that the pesticide applied remains on the seed; trials showed the considerable benefit to dieldrin seed treatment derived from pelleting (Dunning & Winder, 1965a).

The rapid increase in the use of pelleted sugar-beet seed (Dunning & Davis, 1975) appears to offer further scope for incorporation of pesticides; a normal seeding rate is 8 kg/ha, of which 6.7 kg is pelleting material. A considerable proportion, even as much as 25% of this 'clay', could be replaced by pesticide (R. D. Reid, pers. comm.). However, phytotoxicity would be an almost insuperable hazard with current pesticides. Menazon seed dressing (4% a.i./wt of seed) is effective and recommended for use on unpelleted seed (Jones & Dunning, 1972); it was effective when incorporated in the pellet shortly before sowing (Dunning & Winder, 1964) but in further trials it was found to be phytotoxic during storage of the pellets (Heathcote, 1970).

A pesticide incorporated in the seed pellet has to remain active for up to 18 months, must not adversely affect germination in the laboratory or field, and its use on the seed has to be justified for the country's total beet area (205,000 ha in 1976). Seed treatment therefore seems unlikely to develop beyond the current prophylactic use of dieldrin or methiocarb, at 0.2% of seed weight, to help seedling establishment should soil-pest damage occur unexpectedly. (Where such damage is expected, overall soil treatment with gamma-BHC spray, or in-seed-furrow treatment with oxime carbamates is recommended.) Nevertheless, broader spectrum pesticides such as carbofuran are currently being tested in the seed pellet (Winder & Dunning, 1976), and are being used on a limited commercial scale in some Continental countries (Dunning, 1976).

SOIL TREATMENT : BROADCAST

Seed and soil treatments with disulfoton and phorate were compared in 1958. Trials in 1957 had shown that phorate at 0.625% of seed weight controlled leaf mining by Pegomya betae for up to eight weeks after sowing but that larger amounts were phytotoxic. The results of a 1958 trial (Fig 1; disulfoton treatments only) emphasised the serious risk of seed treatment damaging seedling growth, and showed the value of applying granular formulations to the soil at sowing. Sufficient pesticide could be applied to give better insecticidal effect with much less risk of injury. Broadcast application was less phytotoxic than in-seed-furrow treatment, but more active ingredient per hectare was necessary for equivalent insecticidal action; the broadcast treatment halved virus yellows infection in September. Subsequent trials in 1959 to 1962 produced similar results (Dunning & Winder, 1960, 1961b, 1962, 1963). Overall treatment required large amounts of pesticide and was uneconomic; in addition, application and incorporation was difficult and adverse side effects on beneficial insects were feared. No more work was done on broadcast treatments.

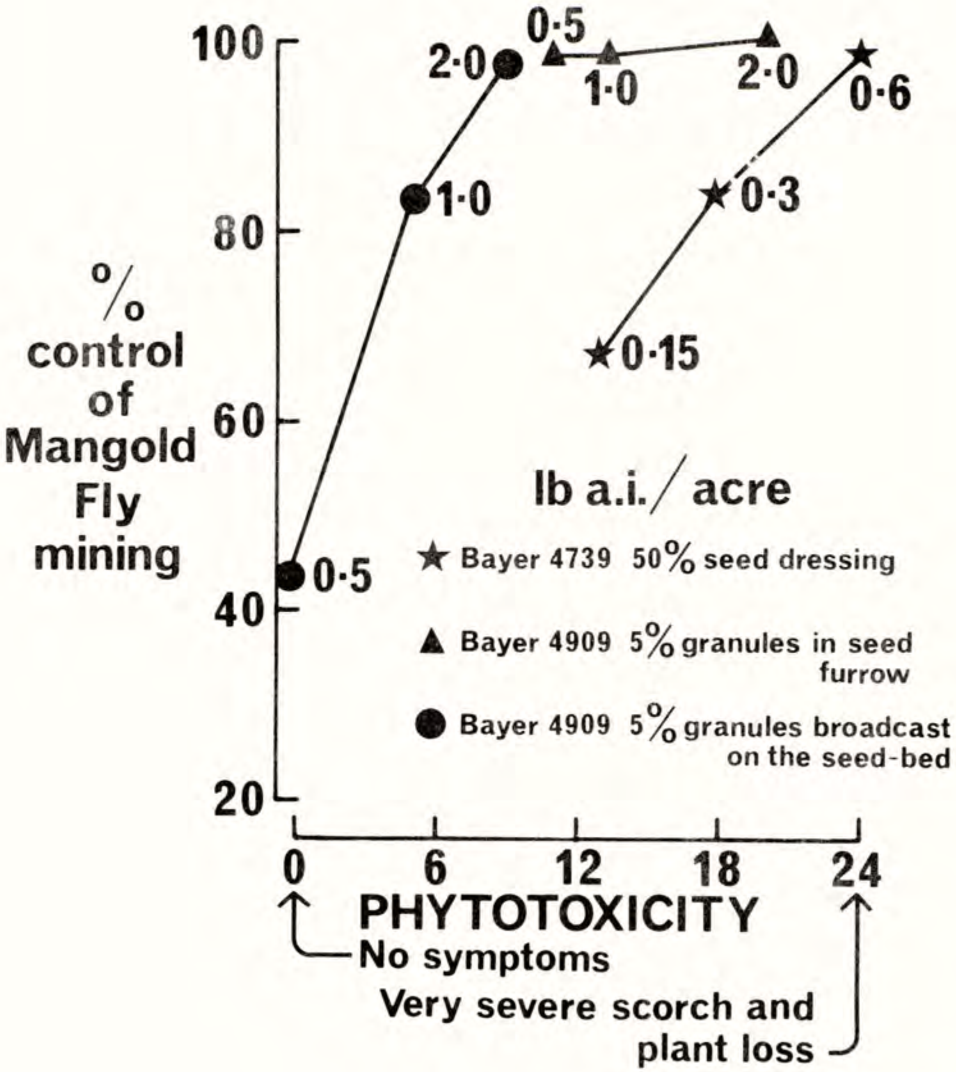

Fig 1. Insecticidal and phytotoxic effects of three different formulations of disulfoton, 52 days after sowing on sandy clay loam with fragments of limestone, Dunholme, Lincoln, 1958.

: IN ROW

Further tests were made of the 1958 trial technique of applying granules in the furrow with the seed, at first by hand, then by mixing seed-sized granules with the seed (5% disulfoton, Bayer 4909a, 3-5 mm average diameter : Dunning & Winder, 1961b), and later by granule applicator ('Gandy' or, preferably, 'Horstine Farmery' machinery) metering and delivering into the seed furrow. In the latter case, measurements were made of the position of granules of disulfoton (pumice base, average size 1.25 mm) in relation to seed position; the granules were well covered and all were found within 1 cm of the seed (Fig 2).

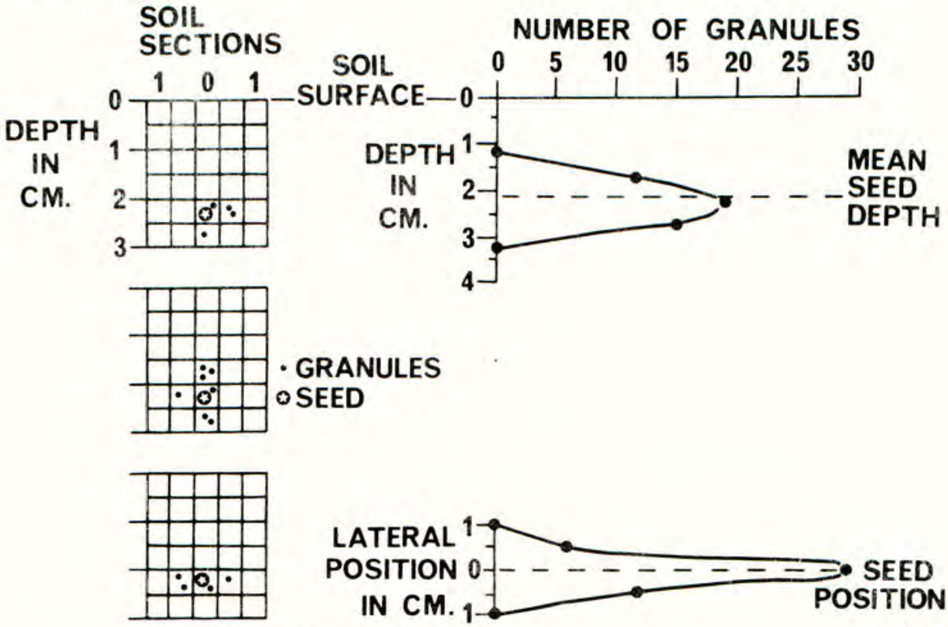

Fig 2. Position of disulfoton granules (average size 1.25 mm, pumice base) relative to sugar beet seed, when applied in-seed-furrow during sowing on sandy loam soil at Broom's Barn.

Only phorate and disulfoton granules were available at this time and, despite insecticidal efficiency, phytotoxicity often seriously affected growth and yield.

Attempts were made to avoid phytotoxicity but retain inseticidal effect, by three methods.

The effect of granule size on phytotoxicity was tested in 1960. Disulfoton granules (Bayer 4909 - up to 2 mm v Bayer 4909a - up to 6mm, both 5% concentration: see Dunning & Winder, 1961a for sieve fractions) were tested in-seed-furrow at three rates; the smaller granules were more injurious than the large, giving more cotyledon tip scorch, smaller seedlings and fewer plants (Dunning & Winder, 1961b). However, the small granules proved preferable for top dressing foliage (Dunning & Winder, 1961a), a treatment that was adopted commercially. Large granules were designed for mixing with large natural seed but the use of small, carefully graded seed in precision drills was increasing; the large granules were not studied further, especially as their distribution along the seed furrow was irregular.

