Application techniques

G.S. Hartley
36 Surrey Crescent
Palmerston North, New Zealand

INTRODUCTION

Most of the large tonnage of pesticides of all kinds produced by the chemical industry is dispersed over wide areas. There is little scope for aiming except in the gross sense of putting the pesticide on the target paddock rather than, with waste or damage, on neighbouring crops, houses, people and watercourses. Biochemistry, with some contribution from timing, is relied on to achieve the desirable selectivity. The properties of the chemical weapon which are exploited are that it can get to sites difficult of mechanical access, that it can hit a very numerous population, that it is to some extent self-dispersive and can hit an enemy that cannot be seen, and lie in wait for one that is not present at the time of application.

There are, of course, situations where application is more localized than the overall spraying of land or crop - fumigation of rabbit burrows, wasp nests, empty warehouses etc. and spot treatment of noxious weeds at a low population density. The advantage of self-dispersal within the local site is again exploited but means of application must, of course, be different. Localized treatment is difficult to exploit at the speed with which pesticides can be dispersed by overall spraying. Band-spraying in now crops is an exception. In overall spraying, the engineer strives for uniformity of distribution of the chemical. Band-spraying is deliberately non-uniform across the swathe but uniformity along it is just as necessary.

What one may call the physics of encounter can, in some situations, introduce an automatic local selectivity with respect to dosage. A good example is the reception of a herbicide spray by wettable weed leaves in a pea crop while the crop leaves reflect the droplets entirely if they are not too small and do not have too much wetting agent. Weeds with unwettable leaves may also escape but there are also usually some resistant weeds which escape a biochemically selective treatment - continued use of atrazing has almost created a panicoid grass weed problem in maize. Small granules bounce off any leaves and their ability to penetrate a canopy is exploited in attack on aquatic insects in overgrown water-ways. They can also collect in upwardly-open funnel-shaped structures and this has been exploited to locate insecticide at just the site in maize plants where the stem-borer makes entry. (I make no apology for taking examples from insect control in a conference on weed control, since many formulation-application problems are common). Selective reception of droplets, and especially of micro-granules, can be controlled to some extent by devices of formulation as well as of application. The two must progress hand-in-hand and one cannot discuss advances of application technique independently of those in formulation.

Localization by aiming - except in the limited sense of laying down narrow bands in row crops - is more difficult to exploit. The method could appear to be less advantageous because, if we can aim at randomly distributed local targets, we should perhaps complete the job by using more elaborate machinery. "Elaborate Machinery" is perhaps an exaggerated description of an ancient hand-tool, like a sharp, narrow-bladed Dutch hoe, called a thistle "spud". My point is that, if you are prepared to spray by hand individual plants, why not excise them at just below soil level? The spray needs marginally less effort and can achieve a more reliable kill. The self-dispersal advantage of the chemical applies within the weed, causing deeper systemic damage and giving less chance of regrowth. There may be advantages, therefore, for the chemical weapon even when it is not widely dispersed. Additionally, there is much more possibility of mechanizing spot-spraying with advantage in speed.

Whether distribution is dispersive or in some degree localized, the chemical weapon has a longer period of action. It may be embarrassingly long. It may not be long enough or it may expend its potential effectiveness before the pest has arrived. There are possibilities of extending the period during which a granular formulation "releases" its active ingredient and even of arranging a delay before release commences. Controlled release, like controlled drop application (C.D.A.), is a subject receiving much recent attention.

My object in this review of the obvious is to emphasize that improvements in application methods can have quite different objectives. My attempt to classify these would be as follows:

1. To increase speed of operation.
2. To reduce risk or degree of damage to the crop and/or to the environment, local or general.
3. To increase selectivity and/or efficiency by automatic physical selection.
4. To increase selectivity and/or efficiency of localized aiming.
5. To increase selectivity and/or efficiency by controlled release.

These objectives are to some extent iner-related. Most of the obvious ways of increasing speed of operation will increase off-target damage. Selectivity is often in conflict with efficiency.

