THE PHYSIOLOGY OF ENTRY OF HERBICIDES INTO PLANTS IN RELATION TO FORMULATION

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Whether or not a particular species is affected by a herbicide applied to the ecosystem of which it is part depends upon a number of more or less variable factors. Innate physiological resistance of a crop to an absorbed chemical which proves herbicidal to an adjacent weed species is a phenomenon too seldom met with by the weed technologists; hence his reliance so often upon techniques which tend to isolate the crop plant more or less completely from the herbicide. Young roots of all species readily take up most water soluble compounds presented to them in the soil solution. Isolation of a crop plant from a soil applied herbicide can, however, be achieved by placement of the crop seed and subsequently the root absorbing zone of the seedling from which it develops below that level of the soil where weed species germinate and in which the herbicide is, or will be, localised. Of course the depth to which a soil applied herbicide penetrates depends upon whether it is merely applied to the soil surface or is mechanically incorporated to a certain depth. Downward movement of water following natural or artificial precipitation regulates leaching of the chemical through the soil which, depending upon its capacity to bind the chemical, will more or less resist this process. Resistance to downward movement of the soil applied herbicide may be achieved by formulation in a less water soluble form, for example the application of 2,4-D as its ester, or by the placement of an adsorptive barrier between the herbicide and crop seed. Nevertheless a developing seedling must push upwards through the herbicide treated layer or soil. Immunity can follow only if those parts of the seedling which come into contact with this layer do not readily allow entry of the chemical. The immunity which usually does ensue results from the fact that in contrast to the root system the upper parts of plants are covered by a layer which resists not only excessive loss of water but also free entry of externally applied materials. Just how effective this layer, the cuticle, is in isolating the plant from its environment depends upon its structure and, before we consider how we might by formulation influence the permeability of the cuticle to the applied herbicide, we should consider its structure in some detail.

Each cell of the epidermis is, like every other live plant cell, bounded by a wall consisting of a matrix of pectin in which are embedded strong elastic fibrils of cellulose. Both of these components are hydrophilic and contribute to that part of the plant body known as the apoplast (Crafts, 1961). This is a continuous, non-living aqueous phase in which each living protoplast is bathed. The protoplasts are themselves interconnected by protoplasmic strands and collectively make up the symplast which is separated from the apoplast by a delicate membrane, the plasmelemma. Upon the outer cell wall of the epidermis is deposited the cuticle. This, in contrast to the cell wall, is lipophilic in nature consisting of cutin with larger or smaller amounts of wax embedded within it and projecting from it (van Overbeek, 1956). Thus the cuticle if continuous would provide the leaf with a seal impervious to the passage of water in liquid or vapour form and repellent to wetting by aqueous solutions. Only lipophilic substances would be able to cross it. However, cuticular transpiration through most leaf surfaces does occur. Furthermore, only rarely is the cuticle entire over a leaf surface. Stomatal pores are usually abundant, particularly on lower surfaces, serving to connect the intercellular spaces within the leaf with the atmosphere. In many if not all species an internal cuticle lines the intercellular spaces and is continuous through the stomatal pores with the external cuticle (Scott, 1950). However, the internal cuticle must be far less lipoidal in nature for through it passes most of the water which moves from the roots to the leaves to be transpired as vapour through the stomata.

The role of stomata in the penetration of foliar applied herbicides will be considered later in some detail but it is pertinent in a discussion of the structure of the cuticle to note that polar substances can, to a limited extent, penetrate a leaf surface which is either devoid of stomata or possesses stomata which are closed. This has led Crafts (1961) to suppose that the cuticle is perforated by micropores which are more or less filled with an aqueous phase depending upon the conditions to which the plant is subjected. Thus, Crafts supposes, a water continuum exists across the cuticle under conditions of high humidity providing a route for the penetration of polar substances alongside the permanent lipoidal pathway which non-polar substances can take. That pores similar to those postulated do in fact exist has been demonstrated by Franke (1961, 1964b,). These pores, the ectodesmata, can be resolved under certain conditions by the ability of the ascorbate which they contain to reduce heavy metal salts. Franke has shown that ectodesmata are not evenly distributed over the epidermis but are frequently found grouped over certain anticlinal cell walls and to be associated with the guard cells which surround each stomatal pore. He has shown too that after each of a number of radioactively labelled substances in aqueous solution is applied to a leaf surface radioactivity becomes associated with those areas where the ectodesmata are located (Franke, 1964a).