Placing 2.5% disulfoton granules 5 cm deep and 10 cm to the side of the seed (as near as the machinery available would allow) on April 15 completely avoided phytotoxicity in a 1961 trial. However, the treatment controlled aphids very little in June and July and did not increase yield (Dunning & Winder, 1961a). Side-placement of granules during steerage hoeing in May or early June seemed preferable (Dunning, 1962) and proved effective in controlling aphids and yellows and in increasing yield; in 1962-4 trials menazon was usually more effective than disulfoton (Dunning & Winder, 1963, 1964, 1965b). The risk of the knife coulters cutting too close to the sugar beet plants and damaging them prevented the method being developed commercially, especially as the results were obtained at the beginning of a decade of low virus incidence.

A bow-wave technique was tested, metering the granules in a 10 cm band on the soil surface in front of the coulter, which then mixed them in the soil; the method decreased phytotoxicity (Dunning & Winder, 1963). Clear differences in aphicidal effect could not be demonstrated due to the paucity of aphids and yellows in the trial but the method tended to give erratic and less effective results. This was thought to be due to the variable mixing of granules in the soil, and to the effects of soil type and moisture. The method was abandoned with the advent of menazon.

Menazon granules in-seed-furrow, at rates of up to 1.5 kg/ha, were not phytotoxic and their aphicidal persistence was good. Menazon seed treatment and seed-furrow granule treatment were compared in 1962-4 trials on the sugar beet seed crop. In 1962, when the aphid infestation continued into September, granules applied at sowing in July (1.1 kg a.i./ha) controlled aphids better than seed treatment (0.4 kg a.i./ha) and this was reflected in better virus yellows control in the subsequent seed crop (Dunning & Winder, 1963, 1964). In 1963 and 1964 trials menazon granules were no more effective than menazon seed treatment in controlling yellows, despite respectively two and five times as much active ingredient being applied per unit length of row (Dunning & Winder, 1965b); this was because the invasion of viruliferous aphids occurred only in the seedling stage, presumably before uptake of menazon.

On the root crop, in 1962 trials, and in some 1963 trials, in-seed-furrow granules of menazon (1.12 and 2.24 kg a.i./ha) increased plant population, and in 1962 sugar yield, probably reflecting menazon's fungistatic properties (Dunning & Winder, 1963, 1964). In other trials in 1962 menazon granules in-seed-furrow were more persistent than disulfoton in aphicidal effect; the reverse occurred with foliage treatment (Dunning & Winder, 1963). This work was not developed further; menazon granules were not available commercially and, moreover, it seemed that prophylactic treatment against aphids and yellows could not be recommended.

Parallel work on control of <u>Agriotes</u> damage showed no benefit from using dieldrin granules in-seed-furrow, even at eighty times the seed treatment rate (Dunning & Winder, 1965a), but suggested that systemic materials may be efficient when applied in-seed-furrow. This suggestion was borne out by results on the control of Docking disorder; seed-furrow treatment with granules was effective (Dunning & Winder, 1967). Phytotoxicity was a particular hazard, because the Docking disorder problem occurs only on light soils with very low organic matter content; however, risk of damage with aldicarb only occurred at rates of 1 kg a.i./ha or more (Dunning & Winder, 1969). In-seed-furrow application of pesticide is particularly effective for the control of damage by this pest, which occurs in the very early seedling stage; seed treatment could be effective but is impractical, whilst overall soil treatment is unnecessarily expensive and perhaps has adverse side effects. Use of 'nematicides' is now extensive on soils prone to Docking disorder (Cooke, 1975).

We have used in-seed-furrow treatment, with liquids or granules, as a convenient technique for screening large numbers of materials to determine the most suitable to test as alternative seed treatments to dieldrin (Dunning & Winder, 1971). In addition, seed-furrow treatment has been tested, and shown to be effective, for the control of soil-inhabiting pest damage, in the expectation that such a treatment would be more necessary in the future with increased planting-to-stand (Dunning &

Winder, 1973). That this assumption was perhaps correct is being borne out by the growers' increasing willingness to use in-seed-furrow treatment with aldicarb or oxamyl. The abnormally high incidence of virus yellows in 1974 and 1975 further encouraged this (Dunning & Davis, 1975), especially because control by foliage-applied sprays was poor, in part due to resistance to organophosphorus insecticides (Devonshire & Needham, 1975; Dunning & Winder, 1976).

LIQUID OR GRANULE FORMULATIONS FOR IN-SEED-FURROW TREATMENT?

In-seed-furrow use of liquid formulations of pesticides has been neglected, probably because of the mammalian toxicity of effective pesticides. We made comparisons of materials, using them as liquids or granules and applying equal rates of active ingredient per unit length of row on sites where soil-inhabiting pests were prevalent. In three trials in 1973 oxamyl was equally effective as a granule or a liquid; in trials in 1972 and 1973 mecarphon proved to be insecticidally more active as a granule than a liquid, especially when applied in small amounts (Dunning & Winder, 1973). A trial at Broom's Barn in 1973, where pest damage was slight, measured mainly the phytotoxicity of some materials; liquid gamma-BHC was much more phytotoxic than granules but the reverse occurred with chlorpyrifos (Fig 3) and with Ciba Geigy compound 'CGA 12223' - O-(5-chloro-1-isopropyl-1,2,4-triazol-3-yl) OO-diethyl phosphorothioate (Dunning & Winder, 1973). Results of 1974 and 1975 trials have been recorded (Dunning et al, 1975; Winder & Dunning, 1976).

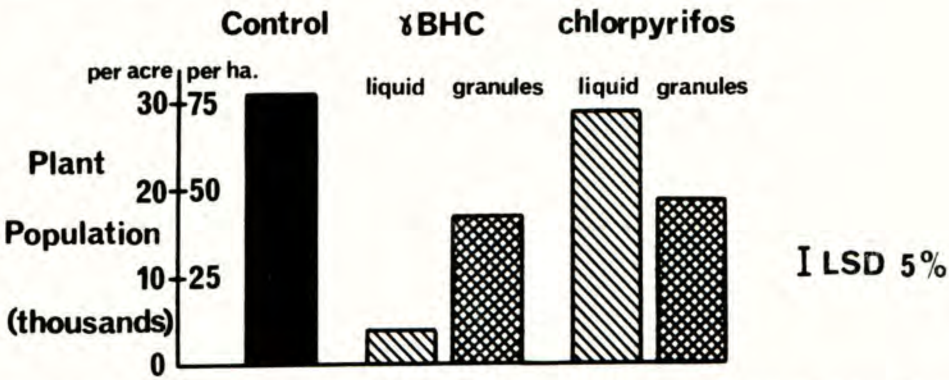

Fig 3. Effects on plant population, as a measure of phytotoxicity, of liquid and granule formulations of gamma-BHC and chlorpyrifos applied in-seed-furrow at 1.1 kg a.i./ha on loam soil, Broom's Barn, 1973.

Gamma-BHC spray, as an in-seed-furrow treatment, has been used commercially in the Netherlands (Heijbroek, pers. comm.). Further work on this technique is needed.

PROPERTIES OF GRANULE FORMULATIONS

The granule bases, their size distributions and the concentration of active ingredient chosen for commercial meterials currently being used differ widely (Table 1). Have these arisen by chance, or commercial necessity, or are they based on any biological evidence? Such evidence is necessary for each pesticide and granule base in relation to each pest and its mode of attack.

Table 1

Some physical data on granule formulations (Broom's Barn measurements on sample taken from commercial pack supplied March, 1976)

Material	Base	Density g/ml	% of total weight of granules retained on test sieves of nominal aperture widths (mm):									Approximate number of particles +	
			1.4	1.2	1.0	0.85	0.70	0.50	0.35	0.21	0	per g product	per 10mm of row
'DACAMOX 5G' (5% thiofanox)	'Clay'	0.73	t	< 1	< 1	2	12	35	33	11	7	73000	727
'DACAMOX 10G'* (10% thiofanox)	'Clay'	0.70	t	t	< 1	3	17	43	30	7	< 1	9000	44
'TEMIK 10G-BC' (10% aldicarb)	'Coal'	0.92	20	15	19	15	14	14	4	< 1	t	800	4
'VYDATE' 10% oxamyl)	'Clay'	0.67			t	< 1	15	43	32	10	< 1	21000	106
'YALTOX' (5% carbofuran)	'Silica sand'	1.35			t	2	26	56	15	< 1	t	2900	29

* = Experimental material

t = Trace, i.e. a very few granules

\+ = 50 cm row spacing : 1 kg a.i./ha

DISCUSSION

Damage to the seedling root system, whether by nematodes or insects, can start before seedling emergence. Where pesticides are necessary they need be present only in the zone of the hypocotyl and seedling roots. Such placement also allows uptake into the seedling and systemic activity in the foliage. Seed treatment can be very effective with some materials but the risk of phytotoxicity prevents sufficient material being applied for the longer persistence needed to control some pest damage.

In-seed-furrow application of pesticides does not interfere with seed drilling methods and it puts pesticides that are toxic to vertebrates safely below soil level. Ninety-five percent of the surface area of the field remains free of pesticide at the time of application, and subsequent dispersion (diffusion and moisture) only decreases this to about ninety percent; adverse side effects should be minimal.

The original objectives of the work - to develop a commercially acceptable and flexible method of applying the minimum amount of pesticide in the most biologically effective place - have been achieved. However, because the method is so easy and can be so effective where there is a pest problem, usage seems to be increasing onto fields where there is no obvious pest problem. This is largely a result of the wide spectrum of activity of aldicarb; further trials are in progress to determine whether this use can be justified.

New pesticides, especially of different groups, may control damage even more effectively but further work is needed on many of the principles involved in using granules as a carrier for the active ingredient - for instance the type and size of granules, release of active ingredient, optimum position of the granules in the soil. Progress is likely to be better if such basic knowledge can be obtained than by further empirical testing of yet more products.

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THE DEVELOPMENT AND ADVANTAGES OF A MICROGRANULAR FORMULATION OF METOXURON FOR USE IN WINTER CEREALS IN THE UK

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Summary Results from trials over three years with a 40% microgranular formulation of metoxuron applied through various applicators are described. Some of the techniques of development work with this formulation are evaluated and related to commercial practice.