Many attempts at improvement along one or more of these lines are very old. This is the only excuse I can think of for your organization having called on one of its oldest available candidates to give this introductory paper on New Advances in Application Methods. To give a few examples. The rotating brush was used by Millardet about the middle of last century to spray vines with Bordeaux mixture. A device which I invented about 1945 to give sown seeds the protection of active charcoal against a general soil applied herbicide met problems in patenting because of a U.S.A application with a 2 digit number! The Monsanto Co. is now experimenting with a "recirculation sprayer" in which a horizontal jet of liquid is collected and used again if it is not interrupted by upstanding weeds. The idea appeared 20 years ago in New Zealand. Rotating disc spraying was a familiar laboratory tool to me 30 years before it was considered seriously as a field tool. The reasons for these delays are worth analysing in the interests of further New Advances.

THE DOMINANCE OF CHEMICAL INDUSTRY IN INNOVATION

The enormous advance of chemical pest control over the last 40 years has been led or driven mainly by firms producing industrial chemicals. DDT, benzenehexachloride and 2,4-D started it all. They leapt, particularly DDT and 2,4-D, into enormous and, in many respects, careless, use because their production coincided with urgent and rather uncritical demand. If these, why not others? The race was on. Thirty or more large chemical companies poured vast R. & D. resources into finding new exclusive and profitable chemicals, not into their manner of use. The funds and effort put into application technology - even into formulation technology - has been altogether trivial compared with that put into the search for new compounds. The reasons for this are also worth analysing but I want first to emphasize a very important consequence. The solution of particular agricultural problems is mainly vested in organizations in the public sector. They have all methods, not only chemical, under review. "Integrated Control" and "Pest Management" which we hear so much about must be guided by these research organizations of wide responsibility. To fit a chemical into a general management strategy may require knowledge which the producer of that chemical has not got and may not think it profitable to get. His interest, let it never be forgotten, is to sell chemicals profitably. It has to be. He cannot pay either his shareholders or his research staff otherwise.

There is already increasing activity evident in the public sector in new methods of use of chemical pesticides and this is going to increase further and more rapidly but, in my experience, one rather important aspect tends to be under-researched. This is formulation adapted to the biological situation. There is too much reliance on industrial firms to provide formulations. Their interest in formulation has, for the most part, a quite different objective - to make a product convenient and safe to package and use, with adequate shelf life and in containers free from corrosion problems. Research into formulations adapted to a particular biological situation is rarely undertaken and then only to help sell an exclusive chemical in a market otherwise not open. An outstanding novel chemical is necessary to motivate this type of research in industry - the development of no-tillage drills to exploit a wide potential new market for paraquat is a good example.

The reasons for a general lack of interest in industry for innovative research into formulation and application are:

1. Limitation of size of market, special methods being mostly needed in particular crop-pest situations.
2. The biological requirements are too difficult to define whereas problems of storage and ease of mixing are evident and urgent.
3. Improved biological performance in the long term may

demand a method of use which is inefficient in the short term and/or use a reduced amount of chemical. The first step, for the industry, is vulnerable to competition. The second is unfavourable to profit.

4. Most importantly, research into Novel Methods, as such, is likely to lead to an improved sale of a competitor's product rather than of an exclusive product of the company undertaking the research. It does not fit into a policy of dependence on exclusive new compounds. This policy is generally adopted in the chemical industry for traditional reasons, past profitability and greater strength of protection under patent laws.

Of course, if a novel method initiated in the public research sector and backed by government regulations, is obviously going to become established, industry must co-operate. It will prefer a reduced market or a reduced share of market to none at all unless the reduction is too great. We cannot, however, expect the chemical industry to take the initiative in these developments. Basic research into formulation and application must be undertaken in the public sector. Lack of appreciation of this, in respect of formulation particularly, is, in my experience, very widespread. Few stations employ a physical chemist to help with new formulation possibilities. They find themselves relying on the standard products of the chemical industry which, in many cases, are unsuitable for the intended use or at least not designed for that use.