Thus the cuticle appears not to be a homogenous water-tight skin enclosing the tissues of the leaf but a dynamic structure resembling a sponge, the matrix of which is lipoidal providing a route for the penetration of non-polar substances while the pores may, under certain conditions, become filled with an aqueous medium permitting the passage of polar materials. However, only under conditions of high relative humidity will the water continuum extend through the cuticle to the surface, a condition seldom encountered by surfaces freely exposed in a position likely to receive spray droplets. Thus the less polar a substance is the more rapidly will it penetrate a leaf surface to which it is applied. The difficulty with which anions penetrate the cuticle is increased by the dissociation in the presence of water of carboxyl groups possessed by the polymerised acids and alcohols which make up cutin. It is not surprising, therefore, that an organic acid such as 2,4-D penetrates the surface of the leaf of *Phaseolus vulgaris* most rapidly when applied in solution of low pH in which it will, to a certain extent, exist in the undissociated non-polar molecular form. Nevertheless, penetration does occur to a very small extent at pH values which cause 2,4-D to dissociate completely further evidence of a polar route through the cuticle (Sargent and Blackman, 1962).

In order that the herbicide may penetrate a leaf to which it is applied, two prior conditions must be fulfilled. Firstly the applied solution should remain on the leaf and secondly the herbicide should remain in an available form long enough to be absorbed sufficiently by the plant. The orientation of leaves and the physical condition of their surfaces effects their relative abilities to intercept and retain spray droplets. This is frequently the basis of selectivity.

Reference has already been made to the waxes embedded within the cuticle and projecting from it. Little is known of the biochemical events which lead to the formation of these waxes or of the way in which projections arise from the leaf surface. However, thanks mainly to the elegant electronmicrographs of leaf impressions prepared by Juniper it is now clear that the amount of wax present on a leaf surface varies from species to species and that the shape and density of the wax projections is characteristic for any one species. Juniper (1959a) has illustrated the range which exists between the leaf surface of a species like Beta vulgaris which is almost completely devoid of wax projections and is easily wetted and one like Pisum sativum which carries on its cuticle a dense mat of wax projections which completely prevent wetting of the surface by water droplets.

However, the nature of surface projections makes little difference to the water-repellency of the surface provided they are below a certain size. The highest contact angle known for water on a smooth surface of naturally occurring material is probably 110° on hexatriacontane (Adam, 1958), yet contact angles of the order of 140° are not uncommon on plant surfaces. Such high apparent contact angles result from the trapping of air between repellent projections which are small and numerous enough to present a very large number of separate points of contact with an impinging water droplet yet rigid enough to withstand the capillary forces tending to draw them together. The leaf surface of Lupinus albus, for example, with up to ten wax projections per square micron would support most droplets from a low volume spray nozzle by at least several thousand projections. Microroughness of leaf surfaces may arise from undulations in the epidermis itself. The cuticle of Juncus inflexus is extremely smooth yet corrugated enough to yield a contact angle of about 140° (Juniper, 1959 b). Epidermal hairs may also be sufficiently rigid and water repellant to prevent applied water droplets contacting the cuticle appreciably. The hairy upper surface of the Salvinia frond is notoriously difficult to wet.

These problems of wettability can readily be overcome by including in the formulation a suitable concentration of surfactant. Provided its surface tension is lowered sufficiently an applied solution will flow amongst the fibres of a wax blanket, into the furrows of a ridged cuticle and between the haris of a pubescent surface. Likewise formulation in oil or an emulsion will result in plant surfaces becoming more easily wetted. Advantage might also be taken of the fact that wetability may vary throughout the life of a leaf surface, or may be lowered in particular regions of the leaf or might even be controlled artificially. For example, soil treatment of pea with TCA or dalapon reduces the amount of wax subsequently produced by leaves and the number of wax projections which arise from those leaves (Juniper, 1959c; Dewey et al, 1956; Pfeiffer et al, 1957).

The wetability of a leaf surface, however, does not necessarily indicate the amount of spray which that leaf is capable of retaining. It takes no account of leaf size or posture. Furthermore, as noted earlier, the wettability of a leaf surface is likely to change throughout the life of a leaf, for example by differential rates of leaf expansion and wax deposition or by leaf abrasion as a result of climatic conditions.