Results indicate that as a blackgrass herbicide applied at rates between 3.6 and 4.4.kga.i./ha there is little difference between the microgranule and the wettable powder. A number of advantages resulted from the change from a wettable powder to microgranular formulation, including increased varietal tolerance, faster weed knockdown and all the generally accepted advantages of granular applications such as speed and ease of application.

INTRODUCTION

Metoxuron has been used in the U.K. in the form of an 80% w.p. for the control of Alopecurus myosuroides, other annual grasses and some annual broadleaf weeds, since its introduction in 1968. (Glenister and Griffiths 1968) (Griffiths and Ummel 1970)

Since 1972, trials have progressed using several formulations and application methods to find a biologically efficient and commercially appliable microgranule; i.e. of size 50-250 micron.

The aim of these tests was to achieve a granular formulation which would give leaf adhesion, for contact activity, as well as soil activity, and thus produce the same high level of biological activity as metoxuron 80% w.p.

MATERIALS AND METHODS

a) Formulations and rates of application.

1. Metoxuron 80% w.p.- normal rates 3.6 kg a.i./ha and 4.4 kg a.i./ha depending upon growth stage of weeds.

2. Metoxuron 40% mgr.* applied in the range of 3.2 - 8.8 kg a.i./ha. A fairly hard microgranule of actual size range 80-200 micron. (Ummel et al, 1974) A series of variety tests at 2n rate were conducted and results for the 40% mgr. were compared to the 80% w.p.

* mgr. = microgranule.

b) Application techniques

1973 1. Hand applied from shaker tube - plot size very small, i.e. less than 10 m^2.

2. Fischer pneumatic knapsack plot applicator - for small plots, i.e. less than 40 m^2.

1974 1. Horstine-Farmery hand-drawn rickshaw pneumatic applicator. Plot size 20 m^2 minimum.

1975 1. Fischer small plot applicator.

2. Tractor mounted Horstine-Farmery TMA 2 - plot size from 0.5 ha.

3. Tractor mounted Horstine-Farmery TMA 4 - grower scale, very large plots, circa 2 ha.

RESULTS

a) Formulation suitability

The metoxuron 40% mgr. formulation was tested in the Spring of 1973 and found to be completely compatible with the Horstine-Farmery TMA series. This formulation was subsequently used for critical field trials up to and including this year.

b) Methods of application and weed control results obtained

1. Shaker tube:- this method, although displaying the considerable biological activity of metoxuron 40% mgr. was inadequate due to uneven distribution over the plots. Results as shown in Table I, however, were encouraging enough to consider further work with improved application techniques.

TABLE I

Mean % control of A.myosuroides achieved in 1973 trials

Treatment	%	Rate kg a.i./ha	No. of trials	Mean % control A. myosuroides	Standard Deviation
Metoxuron	40 mgr.	3.2	4	82.0	15.3
"	"	3.6	4	78.3	14.4
"	"	4.0	6	84.0	8.4
"	"	8.0	4	91.0	5.8
Metoxuron	80 w.p.	4.0	4	76.0	32.6
"	"	8.0	4	83.0	29.2

2. Horstine-Farmery Rickshaw: This method gave a much more even application, although time required for trials was increased considerably due to problems of changing pulleys and metering systems for different rates.

3. Fischer Small Plot Applicator: A fast easily used and accurate machine, well suited to small plot work, giving highly reproduceable results.

4. Horstine-Farmery TMA 2 & TMA 4 Applicators: No problems were encountered in static tests, or field applications, using various rotor types i.e. alloy or plastic.

Results from late applications were exceptional considering the advanced crop and weed stages. Since granule distributions using methods 2, 3 and 4 are highly comparable, the results have been collated from various trials programmes and collectively tabulated in Table II.

The programmes included up to 10 trials where A.myosuroides was present with Avena spp. to varying levels of infestation, and in a number of isolated cases, ancillary broadleaved weeds occurred.

TABLE II

Mean % control of various weed species achieved in 1974 and 1975 replicated trials, from comparable rates of metoxuron w.p. and metoxuron mgr.

Weed species	% control from Metoxuron 40 mgr. (n)*	No. of trials	Metoxuron 40 mgr. (2n)*	No. of trials	Metoxuron 80 w.p. (n)*	No. of Trials
A.myosuroides	92.8	10	88.2	3	86.2	9
Avena spp.	44.5	8	74.5	5	60.0	5
Lolium spp.	78.0	2	93.0	1	97.0	2
Poa annua	97.0	1	100	1	100	1
Poa trivialis	100	2	100	1	97.0	2
Aphanes arvensis	89	1	99	1	100	1
Geranium molle	100	1	100	1	100	1
Lamium spp.	100	2	100	2	100	2
Matricaria spp.	97	2	100	2	100	2
Papaver rhoeas	94	2	97	2	98	2
P.aviculare	81	1	89	1	88	1
Stellaria media	95	5	100	3	98	3
Veronica spp.	78	4	80	3	81	3

* For the purpose of this table, rates of application are shown as 'n' or '2n', because of the rate variations due to early and late application times, and minor variations due to the individual limitations of the granule application equipment used.

The rate ranges cover 3.6 kg a.i./ha for early application, to 4.4 kg a.i./ha for late application (n), and 7.2 - 8.8 kg a.i./ha (2n). In most trials the 'n' rate of microgranules was compared directly with the 'n' rate of the w.p.; exceptions occurred in a very few cases where treatment data was extracted from other programmes.

c) Effects on yield and crop tolerance

1. Yield: Several replicated trials in the 1975 programme were assessed for yield at sites where annual grasses, wild oats and in most cases some annual broadleaf weeds were present together. Results are given in Table III below.

TABLE III

Yield results from 5 trials in 1975 expressed as % of untreated

Variety	Levels of main weed species		Metoxuron 40 mgr.		Metoxuron 80 w.p.
			kg a.i./ha		
Winter Wheat	A.myosuroides/Avena		4.4	8.8	4.4
Cappelle	High	High	118.2	126.8	126.2
Champlein	Moderate	Moderate	125.4	122.4	123.0
Bouquet	Nil	High	128.3	134.6	113.8
Flinor	Moderate	High	138.6	142.0	147.8
Mean			127.6	131.5	127.7
Analysis of variance gave no significant differences between treatments.					
Winter Barley					
Maris Otter	Nil	High	96.7	89.6	81.4*

* Result of a trial on crop severely retarded by waterlogging.

2. Crop tolerance

Over three years a large number of recommended varieties, and varieties under test, of winter wheat and winter barley have been treated at the '2n' rate of metoxuron formulations.

Of 35 varieties of winter wheat only three were slightly susceptible to the microgranules, whereas eleven showed some susceptibility to the w.p. formulation. Of nine winter barley varieties one, only, was slightly susceptible to the w.p. formulation; none were susceptible to the microgranules. The microgranule formulation was in fact less aggressive on all the varieties of winter cereals tested.

DISCUSSION

a) Effects of formulation change

1. Weed control:- The results from Table II cannot be effectively analysed due to the great variation in the sources of the information. The ranges of observed results were such that it is possible to conclude that very little difference is shown between equivalent rates of active ingredient of the microgranular or w.p. formulations, with the exception of Avena which to date appears more tolerant of the microgranule (Table II). This may possibly be due to the advanced growth stages at the applications, which is being further investigated this year. Field observations have shown very rapid knockdown of dicotyledonous weeds, inferring good leaf activity. This is supported by field observations of good leaf adhesion, despite adverse weather conditions subsequent to application.

2. Yields:- There was no significant difference in combined yield between 4.4 and 8.8 kg a.i./ha rates of the microgranule or between microgranule and wettable powder, although there was a tendency for the higher rate to give increased yields. All treatments gave significant increases over the untreated at the 5% level. Whilst it has been noted in the past that the use of metoxuron 80% w.p. gives increased yields with winter wheat, even with low infestations of weeds, it is interesting to note that this property is shared by the microgranule. Reference to the trial on winter barley c.v. Maris Otter, indicates that in the case of a crop suffering from serious waterlogging at application time, the microgranule formulation has little or no yield depression at normal rates, whilst the wettable powder appears to have depressed an already suffering crop.

3. Varietal tolerance:- Under UK conditions this appears to be substantially increased with the micrograńular formulation in comparison to the w.p. under conditions where the w.p. has given its predictable phytotoxicity on certain susceptible varieties e.g. Maris Nimrod, Mega, etc. Field observations show the usual normal w.p. effect is side tiller damage which is reduced under dry conditions, the inference of which is that this damage is caused via root uptake. This further reinforces the view that there may be greater leaf activity on crop and weeds from the microgranular formulation.

b) Trials related to application techniques

1. Aerial application:- Tests in the U.K. and elswhere (Ummel et al 1974) have shown that the microgranule formulation can be applied through aerial equipment, but variations across the swath can lead to anomalies in weed control.

2. Small plot trials:- Experience with both this microgranular, and other granular, formulations has shown that for trial work the Fischer small plot applicator gives distribution very closely resembling commercial applications on a very small scale i.e. it is comparable to the Horstine-Farmery TMA series.

3. Commercial applications:- Applications through Horstine-Farmery TMA series have given very satisfactory results and may even improve on small scale work. Further work with these and other commercial applicators is being carried out in 1976.

Also it can be seen that a 40% microgranular formulation of metoxuron gives obvious application advantages in low rates of product per hectare. (circa 9-12 kg/ha), thus improving efficiency and work output at application time.

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GRANULAR FORMULATIONS OF DICHLOBENIL

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Summary The evaporation loss of dichlobenil, the active ingredient of CASORON-formulations is enhanced under drying conditions. As a consequence a granular formulation has a longer residual effect than a water dispersible powder. Particle size and dichlobenil content of the CASORON granules for various applications are discussed.

INTRODUCTION

According to its biological properties the active compound of CASORON ®, dichlobenil, can be characterized as a pre-emergence herbicide. For the use of the product this implies the application of the formulated material to the soil, where it must remain biologically active during a prolonged period, at least several months. In the selection of the optimum formulation for dichlobenil its physical properties had an important influence.