REGISTRATION AND ITS IMPACT

No-one can deny the right of responsible government to impose restrictions on the use of pesticides and demand a great deal of information about the safety aspects of any proposed new compound. Legislation, however, does not always achieve its objectives. Like technical innovation it may create new problems when it solves an old one. The major new problem for the pesticide industry arises from finding the profit with which to pay for the very costly investigation demanded. The cost of safety investigations, continually rising not just through inflation but because more exacting tests are continually added to the list, must be paid for. The cost is not nearly proportional to potential use and the net result is to force the industry to concentrate on broad-spectrum wide-market compounds. Basically this is against safety interests but it a result of safety regulations. Anyone with inside knowledge of the registration busines is now aware of this dilemma but no-one has proposed a satisfactory solution.

While one result is to inhibit the development of specific minor crop compounds, another is to slow down (relative to the rate it could have attained) the development of compounds for major crops . This should put a premium on the improved use of existing compounds. To some extent it has done so and is probably a major factor in the increased innovative research now found in the public sector. The safety-proving costs are mainly borne by a new compound. A changed formulation or use is less costly to re-register, although the exploitation of devices which could give rise to increased environmental hazard could change this situation. Dispersal of very fine droplets for direct attack on small insects is a case in point. Unquestionably the efficiency of the direct attack is increased but so is the proportion of the output which drifts a long way. Effect on predators, which are in general more mobile and exposed than phytophagous pests, is likely to be made relatively greater. One must expect increasing interest of permitting authorities in formulation and application developments.

I will now attempt to review the developments in formulation and application of herbicides which are the subject of current research interest at field, as well as laboratory, level.

CONTROLLED DROPLET APPLICATION

The spinning disc has been a laboratory tool for at least 40 years and has found extensive use in spray-drying processes in chemical engineering. It is considered to have two advantages over conventional spray nozzles. If the supply of liquid is kept below a certain level, it produces drops of remarkably uniform size - much more uniform than can be obtained from any hydraulic nozzle (i.e. a nozzle energized by liquid pressure only). It can also produce a much finer dispersion. I have qualifications to make later about both advantages. Both have been exploited. Their exploitation in the field had to await developments in cheap high-speed low-voltage electric motors. I know nothing about these except that they exist now and did not,30 years ago

A very handy tool - the Micron Ulva (Bals, 1975) - can distribute droplets in the 20 to 100 micron range from something little more weighty than a walking stick. Contained in the hollow handle is a series of cylindrical dry cells in number selected for the motor speed, and therefore drop size, required. The sprayer is held in an oblique position, emitting spray above head height. Spraying can be stopped at once by rotating the handle about its axis through 180°. Similar high-speed rotary devices have been adapted to aerial spraying, particularly of technical unformulated malathion against forest insects. This is the U.L.V. development and has very limited potential for herbicide spraying. Your neighbours, unless they be orchardists or honey or silk producers do not generally object to your killing their insects, but they do object to your killing their crops. Very small drop spraying of herbicides is not, however, entirely to be dismissed, particularly in a country where your neighbour may be 10 or 100 miles away. Very small drops in a high wind could leave a relatively dense deposit on upstanding unpalatable weeds in grazed pasture.

Avoiding very small drops on account of drift damage, the Weed Research Organization in the U.K. has concentrated attention on the uniformity of size of drops delivered by rotating disc sprayers. It is not uniformity itself which gives advantage but the fact that it enables a smaller mean drop size to be used while avoiding the very small drops which give rise to drift damage. Spray from a hydraulic nozzle with a mean size of 500 microns still contains a considerable fraction under 100 microns. A spinning disc, if not overloaded, can deliver 150 micron diameter drops with practically none under 100 microns. For this reason and to avoid unnecessary identification of small drops and low volume per field area, the W.R.O. has popularized the expression "controlled drop application" to describe the method they are examining. The W.R.O. has examined drops in the 150 to 450 micron range. Cussans and Taylor (1976) have reviewed the work to that date and the experimental field sprayer is described by Taylor, Merritt and Drinkwater (1976).