Blackman, Bruce and Holly (1957) examined the effect of surface tension, spray volume and plant development on the levels or retention of aqueous spray by a range of species. They chose Brassica alba and Helianthus annuus because of their broad, horizontal leaves, Hordeum vulgare because of its upright leaves and more developed cuticle, Pisum sativum because of its waxy surface and Linum usitatissimum because it has true leaves which are narrower and more difficult to wet than the cotyledons. They found that in general retention decreased in the order Helianthus, Brassica, Pisum, Hordeum, Linum. The effect of varying the spray output and surface tension was markedly different between the two morphological groups. With both Brassica and Helianthus the leaves remained incompletely wetted by the lower output levels irrespective of whether the drops remained discrete or coalesced following addition of a surfactant. However, as the output was increased the leaf became covered with a continuous film which, above a certain thickness, began to run off. This critical thickness decreased as the surface tension decreased. For Pisum and Hordeum the relationship and spray output is quite different. No significant difference in retention was observed as the surface tension was lowered from 70 to 40 dynes/cm but at all outputs there was a very large increase in retention when the surface tension was reduced to 30 dynes/cm. The degree of retention was linearly related to output at each level of surface tension. With Linum, addition of a wetting agent greatly increased retention under all conditions of spray volume but the smaller plants retained proportionately more. This resulted from the readily wettable cotyledons contributing an important part to the total leaf surface whilst the plant is young but becoming less significant relative to the total leaf area at later stages of growth before they eventually wither. Lowering the surface tension resulted in increased retention by the true leaves but a concomitant increase in run off from the cotyledons.

Throughout the range of species, regions which are difficult to wet like the apices of Helianthus and Linum do retain significant amounts of solution following low volume treatment with solutions of low surface tension. The leaf axil of Pisum is another region where retention may be high, as a result, in this case, of solution becoming trapped after running down the petiole.

Despite such anomalies Blackman, Bruce and Holly were able to conclude that "the maximal difference in retention between two species will be attained when the spray consists of large drops with a high surface tension and the leaf surfaces of one species repel the droplets, while those of the other do not", and that "the volume of spray applied should be so regulated that the amounts retained by the weed species are just below levels where run off takes place."

Foliar penetration of a compound, following its successful application to the leaf, can only occur if it remains in a form which can easily be absorbed by the plant. Generally penetration is largely arrested if the applied solution dries out, a situation which can be prevented with aqueous solutions by the incorporation of a hygroscopic substance. Glycerol, for example, has been shown by Holly (1956) to extend the period over which penetration of 2,4-D occurs from drops applied to leaves of Avena and Helianthus under conditions of low humidity. No effect of the glycerol was observed under high humidity when crystallisation failed to occur. Under field conditions the value of a humecant lies in its ability to allow uninterrupted penetration of applied compound to continue until absorption is complete. Penetration in the absence of a humectant still occurs during periods of high humidity but the longer the period required for complete absorption, the greater the chances of removal of spray deposit by rainfall.

The participation of stomata in the penetration process has been extensively examined. At first sight these pores in the leaf surface would appear to be vulnerable areas in the plant's protective cuticular sheath. However, their role as sites for entry of applied solutions is without doubt small. Although stomata are usually abundant on the underside of leaves of most species, they are often sparse if not absent on the upper surface, which usually receives the bulk of spray droplets. Furthermore their dimensions are such that an aqueous solution devoid of surfactant cannot infiltrate them by reason of the forces of surface tension (Adam, 1948). Claims have been made that mass flow of solution through stomatal pores will occur if the surface tension of the solution is lowered sufficiently (Dybing and Currier 1961). Even so, published figures suggest that only a proportion of the stomata are infiltrated under these conditions. Experiments with Phaseolus leaf discs have shown that in darkness penetration of 2,4-D from aqueous solution is promoted by the additon of a wetting agent but that the effect is not proportionally greater in light when the stomata are open (Sargent and Blackman, 1962). Enhanced penetration appears to result from the better contact between the solution and the leaf surface. Further experiments with leaf discs have revealed a close relationship between the relative rates of penetration of 2,4-D through the two surfaces and the density of stomata at those surfaces. This relationship holds in darkness when the stomatal pores are closed and it seems likely that the guard cells and perhaps the accessory cells which surround each stomatal pore may be major sites of penetration. Support for this hypothesis has been provided by Franke (1964a) who applied radioactively labelled sucrose to epidermis stripped from the leaves of Spinacia oleracea and Viola tricolor. After 10 to 60 minutes the tissues were rinsed and examined autoradiographically. Radioactivity did not emanate evenly from the epidermal surface but was confined almost entirely to the stomatal apparatus. Furthermore, the guard cells themselves appeared to have absorbed the labelled sucrose in a differential manner. Franke had previously demonstrated a high density of ectodesmata above each guard cell and he suggests their involvement in the absorption of the sugar. Also consistent with the view of differential penetration through guard cells are the observations by Dybing and Currier (1961) that an iron salt applied to the leaves of Zebrina in surfactant-free solution enters the guard cells and accessory cells but not the substomatal chambers. They also noted that a fluorescent dye which is not absorbed by leaves with closed stomata or in the absence of surfactant does occasionally stain the guard cells and accessory cells.