Dichlobenil is a solid material with a melting point of 145°C for the pure active ingredient. The solubility generally is low, e.g. in water of 20°C only 18 ppm. In the organic solvents most often used in emulsifiable concentrates, the solubility of dichlobenil usually is less than 100 grams per litre, rendering the e.c.-formulations less attractive from the economical point of view.

The most obvious type of formulation for a solid active substance with a low solubility is the water dispersible powder and actually this was the formulation with which the initial development of the product took place.

Water dispersible powder formulations

Dichlobenil can easily be ground and formulated into a water dispersible powder (w.d.p.). The formulation used in most of the trial work contained 50% active material. Although generally good herbicidal effects were found, it appeared that a wide variation of results could be observed, especially so for the residual effects.

When considering the climatic conditions during the trials it was established that higher soil moisture contents reduced the activity of the product. Especially in the case of a high soil moisture and a low humidity of the air -so drying conditions- the biological effect lasted shorter than the average.

The above effects can partly be attributed to the volatility of dichlobenil, which has a vapour pressure of 5.5×10^{-4} mm Hg at 20°C.
Still more important, however, is the fact that the evaporation is facilitated considerably in the presence of water.

® = Trade mark Philips-Duphar

To enable a judgement of the evaporation losses under practical conditions a series of small scale field trials was carried out on a sandy soil containing about 5 % of organic matter. The first trials were performed under selected sets of metereological conditions (Table 1).

Table 1

Loss of dichlobenil after application of CASORON-133 W

Application	Conditions				Percentage recovery of dichlobenil after a period of:			
no.	T °C	soil	weather	RH %	0 hrs	3 hrs	24 hrs	7 days
1	9	moist	cloudy	-	100	80	65	25
2	19	moist	sunny	50	100	65	25	10
3	23	dry	sunny	40	100	80	50	15
4	29	dry	sunny	55	100	60	35	20

These results confirm the conclusion that under drying conditions a rapid loss of dichlobenil occurs, whereas under cool and dry conditions losses are relatively low. Warm and dry conditions result in intermediate losses.
(Verloop, 1973)

In a second series of trials the influence of rain on the persistence of dichlobenil was studied, again using w.d.p. as a formulation. The results are presented in Table 2. It can be seen that, whereas artificial rain before the application -drying conditions- enhances the evaporation of dichlobenil, rain after the application greatly reduces the evaporation loss.

Table 2

Loss of dichlobenil after application of CASORON-133 W

Application	Conditions	Percentage recovery of dichlobenil after a period of:			
no.	30 °C RH 50 %	0 hrs	3 hrs	24 hrs	7 days
5	dry soil, no rain	100	50	25	20
6	50 mm of artifical rain <u>after</u> application	100	80	65	45
7	50 mm of artificial rain <u>before</u> application	100	50	15	10

Similar trials were carried out using various formulations of dichlobenil i.e. :

(i) w.d.p. 50 % dichlobenil

(ii) granules, containing 7.5 % dichlobenil
particle size 0.1 - 0.25 mm

(iii) granules, 7.5 % dichlobenil
particle size 0.6 - 0.7 mm

The results are shown in Table 3.
The experiments were carried out under the following meteorological conditions : 20 °C, RH 75 %, moist soil, no rain.

Table 3

Loss of dichlobenil after application of various formulations

Application no.	Formulation	Percentage recovery of dichlobenil after a period of :			
		0 hrs	3 hrs	24 hrs	7 days
8	water dispersible powder	100	65	25	20
9	granules, 0.1 - 0.25 mm	100	95	70	10
10	granules, 0.6 - 0.7 mm	100	100	95	35

From the results it can be seen that with the granular formulation the vapour losses are reduced considerably.

Granular formulations

The above mentioned results clearly show that with granular formulations evaporation losses are greatly reduced. Consequently, a more consistent biological effectiveness is to be expected with granules as compared with a dispersible powder.

From the well known techniques for the production of granules, the dry compaction technique was selected for CASORON-G, mainly to avoid losses of dichlobenil in the drying processes required in other techniques.

The compaction technique is quite versatile in that a wide range of contents of active material(s) can be included in the formulation. The optimum content of dichlobenil in CASORON granular formulations is to be related to both the dosage rate required and the distribution characteristics of the application equipment. With most ground equipment a thoroughly even distribution of the granules is only possible when the total amount of material to be applied is over about 40 kg/ha.

For selective weed control, in which 3 to 6 kgs of active ingredient per hectare are used, this implies that the content of dichlobenil may be 7.5 % at the maximum in order to cover all applications.

For total weed killing operations, in which from 9 to 15 kgs a.i./ha are used, the dichlobenil content should be 22 % at the maximum.

Apart from the total amount of granular material also the particle size distribution is of vital importance in obtaining an even coverage of the soil surface.

The relationship between the granule density and the biological effectiveness was studied in small scale field trials in which granular products with narrow granule size ranges were applied carefully to a sandy soil. The products studied contained (i) 7.1 % of dichlobenil and (ii) 17.4 % of dichlobenil.

Prior to these applications garden cress (Lepidium sativum) had been sowed in the plots. Approximately 6 weeks after the applications the numbers of Lepidium plants in various plots were counted.

The results are collected in Table 4

Table 4

Herbicidal effects of CASORON granules

Granule size range	Number of granules/ gram	Dosage rate kg a.i./ ha	Number of Lepidium plants 7.1-G	17.4-G
1 - 1.19	550	1½	129	245
		3	35	101
0.71 - 0.85	1,700	1½	61	80
		3	8	65
0.5 - 0.6	4,000	1½	59	72
		3	4	8
0.35 - 0.42	12,000	1½	26	68
		3	9	8
0.25 - 0.3	30,000	1½	4	27
		3	15	6

From this table the relationship between the number of plants and the granule density can be derived (Table 5).

Table 5

Relationship granule density vs herbicidal effect

Dosage rate 1½ kg a.i./ ha			Dosage rate 3 kg a.i./ ha		
granules/ cm^2		plants	granules/ cm^2		plants
0.05	a	245	0.10	a	101
0.12	b	129	0.24	b	35
0.15	a	80	0.30	a	65
0.34	a	72	0.69	a	8
0.36	b	61	0.72	b	8
0.84	b	59	1.68	b	4
1.03	a	68	2.07	a	8
2.52	b	26	5.04	b	9
2.58	a	27	5.17	a	6
6.3	b	4	12.6	b	15

(a = 17.4% granule; b = 7.1% granule)

From the results there appears to be a clear relationship between the granule density and the herbicidal effect. In these trials in which a very thorough distribution was obtained by the method of application, it appears to be necessary to have at least 2 to 3 granules per cm^2 at the dosage rate of 1.5 kg a.i./ ha. At the dosage rate of 3 kg a.i./ ha the good herbicidal effect is already obtained at a lower granule density, which may well be explained from the larger deposit of dichlobenil per granule.

Based upon the above information a rough indication for the granule density might be about 1 granule per cm^2. However, it should be borne in mind that:

(i) The distribution was particularly even
(ii) The test plant is very sensitive to dichlobenil.

In field trials two formulations of dichlobenil were compared:

(i) normal CASORON-G, content of dichlobenil 6.75 % , approx 5500 granules per gram, size range 0.25 - 1.0 mm

(ii) coarse CASORON-G, 6.75 % dichlobenil, approx 900 granules per gram, size range 1.0 - 2.0 mm

The products were applied with practical equipment to both a sandy soil and a clay soil for total weed killing. The results are shown in Table 6, in which the herbicidal effects are given, ranging from 0 (no effect) to 10 (all weeds killed).

Table 6

Total weed killing with CASORON-G (6.75%)

formulation	dosage rate kgs a.i./ha	herbicidal effect after			
Sandy soil		11 weeks	16 weeks	20 weeks	
normal	9	9.3	8.8	7.0	
	12	9.5	9.3	7.5	
	15	9.5	9.5	8.8	
	18	10	9.9	9.3	
coarse	9	7.3	7.5	6.0	
	12	8.3	8.8	7.5	
	15	8.3	9.0	8.5	
	18	9.0	9.3	8.8	
Clay soil		4 weeks	6 weeks	8 weeks	12 weeks
normal	9	7.2	9.5	9.8	9.3
	12	7.0	8.7	9.0	9.5
	15	6.8	8.2	9.3	9.0
	18	7.0	8.5	9.3	9.3
coarse	9	6.7	8.7	7.8	8.3
	12	7.3	8.8	9.3	9.2
	15	6.8	7.8	9.3	9.5
	18	7.7	9.2	9.5	9.3

It is clearly shown that at the dosage rate of 9 kg a.i./ ha the coarser formulation (granule density 1.1/cm^2) was inferior to the normal product (approx 6.7 granule/cm^2). At the dosage rates of 12 and 15 kg a.i/ha (1.4 and 1.8 granule/cm^2 respectively) the results with the coarse product were inferior to those of the normal product on the sandy soil but on a par on the clay soil.

Similar results were obtained in numerous other field trials. Consequently the conclusion may be drawn that under practical conditions the density requirement of CASORON granules should at least be 2 to 3 granules/cm^2 is confirmed. This conclusion need not be in contradiction with results reported in the literature (e.g. Horowitz,1966), where areas of contamination of several cm^2 's are indicated. In those cases the heavy dichlobenil vapour may be present close to the soil surface and may further on be absorbed by the soil again. In practical circumstances this will not take place due to the air movement.

Based upon the above derived conclusion it should be emphasized that for an optimum result CASORON-G (6,75%) should be used in selective or semi-selective applications, whereas CASORON-GSR (20%) should be used in those cases where high rates of active material are required (over 8 kg a.i./ha) or where distribution is less critical such as in aquatic weed control.