Other publications from the W.R.O. are in preparation. A particularly important development is the production by E. Bals (Micron Sprayers) of a plastic dish with a multi-toothed edge in place of the smooth edged disc or dish. This permits the satisfactory performance of water-based sprays, whereas the smooth edge could be used with oils only, and it also virtually eliminates the formation of small satellites. To secure uniformity across the swathe and adequate volume rate at acceptable tractor speed without overloading the dishes, these are mounted in tiers of 5 and the output of the top 4 is restricted by shrouds to a 60^0 arc. The liquid collected by each shroud supplies the next lower dish.

Although, as stated above, the development of small, low voltage, reliable electric motors played a great part in the development of spinning disc sprayers, whcih were, in the first place, hand tools, they are not essential to the multiple disc boom sprayers where belt drive from the P.T.O. is more practicable. It must also be appreciated that the unique drop size advantage of the spinning disc is realized only when it is not overloaded. When heavily overloaded, the disc gives as much of a miscellany as a hydraulic nozzle. It would in fact be true to say that all nozzles can produce homogeneous sprays (but usually each drop being accompanied by a very much smaller satellite) if not overloaded. A slowly dribbling fan nozzle produces remarkably uniform drops but they are too big and formed only at a uselessly low volume rate. The advantage of the spinning disc is that its limiting volume rate for producing uniform drops of useful size is in the practical range. A combination of the anvil and air-blast nozzles may be able to disperse sufficiently uniform drops at a more economical limiting volume rate. The film of liquid, instead of being discharged centrifugally from an edge is both spread and discharged by air pressure. Once the C.D.A. principle is established, commercial machines may dispense with rotors. The airflow and anvil nozzle shares with the spinning disc the advantage of being a rejecting device: provided the feed to it is at low pressure through a much larger hole than that in a high pressure nozzle, it is much less vulnerable to blockage by suspended matter.

As Cussans and Taylor emphasize, if drop size, under good control, and spray volume per field area are both to be examined and the possibility faced that the optimum formulation may be different according to the choice of these parameters, the research program becomes monumental. Regretfully I feel that yet another variable must be added. Advantages have sometimes been found in laboratory tests for an optimum size of drop which have not been confirmed in field tests. One possibility is the sharper shadowing of one leaf by another when drops of unique size following the same trajector fall into a crop. Uniformity of dosage may be increased by non-equality of drops, not however covering the very wide range of a hydraulic nozzle. Such controlled non-equality could be achieved by using discs of different diameters or even elliptical discs. The W.R.O. has concentrated on demonstrating that the method can give as good results at a low spray volume as a conventional boom at a much greater volume. This achieves some improvement in the first two points on our list of objectives for spray improvements. Reduction of spray volume reduces weight and enables a machine to get on the ground without undue soil compression under conditions too wet for a heavy machine. Increased speed allows more choice of spraying conditions. These advantages can be gained, because of control of drop size, without increased drift problems.

Laboratory work is going on in the same organization to see whether formulations can be found which will give improved effect or whether C.D.A. can give a more effective distribution on the weeds. Rather surprisingly, the C.D.A. machine does not seem to enable more spray to penetrate the foliage of a young cereal crop despite the free fall of the drops and the absence of a flattening wind component (Taylor and Merritt, 1975).

Of three drop sizes (110, 220, 440 μ diameter of barban emulsion) applied to wild oats in the laboratory from a machined aluminium alloy disc, the smallest had consistently the greatest effect (Lake and Taylor, 1974) but later field work (Wilson and Taylor, 1978) showed no advantage of 150 over 250 μ drops with this herbicide or difenzoquat except at the very low volume rate of 5 ℓ/ha when it was attributed to the great variation in drop numbers per plant. At 5 ℓ/ha the average number of drops per cm^2 plan area for these sizes is 28 and 6. With random distribution the fraction of cm^2 areas receiving half their numbers or less would be 0.2% and 15%. It seems at present unlikely that reliable results will be obtained at less than 15 ℓ/ha.