When a solution of 2,4-D is applied to either surface of a Phaseolus leaf disc kept in darkness the herbicide begins to enter the tissues immediately and continues to penetrate at a constant rate over at least 72 hours provided the external concentration is maintained. A change in the external concentration results only in a proportional change in the rate of penetration. This is a pattern of uptake which is uncommon in living systems but the fate of 2,4-D within the plant provides a clue to its mechanism. 2,4-D, having entered the bean leaf, is very rapidly bound. It will not diffuse from the leaf disc even through the cut edge, neither will it exchange with further 2,4-D. Moreover, it remains firmly bound even after disruption of the cells and organelles by freezing and thawing. 2,4-D, then, is rapidly removed from solution soon after crossing the cuticle. Movement across the cuticle is probably a physical process and its rate will depend on two factors. Firstly, the solubility of 2,4-D in the various components of the cuticle and secondly the concentration gradient across the cuticle. There is no reason to believe that the structure of the cuticle changes over short periods in darkness and if the internal concentration of 2,4-D is kept minimal the rate of penetration will be directly proportional to the external concentration. Metabolic inhibitors have little effect on penetration in darkness and, although the penetration rate increases as the temperature is raised, this probably results from changes in certain temperatures sensitive properties of the cuticular components.

The effect of light on penetration of 2,4-D into Phaseolus leaf discs is complex and there is evidence of a metabolic component becoming limiting (Sargent and Blackman, 1965). Over an eight-hour period light has little effect below an intensity of about 800 foot candles even though the stomata open in response to an intensity of about 250 f.c. At higher intensities up to 1800 f.c. there is a marked enhancement of penetration. A number of features of this light-induced phase are noteworthy: (i) it can be induced only in young expanding leaves; (ii) it occurs only at the lower surface; (iii) it becomes manifest only after some hours of irradiation; (iv) it can be stopped by interrupting the illumination; (v) it is sensitive to temperature, sublethal irradiation by ultraviolet light and metabolic inhibitors; (vi) leaf discs which have been excised some hours before being supplied with 2,4-D lose their sensitivity to light but sensitivity can be maintained by supplying an auxin.

It seems clear that the light-induced phase of penetration is metabolically governed and that a sufficiently high endogenous level of auxin is required. If structures, such as ectodesmata, are involved, they are absent or non-functional at the adaxial surface and at both surfaces in mature leaves, or they are prevented from reaching the surface. Moreover, if such an additional path of entry is opened by light a period of several hours is required for its activation.

Apart from the contact types, herbicides, to be effective, must move from sites of penetration to regions of active or potential growth. Both the apoplast and the symplast are possible routes along which movement can occur. Some compounds such as the substituted ureas and the triazines move throughout the plant in the apoplast following the transpiration stream. Others like 2,4-D are actively accumulated by the symplast and move almost entirely in the phloem conducted along with the photosynthetic products. Between these two extremes are compounds represented by amitrole which become distributed throughout the leaf to which they are applied in the symplast but are exported from the leaf through the sieve tubes.

It has already been pointed out that the rate at which an applied compound penetrates the cuticle is governed by the rate at which it is removed from solution at or conducted away from the inner surface of this barrier. Flow through the sieve tubes occurs following an increase in the level of transferable carbohydrate in the leaf. This can be achieved either through photosynthesis following illumination of the leaf or by supplying sucrose exogenously to the leaf. Thus, although it can be demonstrated that sucrose supplied exogenously does not alter the permeability of the cuticle to 2,4-D, it does increase the absorption of 2,4-D by attached leaves as a result of a stimulation of flow through the sieve tubes.