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SOME EFFECTS OF FORMULATION ON THE BIOLOGICAL PERFORMANCE OF DICHLOBENIL

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Summary Dichlobenil is a soil applied residual herbicide effective in the control of terrestrial and aquatic weeds. It proved unreliable when formulated as a 50% wettable powder due to excessive volatilization between application and soil absorption. Further work showed these losses to be greatly reduced by formulating a granule of the correct density, concentration and structure. The optimum is a compacted granule with a particle size of 0.5 millimetres containing 7.5% technical dichlobenil. In this regard, efficacy is maintained within the concentration range of 4 to 15%, further advantages being derived when concentration is raised to 22%. Deficiencies in the dichlobenil spectrum can be overcome by granulating with other herbicides, a technique for which the compaction process is especially suited.

INTRODUCTION

Dichlobenil is a soil applied residual herbicide being also effective when used in water. It is manufactured and formulated by B.V. Philips-Duphar, Amsterdam and is sold world wide under the trade names Casoron G and Casoron G-SR. Many hundreds of papers have been published which describe its properties, mode of action and biological activity. In this paper an attempt has been made to bring together a mass of scattered data relating to the effects of formulation on biological results. Much of this data has hitherto remained unpublished and stems from trials conducted in Holland and in the U.K.

The first commercial formulation of dichlobenil was a 50% wettable powder, but widespread use revealed serious deficiences in its limited residual activity, accompanied often by an unexpectedly poor level of initial weed control. Dichlobenil is a compound of low solubility combined with a relatively high vapour pressure, properties which under certain conditions can result in the volatilization of active ingredient. Investigation of poor commercial results showed a correlation between indifferent weed control and weather patterns conducive to the evaporation of soil moisture with consequent volatilization of active ingredient. Results of investigations to overcome this situation are presented.

METHODS AND MATERIALS

The various formulations forming the subject of this paper are detailed elsewhere and unless stated otherwise, were spring applied within the general period late February/early April. The large number of trials precludes presentation of detailed data on weeds treated although wherever possible some data is given. Likewise, space restrictions limit the presentation of results largely to one rate - 6 kg/ha. Assessments conform to the scale proposed by the Methods Group of the EWRC where 1 = excellent; 3 = good; 5 = just sufficient and 9 = no weed control. Throughout this paper, concentration is expressed as technical dichlobenil rather than pure active ingredient.

RESULTS

In a series of trials conducted between 1960 and 1964 a 2% granule was compared with the wettable powder but showed little if any improvement. A more elaborate trials sequence was then initiated in 1966 with projects designed to test four formulation types; to investigate different methods of manufacture and to compare a more concentrated granule containing 7.5% dichlobenil with the wettable powder over a range of rates applied in the autumn and spring.

Effect of Formulation

The formulations tested comprised the 50% wettable powder; a 6% emulsifiable concentrate; an 18% paste and a 7.5% granule.

Table I

Comparison of formulations

(Mean of 3 trials - 1966)

		Weed control			
Months post application →		3	4	5	6
Rate kg/ha	Formulation				
6	50% w.p.	5.4	6.3	4.1	7.5
6	6% e.c.	5.6	6.7	4.5	8.1
6	18% paste	4.6	6.9	5.9	7.7
6	7.5% G	2.6	4.5	3.6	6.3

Footnote i) Replicates/trial - 5. ii) Application between 28/2/66 and 8/3/66. iii) Soils - sand (1 trial); clay (2 trials). iv) Weeds controlled - Agropyron repens; Poa annua; Capsella bursa pastoris; Cirsium arvense; Convolvulus arvensis; Polygonum aviculare; Rorippa sylvestris; Senecio vulgaris; Stellaria media.

Results show the level of weed control provided by the e.c. and the paste to be similar to that of the w.p. Markedly superior weed control and extended residual activity were however consistently obtained with the 7.5% granule.

Effect of Manufacturing Methods

Using a 7.5% granule throughout, the effect of differing manufacturing methods was compared, the granules being either compacted, extruded or agglomerated (glomules).

Table II

Comparison of granule types

(Mean of 3 trials - 1966)

		Weed control			
Months post application ⟶		2	3	4	5
Rate kg/ha	Granule Type				
6	Extruded	5.3	5.1	5.2	5.9
6	Glomules	3.9	4.5	4.5	5.6
6	Compacted	3.6	4.3	4.5	5.5

Footnote i) Replicates/trial - 4. ii) Application between 8/3/66 and 8/4/66. iii) Soils - sand (1 trial); clay (2 trials). iv) Weeds controlled - Agropyron repens (dominant on 2 sites); Agrostis stolonifora; Poa annua; Ranunculus repens; Ranunclus obtusifolius; Senecio vulgaris; Taraxacum officinale.

Although in general, the results obtained from the compacted granules were marginally better than those provided by other production methods, particularly on susceptible weeds, control of the more resistant species; i.e. Agropyron repens proved inferior following the use of the extruded granules.

Comparison of the 7.5% Granule and the 50% Wettable Powder

The results of some eighteen trials conducted over the two year period 1966/67 are summarized in Table III.

Table III

Comparison of 7.5% G and 50% w.p.

(Mean of 18 trials)

		Weed control			
Months post application ⟶		3	4	5	6
Rate kg/ha	Formulation				
6	50% w.p.	5.3	5.9	5.8	7.2
6	7.5% G	2.3	3.4	4.5	5.2

Footnote i) Replicates/trial - 3, 4 or 5. ii) Application (both years) between 28/2 and 17/4. iii) Soils - sands (8 trials); loam (3 trials); clay (7 trials). iv) Weeds common to most sites - Agropyron repens (dominant on 2 sites); Poa annua; Capsella bursa pastoris; Cirsium arvense; Polygonum aviculare; Ranunculus repens; Senecio vulgaris; Stellaria media.

Results clearly show the superiority of the 7.5% granule over the wettable powder.

Differential Weed Control

Table IV

Effect of dose

(Mean of 6 trials) (See footnote a)

Months post application →		3	4	5	6
		Weed control			
Rate kg/ha	Formulation				
3	50 w.p.	3.3	5.2	5.7	7.9
	7.5 G	3.9	5.4	6.1	6.2
6	50 w.p.	4.4	4.9	4.4	5.4
	7.5 G	2.2	3.2	4.4	3.8
		(Mean of 4 trials) (See footnote b)			
		Control of *A. repens*			
11	50 w.p.	7.2	9.0	9.0	9.0
	7.5 G	1.0	1.3	3.3	5.3

Footnotes a) Data as for Table III.
b) i) Replicates/trial - 4. ii) Application between 21/3/67 and 5/4/67. iii) Sand (2 trials); loam (1 trial); clay (1 trial).

From Table IV it will be noted that the differential in weed control provided by the two formulations was not as marked at 3 kg as at 6 kg. For difficult weeds however, as instanced by *Agropyron repens*, the difference in performance between the two formulations was most striking when the rate was increased to 11 kg.

Effect of Timing

Results from Holland (not here presented) showed an increase in persistence from both formulations when applied autumn/winter as opposed to normal spring application. This is because winter weather conditions are generally more favourable to the activity of dichlobenil when low soil and air temperatures, enhanced by soil incorporation from winter rains greatly reduce the evaporation losses which may be initiated by rising spring temperature gradients. Similar results were obtained in our U.K. trials where we found persistence to be much longer from autumn than from spring treatment. (Spencer-Jones and Wilson, 1968). These and other factors which affect the behaviour of dichlobenil in the soil are fully described by Verloop (1972) and by Beynon and Wright (1972).

Phytotoxicity

The markedly superior weed control provided by the 7.5% granule was achieved without any corresponding phytotoxicity in tolerant crops. Table V summarizes a long-term trial on apples, var. Golden delicious, conducted in Holland over the eight year period 1967 to 1974.

Table V

Yield and growth of apple trees

Rate kg/ha	Formulation	Total accumulated yield in kg/tree 1967 - '74	% Girth increment 1967 - '74
3	50 w.p.	125	184.2
	7.5 G	128	191.9
6	50 w.p.	132	180.6
	7.5 G	156	210.2
12	50 w.p.	143	186.8
	7.5 G	130	157.2

Footnote i) Replicates - 3. ii) Application (all years) between 4/4 and 14/4. iii) Soil type - sand.

Although yields from granular treatment declined when the dose was increased from 6 to 12 kg/ha, the 12 kg plots nevertheless out-yielded those treated at 3 kg. Our own work in the U.K. has shown maximum rates for the 7.5% granular to be greatly in excess of 12 kg, rates up to 22 kg being well tolerated by apples and pears and 33 kg by blackcurrants and gooseberries. (Spencer-Jones and Wilson, 1968; 1970).

From the work so far described, it is evident that the best weed control was consistently achieved by the 7.5% compacted granule which could be applied at rates far in excess of those needed for selective weed control in top and bush fruit. Two final aspects however needed verification, namely, the effect of particle size or granule density, and the further effect if any, of concentration of active ingredient within the granule.

Effect of Particle Size

The effects of particle size and distribution are described by Maas (1976) who concludes that under practical conditions, an optimum particle size of approximately 0.5 mm and a density of two to three granules/cm^2 is required.

Effect of Concentration

The deficiencies of the 50% wettable powder, although not remedied by a 2% granule were overcome by formulating a 7.5% compacted granule. The further effects of concentration have been studied in trials where comparisons were made between 4%; 7.5%; 10% and 15% granular formulations. (Table VI).

Table VI

Effect of increasing active ingredient. (Mean of 12 trials - 1966/67)

(See footnote a)

Months post appln. →	Weed control 2				3		4			5		
Rate kg/ha	4%	7.5%	10%	15%	4%	7.5%	7.5%	10%	15%	7.5%	10%	15%
1.5	5.2	4.2			5.6	5.5						
3.0	2.3	2.2			1.8	1.6						
6.0	1.6	1.8			2.5	3.3						
							(Mean of 3 trials - 1967) (See footnote b)					
9.0		3.0	4.8	4.5			3.0	3.7	4.2	6.2	6.0	4.7
15.0		2.2	4.4	3.3			2.0	2.5	2.0	2.5	6.0	2.2
24.0		1.5	1.8	2.4			1.0	1.5	1.3	1.5	3.5	1.7

Footnotes a) See data as for Table III.

b) i) Replicates/trial - 2. ii) Application between 1/4 and 8/5/67. iii) Soils - sand (all trials). iv) Weeds controlled - Agropyron repens, Cirsium arvense, Rumex spp, Tussilago farfara.