CONTROL OF APPLICATION RATE

Most machines are operated in a way which tries to put down a predetermined amount of chemical per unit land area. This is sometimes called a dosage, but may not easily relate to the actual dose received by a plant; sometimes an application rate, or a dosage rate. I am trying to popularize the word "appliance". It should not depend on the actual forward rate of the machine. Most machines have independent control of rate of emission of diluted chemical and rate of forward motion. The operator tries to keep both constant. In hilly terrain, or on wet or soft ground, this is not easy.

The problem was easy to solve in railway sprayers and also its solution was much more necessary, because speed varies over a wide range. If the nozzle output varied accordingly, the nozzle performance would be very bad at low speeds. One therefore arranged to push through water at the same rate (volume/time) and feed into it chemical concentrate at a pre set volume per unit track distance. This was easy with the power available and at slow acceleration.

Sudden changes in a land machine are a more difficult problem because a quick response in the control is delayed (by pipe volume) before it emerges from the nozzles. The result may be more patchy than an uncompensated system. To carry the metered concentrate to near each nozzle makes for complex and expensive pipe work.

I do not think the problem has been satisfactorily solved at an acceptable price.

LOCALIZATION OF RECEPTION

The amount of herbicide collected by different species in mixed vegetation can be influenced by deliberate aiming and also, even when the application is indiscriminate, by different collecting properties. The most clearly defined example of the latter is the reflective property of "bloomed" leaves such as those of pea and cabbage. This is exploited in a minor way in practice to make more safely selective the behaviour of chemicals having some biochemical selectivity in favour of these species, e.g. dinoseb for peas, desmetryne for brassicas. Formulation and application requirements are that very little wetting agent must be used and drops below 200 μ diameter must be avoided. Sharper selectivity will therefore be obtained by C.D.A.

Small moving drops are more efficiently collected by small objects and the efficiency of this dynamic catch increases with wind speed. I am not aware of any successful exploitation in the herbicide field, but it could perhaps be found. There are several conflicting possibilities. Finely divided leaves could collect drifting 50 micron droplets more efficiently than broad, smooth leaves. Leaf hairs would be even more efficient collectors, but would they transmit systemic chemicals to the leaf interior? Collection of small particles from the wind will also be greater on objects standing out above general crop level such as thistles in a closely grazed pasture. The use of drift methods for herbicides is not, of course, a practical proposition except on large areas, where its advantage also (in using a very wide swathe and therefore reduced travel) would be greatest. The possibilities need investigating. There has been some use in new forest plantations.

The principle of using a coarse horizontal jet directed into a receiving funnel from which the liquid is returned to the tank approximates more to localized aiming. This will deliver almost nothing on plants which do not reach the jet height. It automatically aims at upstanding weeds. As mentioned above, the idea is an old one but it needs a very well translocated chemical to be successful since only upper parts of a mature, tough plant will be anointed. I understand it is proving interesting with glyphosate for Johnson grass in cotton. Applied to pasture in New Zealand, it is limited because most thistle-infested pasture is on slopes too steep (or with access too steep) for land machines to be useful.

Spot spraying of upstanding weeds can also be done quickly and mechanically, by the use of a boom sprayer with triggered nozzles, activated only when a light bar is dragged back by the weed. Finally, it can be done with eye-to-hand selection. This laborious method is not popular with farmers but I feel rather undeservedly so. There is need for active education. Too often the farmer reaction, in some form, is "my weed problem is not yet bad enough for spraying". "Most of the spray would be wasted". Most smallpox vaccine is "wasted", but you don't wait for an epidemic before you have your child vaccinated. Manual spot treatment is only practicable, of course, at low weed density and therefore in two situations. First, where the weed must be eliminated because of positive noxious properties but its population is never dense: second, where one has the beginning of an "epidemic" in the strict sense (or, as the pedant would say, and "epiphytotic") - i.e. you haven't got that weed seriously yet but it is beginning to invade. That is the time when spot spraying, laborious though it may be, will save you much more future labour. The W.R.O. developed an interesting, and technically successful, "chemical glove" for hand-killing of wild oat flower heads at low population but it has been less well adopted than it deserves. I devised a very convenient hand spot distributor for granules but its use was never pushed except to assist the sale of one particular chemical product.