Penetration through cuticles isolated from the leaf by chemical or enzymatic means has been investigated by a number of workers (Weintraub et al, 1954; Szabo & Buchholtz, 1961; Yamada, Wittwer & Bukovac, 1964). The structure of these cuticles is of course no longer governed by underlying cells and care must be taken in relating observations made with them to the conditions pertaining on the surface of the living leaf. However, Bukovac's recent observation while at Oxford that the rate of penetration of the phenoxyacetic acid molecule through isolated tomato cuticle increases as the molecule is progressively chlorinated is significant as it is this relationship which was earlier found in studies on the penetration of this series into discs cut from live Phaseolus leaves (Sargent, 1964).

It should be clear that a knowledge of the factors which influence the penetration of externally compounds through plant surfaces is not only of academic interest. When we can eventually provide the weed technologist with information on the pathways by which each available herbicide may enter and interact with each plant at the developmental stage it has reached in the selected community, he should be able to chose with confidence a compound to achieve the herbicidal result he has in mind. In the interests both of economy and the desirability of keeping residues minimal weed destruction should be accomplished using the smallest possible quantity of herbicide. A knowledge of the nature of the leaf surfaces of both crop and weeds as well as observations on the size and posture of the leaves of each species should allow prediction of the desired spray volume, droplet size and wetting properties of the formulation to obtain optimal application to the weeds yet minimal retention by the crop.

References

Adam, N.K. (1948) Principles of penetration of liquids into solids. Diss. Farad. Soc., 3, 5-11.

Adam, N.K. (1958) Water repellency. Endeavour 17, 37-41.

Blackman, G.E., Bruce, R.S. & Holly, K (1957) Studies in the principles of phytotoxity V. Interrelationships between specific differences in spray retention and selective toxicity. J. Exp. Bot., 9, 175-205.

Bukovac, M.J. (1966) Private communication.

Crafts, A.S. (1961) The chemistry and mode of action of herbicides. Interscience Publishers, New York, 269 pp.

Crafts, A.S. (1964) Herbicide behaviour in the plant, in The physiology and biochemistry of herbicides, Ed. L.J. Audus, Academic Press, London, 555 pp.

Dewey, O.R. Gregory, P & Pfeiffer, R.K. (1956) Factors affecting the susceptibility of peas to dinitroherbicides. Proc. 3rd. Brit. Weed Cont. Conf., 1, 313.

Dybing, C.D. & Currier, H.B. (1961) Foliar penetration by chemicals. Plant Physiol. 36. 169-174.

Franke, W. (1961) Ectodesmata and foliar absorption. Amer. J. Bot. 48, 683-691.

Franke, W. (1964a) The role of guard cells in foliar absorption. Nature, 202, 1236-1237.

Franke, W. (1964b) The nature and function of ectodesmata. 10th Int. Cong., Edinburgh. Abs. 202-203.

Holly, K. (1956) Penetration of chlorinated phenoxyacetic acids into leaves. Ann. appl. Biol. 44, 195-199.

Juniper, B.E. (1959a) The surfaces of plants. Endeavour, 18, 20-25.

Juniper, B.E. (1959b) Studies on structure in relation to phytotoxicity. D.Phil. Thesis, Univ. of Oxford.

Juniper, B.E. (1959c) The effect of pre-emergent treatment of peas with trichloroacetic acid on the sub-microscopic structure of the leaf surface. New Phytologist, 58, 1-4.

Pfeiffer, R.K., Dewey, O.R. & Brunskill, R.T. (1957) Further investigation of the effect of pre-emergence treatment with trichloacetic and dichloropropionic acids on the subsequent reaction of plants to other herbicidal sprays. Proc. 4th Int. Cong. Crop. Prot. 1, 523-525.

Sargent, J.A. (1964) The penetration of growth regulators into leaves. Zestiende international symposium over fytofarmacie en fytiatrie. Gent. 655-662.

Sargent, J.A. & Blackman, G.E. (1962) Studies on foliar penetration. 1. Factors controlling the entry of 2,4-dichlorophenoxyacetic acid. J. Exp. Bot. 13, 348-368.