Results show differences to be marginal and surprisingly, were somewhat poorer in the case of the 10% granule. However, when the sample batch of 15% granules was ordered, a 22% granule was also prepared. The latter was not however included in these tests as the 22% granules were found after formulation to be extremely hard, so much so that it was thought disintegration and subsequent release of active ingredient would be seriously impaired. Subsequent laboratory tests did however indicate that complete disintegration does in fact occur, albeit very slowly, and the 22% granule later became the subject of further field trials.

Owing to its low rates of application, the 22% formulation on land is only suitable for total weed control. It is however eminently suited for use in water. Results of trials comparing the 7.5% and 22% granules when used in aquatic situations are described by Spencer-Jones (1974) who found in the more concentrated material a greatly enhanced residual activity as indeed might be expected from a harder granule slower in its disintegration.

Dichlobenil Mixtures

Certain weaknesses in activity can be overcome if dichlobenil is combined with other selected herbicides. The compacted granule is especially suitable for such treatment (Maas, 1976). Such granular combinations meet a need in special circumstances particularly if the selected mixture displays synergism. One such example is the addition of dalapon to enable a marked improvement in the control of resistant or partially resistant monocots in forestry, where, in upland areas in particular, weeds such as agrostis and calamagrostis spp; agropyron spp; deschampsia spp; juncus spp etc can become particularly troublesome.

Table VII provides data which typifies the advantages gained by adding 10% dalapon to the standard 7.5% dichlobenil granule. The area cited, destined as a camping site, was newly planted with Pinus nigra martima, the whole site, formerly under arable cropping having become heavily infested with Agropyron repens (dominant); Poa annua; Sonchus oleraceus and Matricaria inodora with other broad-leaved weeds also present.

Table VII

Mean of 3 trials, 1974

	Dichlobenil 7.5% G	Dichlobenil (7.5%) + Dalapon (10%)	Control
Rate kg/ha →	4.7	3.3 + 4.5	
Tree Vigour	2.8	2.8	1.5
% Tree Mortality	14.7	14.2	23.8
% Weed cover			
grasses	5.0	1.0	5.5
broadleaved	1.2	1.8	5

Assessments Tree vigour 0 - 5 where 0 = dead plant, 5 = full vigour.
Weed cover 0 - 10 where 0 = bare ground, 10 = 100% cover.

The data shows a marked improvement in grassweed control from the combination granule but with a rather better level of broadleaved weed control from straight dichlobenil which is to be expected, bearing in mind the difference in the rates of applied dichlobenil/ha. The season was particularly dry and this was reflected in the rather high percentage mortality figures. Despite this, the reduced rate of dichlobenil/ha provided by the mixture enhanced tolerance margins under these unfavourable conditions, an important bonus if conditions are critical.

Other granulated products which have proved successful when combined with dichlobenil include bromacil, fluometuron and monolinuron.

Conclusions

Dichlobenil proved unreliable when formulated as a 50% wettable powder due to excessive volatilization between application and soil absorption. Further work showed volatilization could be minimised by formulating a granule within a concentration range of 4 to 15%. Efficacy was reduced below 4% but at 22%, due to structural changes, residual activity is enhanced. Deficiencies in the dichlobenil spectrum can be overcome by granulating with other herbicides, a technique for which the compaction process is especially suited.

Acknowledgements

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PHYTOTOXICITY OF TWO DIFFERENT PATTERNS OF TRI-ALLATE GRANULES TO EMERGED WILD OAT (AVENA FATUA) AND WHEAT PLANTS

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Summary In a glasshouse experiment the influence of distribution pattern on the phytotoxicity of 10% w/w tri-allate granules to emerged plants of wild oats (*Avena fatua* L. 'Waterstock, type fb') with or without wheat (*Triticum aestivum* L. 'Maris Huntsman') was investigated. Two patterns of granule distribution were tested (1) a uniform distribution at 3.36 kg a.i./ha over the whole soil surface of 21 x 36 cm and (2) a restricted application in which the granules were concentrated in a 90 cm^2 area (dose equivalent to 14 kg a.i./ha). Seventeen days after treatment there was no statistically significant difference between the mean leaf length of the wild oat plants growing on either of the treated areas. Both were however significantly less than the mean control and where distribution was restricted (2) the leaves of the plants were longer the further they were from the granules. Wheat was very tolerant of all the treatments. The implication of these results is discussed.

INTRODUCTION

The post-emergence activity of tri-allate granules on wild oats was reported first in 1968 by Holroyd. Since then little if any work has been published on the relationship between distribution pattern and activity of tri-allate granules applied post-emergence.

Data presently under preparation for publication by Holroyd provide some important guidelines regarding the post-emergence activity of tri-allate granules. Of considerable importance is the fact that the phytotoxic effect on wild oat from post-emergence treatment can be mediated solely through the gaseous phase of the herbicide. In addition, it can be shown by granular placement studies in small pots that very small increases in distance between the granules and the wild oat plant can cause marked reductions in phytotoxicity at granule : plant ratios of 4:1 or less.

In granular placement studies in small pots relatively few granules are applied per pot. For instance, only 24 granules would be applied to a pot containing 6 wild oat plants if the granule : plant ratio was 4:1. Under field rates of application the granule : plant ratio is considerably higher. In view of the volatile nature of tri-allate, a logical question that arises is whether or not the spacing between the granules and wild oat plants is as critical at field rates as suggested by the results obtained with the low granule : plant ratios used in the placement studies. A major objective of the work reported here was to see whether or not a close association between granules and wild oat plants was essential for good control at simulated field rates of application.

*This work was undertaken while the senior author was on sabbatical leave from the Crop Science Dept, University of Saskatchewan, Saskatoon, Sask., S7N 0W0, Canada.

METHOD AND MATERIALS

Wild oat (Avena fatua L.) was grown with and without wheat (Triticum aestivum L. 'Maris Huntsman') in the glasshouse in 21 by 36 by 6 cm (I.D.) plastic trays. The temperature in the glasshouse ranged from 10 to 24°C with a mean of 15°C. Supplemental lighting was provided daily for a 14 hr period by fluorescent lamps which provided approximately 5 watts per m^2 at the plant canopy.

Each plastic tray was divided down the centre with a piece of heavy gauge aluminium strip, cut to make a precise fit in the tray with 1 cm protruding above the rim. One 21 x 18 cm compartment in each tray was sown with 40 caryopses of wheat and 40 caryopses of wild oat, and the other compartment was sown with 40 caryopses of wild oats only. A sandy loam soil, fertilized with John Innes potting base to provide a medium level of nitrogen, was used throughout after screening through a 5 mm sieve. The caryopses were distributed uniformly within each compartment and soil was added to provide a planting depth of 3 cm and 2 cm for the wheat and wild oats respectively. The wild oats were sown with the hull intact. After planting, the soil moisture was brought up to field capacity by surface application, and thereafter water was provided as required until the herbicide was applied.

Granules with a dimension of 500 to 600µ were sieved from a commercial formulation of granular tri-allate (10% w/w active). The granules were applied to the soil surface with a hand-shaker, at a rate of 3.36 kg a.i./ha of tri-allate. At the time of treatment the average shoot height of the wheat and wild oats above soil surface was 10 and 7 cm respectively, and the wheat was entering the 2-leaf stage and the wild oats were in the 1-leaf stage. Two patterns of granule distribution were tested including (1) a uniform distribution of granules over the complete soil surface of both compartments of the tray and (2) the same amount of herbicide as applied in the uniform distribution but with the granules in each compartment concentrated within a 9.5 by 9.5 cm square wire-grid located in the centre of the compartment and hereafter referred to as the restricted placement (Fig I). After the granules had been applied all of the trays were located on a layer of absorbent fibrous-matting placed on polyethylene sheet. Soil moisture was maintained within the 75 to 100% field capacity range by sub-irrigation from the wet mat surface through holes in the base of the trays.

A split-plot arrangement of treatments with granule distribution as the main plots and plant association as the sub-plots was used in a randomised complete block design. Each treatment was replicated three times and the test repeated twice.

At harvest, 17 days after treatment, all the plants in the trays were severed at the soil surface and the extension of each leaf measured. A summation of the measurements of all leaves on each plant was made to give the total leaf extension per plant.

After calculation of the total leaf extension on a per plant basis the data was transformed to square roots for statistical analysis.

RESULTS

When granule placement was restricted there was no effect on the leaf extension of wheat at harvest sites II to IV inclusive (Table 1). There was, however, a significant reduction in the growth of wheat at harvest site I. This is not surprising since all the tri-allate granules in the restricted placement treatment were concentrated in site I. In effect, although the herbicide rate for each tray compartment on a total area basis was equivalent to 3.36 kg a.i./ha, the actual rate within the confines of site I amounted to 14 kg a.i./ha. In view of this fact, wheat showed a remarkably good tolerance to post-emergence treatment with tri-allate granules. No significant reductions in the growth of wheat occurred at any harvest site in compartments treated overall. Similarly, when the data obtained from all four harvest sites within each treatment were bulked to provide an average for the whole tray compartment neither tri-allate treatment resulted in any statistically significant suppression in wheat growth.

Table 1

Effect of two different patterns of distribution of tri-allate granules on leaf extension of wheat

Treatment		Tri-allate dose	Total leaf extension per plant[c]				
Tri-allate	Placement[a]	kg a.i./ha	Site I[b] mm	Site II mm	Site III mm	Site IV mm	Whole tray[d] mm
+	Restricted	3.36	591b	640a	660a	685a	636a
+	Complete	3.36	675a	657a	681a	666a	667a
-	Nil	0.00	671a	659a	671a	680a	669a

[a]In this column 'restricted' refers to the placement of all granules in site I as shown in Figure 1; 'complete' designates a similar amount of granules evenly distributed throughout the tray compartment.