Not only can reception be to some extent automatically selective but the effectiveness of received drops may also vary. This depends on spread behaviour and its relation to drop size and nature of leaf surface. One commonly assumes that, for a given amount of chemical and carrier per unit gross area, the smaller the drops the larger will be the fraction of area actually covered. Two factors can produce very significant deviation from this simple and obvious rule. It is reasonably applicable only to a perfectly smooth horizontal plate when drops have spread under the influence of surface forces to thin "caps". Their further spread is much more dependent on gravity than on surface forces. At this stage, particles will have already become stranded in a limited area and it is only liquid which will continue to spread. This may or may not carry a significant amount of herbicide in solution. On a rough surface, a large drop at low contact angle will spread preferentially along grooves. On a hairy surface, small drops may not penetrate the hair mat, a behaviour which Frick (1970) found set a lower limit to drops useful against apple mildew. On a sloping surface, gravity is dominant in the spread of large drops from the earliest stage and since the descending film, if fully wetting, will not retreat, the area covered, before evaporation and penetration halt the process, can be greater with large drops than small. The large drop on grass leaves is mor likely to spread to the leaf base, and even into the sheath, which Coupland, Taylor and Caseley (1978) find to be the most effective site with wild oat herbicides. Large drops are however antagonistic to the desire for low volume and high probability of hit. More experimentation, with the conflicting possibilities in mind, is necessary to see if improvement can be made.

Micro granules in the size range down to the smallest spray drops from hydraulic nozzles are now being produced. These introduce a whole new series of variables into reception behaviour. Spherical granules, such as are formed when drops of a high-concentration spray of wettable powder evaporate in flight, have very poor acceptance properties on vegetation. Once we depart from the liquid droplet which is automatically spherical, preformed granules can have a wide variety of shapes from "micro confetti" to the short fibres of artificial velvet. If the granules are very aniso-dimensional, and even moreso if they become sticky in contact with moist air, they are adherent. It has been claimed (Jones and Partington, 1976) that microgranules can be equi-effective with spray for foliage-applied herbicides, but essential details of formulation are not disclosed.

This is a subject where one must await developments. There are problems of production and application as well as dependence of effect on size and shape. Industrial developments in the technology of manufacture of special (including micro) granules tend to be held secret by the producer. Granules have also suffered from what are called gimmickry and fashion. A period of settlement is necessary to sort out genuine advantages from specious claims and to ensure that there can be adequate control of properties to ensure reliable performance. A recent published symposium on granular pesticides (British Crop Protection Council, 1976) contains a good deal of information of very varied quality of research and presentation. The main use and reason for development of microgranules was to secure more uniform treatment and quicker action of soil-applied herbicides of low solubility. This is more the subject of the next session. Their significance for selective reception is an incidental, rather than deliberate, development but we may expect some interesting effects to emerge.