Sargent, J.A. & Blackman, G.E. (1965) Studies on foliar penetration 2. The role of light in determining the penetration of 2,4-dichlorophenoxyacetic acid. J. Exp. Bot. 16, 24-47.

Scott, F.J. (1950) Internal suberization of tissues. Bot. Gaz., 111, 378-394.

Szabo, S.S & Buchholtz, K.P. (1961) Penetration of living and non-living surfaces by 2,4-D as influenced by ionic additives. Weeds 9, 177-184.

van Overbeek, J. (1956) Absorption and translocation of plant regulators. Ann. Rev. Pl. Physiol., 7, 355-372.

Weintraub, R.L., Yeatman, J.N., Brown, J.W., Throne, J.A., Skoss, J.D. & Conover, J.R. (1954) Studies on entry of 2,4-D into leaves. Proc. 8th N.E. Weed Control Conf., 5-10.

Yamada, Y., Wittwer., S.H. & Bukovac, M.J. (1964) Penetration of ions through isolated cuticles. Plant Physiol., 39, 28-32.

Discussion

Dr. J. Bruinsma asked if the low rate of absorption of radioactivity from ^{14}C labelled 2,4-D at low pH at the adaxial leaf surface as compared with the abaxial surface suggests that the penetration of undissociated molecules proceeds via possible ectodesmata rather than through the cuticle. Dr. J.R. Sargent replied that ectodesmata are probably not important in this way in the dark. The effect of pH at the upper surface is as great as it is at the lower surface.

Dr. B.J. Heywood asked if absorption into leaves would be greater if a fairly volatile solvent is incorporated into a formulation of a sparingly soluble herbicide, leading to a super-saturated solution by evaporation on the leaf, than if a surfactant is added, which being non-volatile might give a solution on the leaf which is not saturated. Dr. G.S. Hartley agreed that if the deposit is left super-saturated when the solvent has evaporated then penetration would be increased but various external factors may lead to the active ingredient crystallising first.

Dr. P.A. Gabbott stated that the cuticle was in important barrier to the foliar penetration of azido-triazines and that the process had a high temperature co-efficient. He reported that if the herbicide was applied in odourless Kerosene inside a glass well on the leaf surface there was then rapid penetration and movement through the intercellular spaces. To be effective there then has to be a partition back into the water phase within the plant.

Dr. W. van der Zweep enquired as to whether formulation was of importance in influencing the performance of herbicides in the soil, or was formulation for good behaviour in the spray tank the main consideration with soil-applied herbicides. Dr. G.S. Hartley replied that, apart from alteration of the gross pattern of distribution by changing over from spray to granules, formulation cannot have much influence on application via the soil because the active ingredient soon gets distributed in a large volume and is not confined to the very shallow layers in which it must exist on the surface of the leaf.

Dr. W. van der Zweep commented that when more surface-active agent is added than is necessary to give maximum reduction in surface tension, the concentration will eventually reach a point beyond the critical micelle concentration. The active ingredient is probably soluble in the lipoidal phase of the system; consequently it will be deposited finally on the leaf or soil surface in three ways - 1) dissolved in the water phase, 2) dissolved in the lipoidal phase, 3) dispersed in the water phase. The presumption is that the resultant increase in activity, as for example the enhancement of diuron activity by large amounts of surface-active agent, is due to solution in the lipoid phase. Dr. G.S. Hartley agreed that in the type of formulation used for diuron the critical micelle concentration of the surfactants is certainly exceeded but it does not necessarily follow that this will help the active ingredient to penetrate.

Mr. J.M. Winchester expressed surprise that epidermal surfaces should be regarded as continuous, for aqueous systems, lipophilic solvents and gold sols all penetrate leaf surfaces. It would appear that the systems are discontinuous either naturally or are made so by the application of the sprays. The aqueous phase below the wax layer may be exposed by the action of a droplet and this action together with effects from natural causes must make much of the discussion theoretical. He asked for any information on the claim by Melcath and Fukuto that a partition coefficient of 20:1 is advantageous if the phases are continuous. In reply Dr. J.R. Sargent quoted the work of Bukovac working with isolated cuticles from plants. Very rapid penetration of organic compounds occurs through discontinuities such as cracks and scratches in this isolated cuticle. .Cuticles attached to living leaves are probably similar in this respect and experience has been that material collected from the field or greenhouse is penetrated more readily than material grown in constant environmental conditions in which the cuticle has been less exposed to damage. Dr. G.S. Hartley thought that it would not be possible to define an optimum partition coefficient even in the case of a physically simple system. Diffusion coefficients would also be involved and be very dependent on the nature of the penetrating molecules. Dr. W. van der Zweep commented on the difficulties encountered by Dr. Orgell in isolating undisturbed cuticles for his work at the University of California. There may be a need to distinguish between 'physiological' and 'herbicidal' penetration. With the prevalence of a variety of types of damage to cuticle in the field this may be an important factor in the entry of herbicides into plants.