[b]Harvest sites I to IV inclusive are as shown in Figure 1.

[c]Means followed by the same letter within each site are not significantly different at the 5% level according to Duncan's multiple range test.

[d]Based on the measurement of 186 $\pm$ 3 plants per treatment.

The presence of wheat had no effect on the degree of phytotoxicity produced by tri-allate on wild oat. Consequently, the data shown in Table 2 are based on the combined response of wild oat from the two compartments which made up every tray, regardless of the presence or absence of wheat. In effect, each mean shown in Table 2 is based on plants harvested from six complete trays.

Table 2

Effect of two different patterns of distribution of tri-allate granules on leaf extension of wild oat

Treatment		Tri-allate dose	Total leaf extension per plant[c]				
Tri-allate	Placement[a]	kg a.i./ha	Site I[b] mm	Site II mm	Site III mm	Site IV mm	Whole tray[d] mm
+	Restricted	3.36	113b	156b	189b	214b	161b
+	Complete	3.36	131b	131b	143b	136c	135b
-	Nil	0.00	490a	495a	503a	506a	496a

Footnotes a, b and c are similar to those shown under Table 1.

[d]Based on the measurement 421 $\pm$ 6 plants per treatment.

The most important finding apparent from the summation of the wild oat data is the fact that when an average of all four harvest sites within a treatment is computed to produce a whole tray response, there is no significant difference between the restricted placement and the overall treatments in terms of ability to suppress leaf extension. A similar picture is obtained at the individual harvest sites since no significant differences in growth are apparent when comparisons are made between the two tri-allate treatments at sites I to III inclusive. Wild oat growth, however, was significantly better at site IV on the compartments where granule distribution was restricted to site I i.e. no granules at site IV, than where treatment was overall i.e. granules present at site IV. Nevertheless, the reduction in growth at site IV of the restricted treatment is appreciable, amounting to a 58% reduction from the check, in spite of the fact that all of the plants at this site were at least 4 cm from the closest tri-allate granules. In fact isolated plants in the corners of the trays which were as much as 8 cm from the closest granules showed distinct symptoms of tri-allate phytotoxicity.

DISCUSSION

Several phytotoxic effects on wild oats from post-emergence application of tri-allate granules were noted in the course of this study in addition to the suppression of leaf extension. One such response that supports the hypothesis that the active phase is in the volatile form is the rapidity with which interference of wax deposition was observed on the basal sections of the leaf laminae. In the overall treatment this interference with wax formation was visible within 30 hr of treatment. In the case of plants located in harvest site II of the restricted placement treatment at distances of up to 2 cm from the nearest granules visible signs of wax disruption occurred in less than 48 hr following treatment, and within 96 hr of treatment all wild oat plants within the compartment where treatment was restricted showed the effect.

Claim for further support to the volatile phase hypothesis would appear warranted on the basis of the gradient effect in which growth suppression of wild oats decreased with increasing distance from the tri-allate granules. Moreover, since the trays were sub-irrigated after treatment there is little possibility that lateral movement of moisture at the soil surface accounted for the gradient effect which was almost absent in the overall and control treatments.

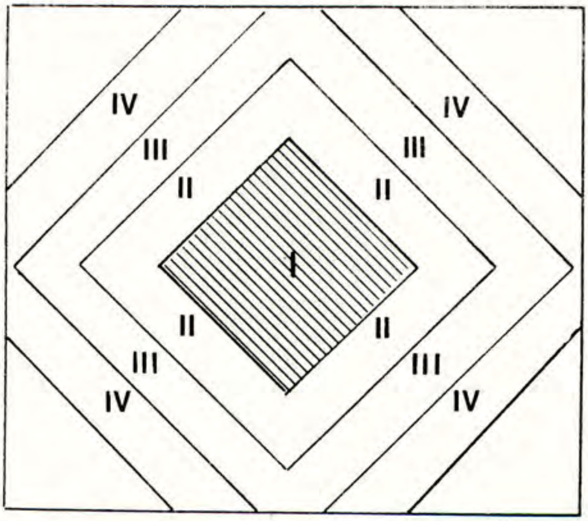
In conclusion, the production of an acceptable level of phytotoxicity by post-emergence application of tri-allate granules is not necessarily dependent on the close proximity of the granules to the wild oat plant as is the case when relatively low granule : plant ratios are used in small pots. At field rates as demonstrated in this study a phytotoxic level of tri-allate can disperse quite readily with lethal effects arising at some considerable distance from the granules.

The major question that remains to be answered is whether or not the volatile phase disperses as effectively under natural growing conditions outside as has been demonstrated here under glasshouse conditions. From a practical standpoint it would seem essential for the volatile phase to disperse to an appreciable degree under field conditions to provide acceptable wild oat control. Even the most sophisticated types of granular applicator do not assure the placement of one or more granules within a few millimeters of all the wild oat plants without the use of excessive rates of application. Work is currently underway to clarify the situation under outside growing conditions.

References

HOLROYD, J. (1968) Tri-allate granules for the post-emergence control of Avena fatua in winter and spring cereals. Proc. 9th Br. Weed Control Conf., 68-73.

Fig. 1. Diagrammatic representation of a single compartment of a tray showing the four harvest locations (I to IV inclusive) applicable to all trays, and also the site of 'restricted granule placement' (location I) - see text



I = 90 cm^2, site I

II = 92 cm^2, site II

III = 122 cm^2, site III

IV = 146 cm^2, site IV

FIELD EXPERIMENTS FOR THE CONTROL OF WILD OATS (AVENA FATUA) IN PEAS WITH GRANULAR TRI-ALLATE

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Summary The results are presented of replicated experiments carried out in commercial green and dried pea crops testing various rates and application methods of a granular formulation of tri-allate. When applied at equivalent rates of active ingredient, and incorporated in the same way to the liquid formulation, the granules gave comparable levels of control and satisfactory control was also achieved from the granules applied shortly before drilling where only light incorporation had been carried out. Applications of granules made after drilling were less effective even when lightly incorporated, while higher rates appeared necessary for post-emergence applications and again control was rather variable.

INTRODUCTION

Wild oats (Avena fatua) can cause serious losses in both green and dried peas. Not only do they reduce yields due to their vigorous competition with the crop for light, moisture and nutrients, but also they interfere with harvesting, increasing losses during vining and combining, slowing throughput, causing stoppages and extra cleaning of mobile viners, and as a result of slowing down the natural drying of the crop increasing losses due to the staining of dried peas.

Previous work(Armsby & Gane 1964,)has already shown the effectiveness and value of applications of tri-allate liquid incorporated before drilling peas, but for early sowings, which can be made in late February or early March, or those on heavy soils, the deep and thorough incorporation essential for effective use of this treatment causes many problems. In 1969, following work carried out at the Weed Research Organisation (Holroyd, 1968) experiments were undertaken to evaluate tri-allate in granular form as a non-incorporated treatment. The two preliminary experiments testing post-emergence applications of 10% w/w granules at 1.68 and 3.36 kg ai/ha proved sufficiently promising to allow more detailed work to be undertaken during the next four years.

METHODS AND MATERIALS

Pre-sowing applications of granules (10% w/w active) incorporated by means of a rotovator, set to work to a depth of 8 cm, post-drilling applications left on the surface or lightly incorporated by hand-pulled harrows or raking, and applications made post-emergence of crop and wild oats were tested and compared to 40% w/v e.c. formulation treatments either applied pre-sowing and incorporated with a rotovator or post-drilling followed by light incorporation with harrows. Post-emergence applications of barban were also included for comparison in three years. The granules were applied with a hand granule applicator while liquid treatments were applied by either 'OPS' or van der Weij plot sprayers in 560 l/ha of water, except barban which was applied in 280 l/ha of water. Plots were 10 sq. m. and treatments were replicated three times. The experiments were sprayed overall with post-emergence applications of dinoseb-amine to control broad-leaved weeds where necessary.

Assessments were carried out during the season for effects on the crop and wild oat control, but the main recordings on the wild oats were made at harvest when the numbers and weights of panicles were recorded. The experiments were harvested at either the green or dried stage and after vining or threshing the weight of produce was measured together with relative maturity in the case of the green peas.

RESULTS

1970 Experiments

Three experiments were carried out in 1970 the soils being fine sandy loams at sites 1 and 2, and a clay loam at site 3. The varieties were Maro (dried pea) at sites 1 and 3 and Dark Skinned Perfection (green pea) at site 2. The crops were drilled on the 27th March, 18th April and the 28th April respectively. Pre-sowing applications of tri-allate liquid and granules were made at sites 1 and 2 three days before sowing and incorporated with a rotovator while at site 3 a post-drilling application of liquid tri-allate was made shortly after drilling and lightly incorporated by harrowing. At this site areas surrounding the experiment treated by the grower with a commercial application of liquid tri-allate were used for comparison. Pre-emergence applications of granules were made twenty one days after sowing at site 1, when the crop was on the point of emergence and some oats had already emerged. At sites 2 and 3 pre-emergence applications were made three days after sowing, no weeds having emerged. The seedbeds were level; except at site 3, where it was rather cloddy. Post-emergence applications of granules were made twenty-eight, nineteen and twenty-four days after sowing at sites 1, 2 & 3 respectively, when the wild oats were at the 1 to 1½ leaf stage at site 1 and at the 1 to 2½ leaf stage at the other two sites. Soil conditions were dry at all sites. Barban was applied approximately seven days later. The number of panicles was recorded at harvest and at two sites the weight of panicles was measured. In table 1 the percentage control of panicles is presented and in table 2 crop yields are shown.

The pre-sowing incorporated liquid treatment gave the most consistent control of wild oats and the pre-sowing granule treatment also worked well at the two sites at which it was tested. The post-drilling liquid treatment at site 3 gave poor control.