CONTROLLED RELEASE

This is a subject on which a great deal of research is going on. The stimulus comes partly from "environmental awareness" and the feeling that pesticides must be used more economically and efficiently. If, to speak in very general terms, a concentration, in some immediate environment of the pest, must be maintained above a certain level for a certain time and the pesticide, desirably, decays to harmles products, then, if we can release this compound only in one initial shot, we must use much more than if we can release it at a rate matching the requirement. The faster the chemical decays when released into its local environment the greater the advantage of controlled release. The subject therefore becomes more important now that chemical stability is considered so undesirable. Then as an important corollary-controlled release could make useful some compounds too transient to be considered without it. It could perhaps be best used with a compound which never got outside the research laboratory, but that missed opportunity is the price we pay for choosing compounds first and looking at formulation very much later. Decay rates can vary over a much wider range than most physical properties. For many applications an initial delay period would be useful. If, for example, we sow a crop which we know is going to be subject to aphis attack in the seedling stage we could save time and avoid an unnecessary passage over the land (perhaps at a time when soil conditions were unfavourable) by laying down with the seed, granules which released nothing for say 6 weeks and then released their content uniformly in time, over the next 10 weeks. This is really a dream specification, The 10 weeks might be 20. The time schedule of the granules might fit in moist soil but not in dry. Each granule would need a minicomputer fed by satellite information. The parallel exploitation of controlled release in the pharmaceutical field is incomparably simpler - and can command much higher price. A pill is received into a environment of nearly 100% R.H. at remarkably constant temperature and fairly constant pH.

I have tried to envisage the coupling of the release mechanism to a biological event. If we are after dormant weed seeds which require a seasonal history to trigger germination, could we incorporate seeds in the granule so that their germination itself caused the fatal release? My one and only attempt merely revealed an interesting complication. I placed radish seed in various natural or artificial hollow straws. If the dry seed only just fitted, its swelling would rupture the straw but it is the emergence of cotyledon and radical, not preliminary imbibition, which is very temperature-dependent. When the straw was wide enough to survive the swelling, the cotyledon had not sufficient strength to rupture the straw. Instead, the hypocotyls emerged and left the cotyledons behind! My failure might amuse. If it does not do more then you had better forget about delayed as distinct from slow release, as a serious contribution to soil herbicide technology.

Granules of any kind in soil provide a mechanism of retarding the attainment of a nearly uniform concentration in soil water. The further apart the granules (therefore, usually, the larger they are) the longer will be this delay. Whether homogenity is necessary for the desired biological effect is a question to which no general answer can be given, but there will be far more situations where release, particularly of herbicides of low solubility, is already too slow than situations where deliberate retardation would be useful. It is the desirable acceleration of spread of low-soluble, adsorbed herbicides which provided the main stimulus for microgranule development.

Two recent conferences in Ohio (1974 at Akron, 1975 at Dayton) have been concerned with the technology and use of slow release pesticide formulations. These have been published. Papers to a Symposium held by a panel of the Society of Chemical Industry in London have not yet appeared. There is a much more extensive literature of slow release from pharmaceutical preparations. The paper by Baker and Lonsdale (1975) gives a useful review.

Release can be retarded by incorporation of the active ingredient (a.i.), as particles or dissolved, in a matrix of low diffusibility. Release rate is very dependent on size. If there is no delay in dispersal away from the outside (e.g. in agitated water), granules identical except in size will reach a corresponding state of exhaustion in times proportional to the square of diameter. For the same time of delay, therefore, smaller granules must have a less diffusible structure than large ones and in practice this means the use of a coherent glassy polymer as the restricting material. Delay in initiation of release, as distinct from retardation of the release when started, requires an outer coating of material initially impermeable but becoming so by the action of some factor of exposure. The most reliable and easiest factor is the transfer from a dry package to wet soil. Release can also be controlled by slow chemical reaction if the a.i. can be linked chemically to an insoluble substance from which it can be detached later, usually by hydrolysis. This method is limited by the chemistry of the a.i. which must be attached by a linkage more easily hydrolyzed than internal ones which would destroy the toxic function. This subject of "polymers with pendant substituents" is reviewed by Harris, Feld and Bowen (1975).

The major pesticide interests are (1) in granules for treatment of aquatic insects, molluscs and weeds, (2) devices for slow release of vapour of pheromones in insect population studies and, perhaps, control, (3) formulations to maintain prolonged insecticidal activity of indoor surfaces and (4) devices for the slow release in enclosed situations of insecticidal (e.g. dichlorvos) vapour. Interest for release to dry land weeds seems confined to soil-applied hormone herbicides in forestry. Neogi and Allan (1974) find advantage in Douglas fir plantations for a formulation in which 2,4-DB is ester-linked to an insoluble hydroxyl-containing polymer which may consist of bark chips: this releases 2,4-DB by slow hydrolysis and this is oxidized to 2,4-D.