Table 1

Percentage control of panicles - 1970

Material	Rate kg ai/ ha	Application	Site:	% control of panicles By number 1	2	3	By weight 1	3
tri-allate (liq.)	1.7	Pre-sow		89	92	86	82	89
" "	1.7	Post-sow		-	-	22	-	29
" (gran.)	1.7	Pre-sow		80	92	-	66	-
" "	1.7	Pre-em.		54	83	58	44	82
" "	1.7	Post-em.		57	75	0	47	0
" "	2.2	" "		67	78	50	61	48
" "	3.4	" "		88	97	58	85	61
barban	0.7	" "		71	75	88	79	92
Number per sq. m./weight panicles kg/sq.m. on untreated				108	3	11	0.85	0.06

Table 2

Yield of shelled peas as percentage of the untreated control - 1970

Material	Rate kg ai/ ha	Application	Site:	Yield % of untreated 1	2	3
tri-allate (liq.)	1.7	Pre-sow		207*	101	108
" "	1.7	Post-sow		-	-	95
" (gran.)	1.7	Pre-sow		154	99	-
" "	1.7	Pre-em		152	106	93
" "	1.7	Post-em.		146	111	92
" "	2.2	"		159*	93	104
" "	3.4	"		182*	96	102
barban	0.7	"		173*	86	103
Yield of untreated (tonnes/ha)				0.71	4.28	2.66
*Significantly different from control @ P = 0.05						
S.E. as % of general mean				19.5	14.4	12.7

The pre-emergence application of granules @ 1.7 kg ai/ha gave only moderate control but was more consistent than the same rate used post-emergence; increasing the rate to 2.2 and 3.4 kg a.i/ha improved the control from post-emergence granule applications, but it was only at the highest rate that it compared favourably with barban.

Those treatments which gave the best control of wild oats generally resulted in the highest yields, although the relatively low wild oat populations at site 2 & 3 did not appear to depress crop development and statistically significant yield differences were only obtained at site 1 where wild oat populations were high. None of the tri-allate treatments affected crop development, but it was noticed that where granules had been applied post-emergence the wild oats were affected by the dinoseb-amine used for broad-leaf weed control. At site 2 barban affected the more sensitive green pea variety and yield was low from this treatment. None of the treatments markedly affected maturity of the produce at site 2.

1971 Experiments

Two experiments were carried out on soils containing approximately 9% organic matter, one (site 4) being a silty loam and the other (site 5) a clay loam. The varieties were Kelvedon Wonder, and Recette, both green peas sown 17th March and 7th April respectively. Post-drilling granule applications were made soon after drilling onto fairly cloddy seedbeds. Pre-emergence granular treatments were applied approximately seven days after sowing and lightly raked into the surface, the soil being moist at site 4, but dry at site 5. Post-emergence treatments of granules and barban were applied forty-one and thirty-four days after sowing at sites 4 and 5 respectively, the wild oats being mainly at the 1 to 2½ leaf stage, but some were tillering. The results of counts for wild oat plants and panicles made shortly before harvest, and yields of produce at site 4, are presented in table 3.

Table 3

Control of wild oat plants & panicles & final yields of shelled peas - 1971

Material	Rate kg ai/ha	Application	% control of wild oat: Plants		Panicles		Yield % of untreated
		Site:	4	5	4	5	4
tri-allate(gran.)	1.7	Post-drill	80	80	53	64	102
" "	1.7	Pre-em(incorp.)	0	80	0	77	96
" "	1.7	Post-em.	0	70	0	68	110
barban	0.7	" "	0	70	67	23	102
Yield of untreated (tonnes/ha)		-	-	-	-	-	6.8
No. wild oat plants/panicles on untreated/sq. m.			0.8	1.0	1.5	2.2	-
No. significant difference @ P = 0.05			-	-	-	-	-
S.E. as % of general mean			-	-	-	-	12.6

At site 4 the only granule application which was effective was the post-drilling treatment, the pre-emergence and post-emergence treatments being completely ineffective, possibly due to the dry conditions. At the other site all the tri-allate granule treatments were considerably better than barban in reducing later development of wild oat panicles and the most effective was the lightly incorporated pre-emergence treatment. None of the yield differences reached statistical significance.

1972 Experiments

In 1972 only pre-drilling treatments of tri-allate granules were tested in two experiments carried out on an organic silty loam (site 6) where the organic matter was 7.0 %, and a silt loam with an organic matter of 2.5% (site 7). The crops were sown on 19th May and 19th April respectively, the variety was Dark Skinned Perfection (green pea) at both sites and the granules were applied shortly before the peas were sown. The only incorporation was by the coulter drill and seed harrows at site 6 and the tine drill used at site 7. At site 6 the soil was dry and rather cloddy and was rolled after drilling, while at site 7 there was a fine moist tilth with some small clods. Post-emergence barban treatments were included for comparison and applied on 23rd June and 6th June at sites 6 and 7 respectively, when the wild oats ranged in size from two leaves up to tillering stage. The results of assessments and measurements for wild oat control made at harvest and the yields of green peas from site 7 are presented in table 4.

Table 4

Control of wild oat plant & panicles & final yields of shelled peas - 1972

Material	Rate kg ai/ha	Application	% control of wild oat Plants(No.)		Panicles (Wt)		Yield as % of untreated
			6	7	6	7	7
tri-allate (gran)	1.7	Pre-drill	67	80	84	86	95
" "	2.2	"	67	83	84	92	107
barban	0.7	Post-em.	77	73	91	82	98
"	1.4	"	80	83	99	86	59*
Yield of untreated tonnes/ha		-	-	-	-	-	3.0
No. panicles on untreated 1000/ha		-	109	145	-	-	-
Wt. " " "		tonnes/ha	-	-	0.3	1.3	-
*Significantly different from control @ P = 0.05		-	-	-	-	-	-
S.E. as % of gen. mean		-	-	-	-	-	19.6

The pre-drilling granule treatments were not quite as effective as barban in reducing the weights of wild oat panicles at site 6, but were more effective at site 7. There was no difference in the level of control between rates of granules of 1.7 and 2.2 kg ai/ha. No effects on the crop were recorded where granules were used, but the barban treatments caused severe chlorosis and stem damage and although this was outgrown by harvest on the normal rate plots, at the double rate yield was significantly reduced below the untreated control.

1973 Experiments

In 1973 two further experiments were carried out in green peas on a silty loam, organic matter 8.0% (site 8) and a peaty loam, organic matter 6.2% (site 9). The varieties were Jade, sown 19th March and Dark Skinned Perfection sown 21st May respectively. Pre-sowing applications of liquid and granular tri-allate were made before sowing and incorporated by means of a rotovator while pre-emergence granule treatments were applied fifteen and seven days after sowing at sites 8 and 9 respectively, and were lightly incorporated by raking. A post-emergence granule treatment at site 8 was applied thirty-nine days after sowing when the wild oats were mainly at the two to three leaf stage. The results of counts of wild oat plants and weights of panicles recorded prior to harvest, together with the yields of green peas, appear in table 5. At site 8 pre-sowing applications of tri-allate granules at 1.7 or 2.2 kg ai/ha and a post-emergence treatment at 2.2 kg ai/ha were as effective as pre-sowing treatment with tri-allate liquid, while a pre-emergence granule application at 2.2 kg ai/ha was only slightly inferior against wild oats. At site 9 pre-sowing granule applications again gave comparable control of wild oats to tri-allate liquid, but pre-emergence granule treatments were disappointing even at the higher rate. None of the differences in yield were statistically significant and no significant differences in maturity of the produce were recorded.

Table 5

Control of wild oat plants & panicles & final yields of shelled peas - 1973

Material		Rate kg ai/ha	Application	% control of wild oats Plants (No.)		Panicles (wt.)		Yield as % of untreated	
			Site:	8	9	8	9	8	9
tri-allate	(liq.)	1.7	Pre-sow	94	62	96	69	93	118
"	(gran.)	1.7	"	95	70	97	66	101	104
"	"	2.2	"	92	66	94	55	95	108
"	"	1.7	Pre-em.(incorp)	60	24	67	10	100	83
"	"	2.2	"	89	39	90	10	102	86
"	"	2.2	Post-em.	96	-	95	-	106	-
Untreated		-	-	0	0	0	0	100	100
Yield of untreated tonnes/ha				-	-	-	-	7.3	2.3
No. panicles on untreated /m^2				7.7	2.6	-	-	-	-
Wt. " " " kg/ha				-	-	222	364	-	-
No significant difference @ P = 0.05				-	-	-	-	-	-
S.E. as % of gen. mean				-	-	-	-	8.9	21.3

DISCUSSION

Experiments carried out in 1970 and 1973 have indicated that tri-allate granules applied at equivalent rates to, and incorporated in the same way as tri-allate liquid, will give comparable and effective control of wild oats. Pre-emergence applications of granules, whether lightly incorporated as in 1971 and 1973 or left on the surface as in 1970 were in general less effective and more inconsistent, the control from an application of 1.7 kg ai/ha ranging from 0 to 83%. Such variation is assumed to have been due to differing levels of moisture in the seedbeds and the fineness of the tilth. The level of control from post-emergence applications was also variable ranging from no control at sites 3 and 4 to 75% control at site 2, from an application of 1.7 kg ai/ha. Increasing the rate to either 2.2 or 3.4 kg ai/ha as in 1970 and 1973 improved control. In general post-emergence applications of tri-allate granules gave similar levels of control to the standard barban particularly when used at a rate of 2.2 kg ai/ha., but with less risk of damage. For the use of granules to be beneficial to growers they must be capable of giving satisfactory control when used either without incorporation or with only limited incorporation. The work carried out in 1972 suggested that if they are applied immediately before sowing and incorporated by the passage of the drill and seed harrows good control can be achieved. From the experiments carried out in 1970 and 1973 it would appear that more extensive incorporation of the granules, as for example may occur during seedbed preparation, is not detrimental. If used post-emergence rates of at least 2.2 kg ai/ha would appear to be necessary and results are likely to be inconsistent particularly under dry conditions.

None of the tri-allate treatments affected the crop and maturity of the produce was also not affected. Barban caused quite severe chlorosis and damaged the stems in some experiments, although at the normal rate of use the crops recovered by harvest.

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