Several factors contribute to the greater success and importance of slow-release formulations in rivers and irrigation channels. Release, in the absence of a delay-mechanism in the granules, is much more rapid in flowing water and better defined because the released chemical is rapidly dispersed. For the latter reason, much larger, and therefore more widely separated, granules can be used. A controllable delay is more easily built into a few large granules than a large number of small ones. Slow release granules are therefore more necessary in river treatment, have a more clearly defined job to do and can, economically, be better adapted to it. Indeed the biological requirement may be less well known than the means to implement it. Bowmer (1975) considers that, with acrolin, it may matter little whether a short pulse of high concentration or a long pulse of correspondingly lower concentration is used, but Payne (1974) reported that, with cyanatryn, an exposure of less than about 10 days at any practical concentration can allow regrowth: slow release is therefore much more economic. There could emerge possibilities of more selective action if concentration - time interrelation were more closely researched.

I think there could be advantages of floating slow-release granules of appropriate shape and size, in weed control in flowing water. They would move freely down stream in stretches where their chemical effect is little needed but be delayed in dense stands of rooted vegetation and supply there a higher concentration of herbicide.

I am not aware of any attempt to use slow release microgranules, or a wettable powder formulation of microcapsules, for foliar application. One could expect better results of some herbicides against established perennial weeds if they could be released so slowly that local damage would not limit translocation. The idea raises many questions which only the weeds can answer. As in the case of C.D.A. and the speedier operation of a lighter machine which it promises, the advance which starts off the commercial development may be much more elementary than such technical subtleties. Delay is certainly difficult to control but the simple change from firm retention of a.i. in the dry state to free release after inhibition of water is much more easily attained in a reliable manner. This can make an important contribution to safety of handling of toxic products, and reduction of waste of volatile products, intended for burial in soil.

TREATMENT OF SEED

The idea has appealed to many people of treating seed before sowing in some way which will protect it from a general soil-applied herbicide. In theory one could break away from dependence on biochemical mechanisms of selectivity with the attendant disadvantage that weeds closely related to the crop may survive. Instead, the crop seedlings would survive purely at the choice of the grower using treated seed. I carried out a number of experiments with active charcoal about 1946-48 and found that for any reliable and substantial effect, coating the seed was not enough. The more vulnerable radical (and sometimes the shoot) soon outgrew the zone of protection. Much more success attended the laying of a narrow band of charcoal over the seed. It saved the crop seedling but also the few weed seeds which were in the most competitive position. It was too expensive for the result achieved and not effective enough for use in a high value seed crop which could have carried the cost. Other's experience has generally agreed.

The use of antidote compounds (Burnside et al, 1971, Chang et al, 1973), has been more successful but necessarily limited to herbicides which can be antagonized biochemically by known reactions. Neither charcoal coating nor chemical impregnation demand any new type of application. Charcoal can certainly be used more effectively - with greater certainty of survival of the protected seed and less risk of protecting unwanted seed - if the geometry of presentation is such that a greater length of radicle and shoot is protected. I found seed inserted centrally between two charcoal-impregnated paper discs was very well protected. The disc is inserted in the soil not too far off vertical. The shoot grows between the charcoal walls along one radius, the radical along the opposite one. The seedling has become intrinsically less vulnerable, and a suitable herbicide sufficiently dispersed and degraded, by the time expansion and bacteria have disintegrated the paper. I think a method of this type is worth considering for vegetable crops. It is much more appropriate now than when I first experimented with it because the grower has now become used to sophisticated herbicide practice and because the extra labour involved - a mass production operation on the stage of the crop most suited to factory methods - is not expensive manual labour.

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