SESSION VIIC INDUSTRIAL WEED CONTROL

Discussion

Mr. A.F.J. Wheeler asked whether in view of high treatment costs it was possible to obtain satisfactory total weed control for two seasons from one application. Dr. A. Gast said that the work with newer triazines described in his paper indicated that this was possible though very high doses were used. In practice, like Dr. Eue, he thought it more important to start with high doses to avoid the development of resistant species and enable low doses to be used subsequently, the cost being calculated over a number of years. Mr. G.G. Fisher said that in the Prairie Provinces of Canada the Railways had found that one application of atrazine at 20 lb/ac gave effective weed control for three years but this was with a very short growing season, low rainfall and a long winter period of frozen soil.

Dr. A.J. Willis thought that in using MH + 2,4-D for grass retardation it might be possible to cut down on the frequency of application of the 2,4-D component after annual treatments for several years. In reply to further questions from Mr. Wheeler, Dr. Willis thought that applications of MH and 2,4-D made in different parts of Great Britain had given results similar to those at Bibury. The best time of application was in mid-April but effective results could be obtained at other times; the chief effect of different spray times was on the height of the vegetation. While treatments initially produced adverse effects and unevenness of vegetation, *Festuca* spp. and *Poa pratensis* quickly recovered and occupied the bare ground left by other species.

Mr. Fisher asked whether 2,4-D affected the production of seed heads in grasses so altering the height of the sward. Dr. Willis replied that at Bibury 2,4-D reduced the effective height mainly by its adverse effect on *Arrhenatherum elatius*; *Poa pratensis* seeded fairly well, but its increase was due chiefly to vegetative spread.

Mr. N.A. Goodman asked if any work had been carried out on chemical control of *Polygonum sackhalinense*, a species related to Japanese knotweed. Mr. K.G. Stott replied that he had no information on this species.

THE SIGNIFICANCE OF RHIZOMATOUS GRASS WEEDS IN ARABLE CROP PRODUCTION TODAY

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The American writer Ralph Waldo Emerson defined a weed as "a plant whose virtues have not yet been discovered".

In any order of priority for weed 'discovery' many farmers in this country would place the rhizomatous grass weeds at the head of their list. Agropyron repens and Agrostis gigantea are troublesome species in many parts of the United Kingdom. Both species are widely distributed but Agrostis gigantea is the dominant weed in southern counties, particularly on the chalkland areas, whereas throughout the rest of the country Agropyron repens is by far the major weed.

Several reasons have been postulated for the increase in intensity of infestations of these rhizomatous grass weeds in recent years. The removal of aggressive broad leaf weeds by herbicides, the growing of short-strawed cereal varieties and the spread of seeds by the combine harvester are only a few of the general causes of a build up of rhizomatous grass weeds collectively referred to as 'couchgrass'. The tides that are flowing through the structure of farming in this country today are also forcing the streamlining of farm enterprises and at its extreme this is leading to cropping systems bordering on monoculture. The intensification of cereal production, in some parts, is undoubtedly increasing this problem of "couch". The control measures that have been advocated for the control of these weeds are basically founded on the principles of disturbance or burial. Existing methods of chemical control of couch, causing disturbance by desiccation or interference with metabolism, can rarely be claimed to give satisfactory control other than by aiding cultivation or by affording means for dominance by a vigorous crop.

The object of this contribution is not however to analyse present day techniques of couch control but rather to define the significance of rhizomatous grass weeds on the arable farm today.

Crop Competition

Perennial grass weeds can compete with crops for light intensity, moisture and nutrients but the ultimate effect of competition on crop yield does depend on the density of weed infestation in relation to crop vigour as determined by husbandry and growth conditions. There are situations today where the intensity of couch is such as to reduce the yields of cereals by more than 20 per cent but they are the exception rather than the rule. A limited survey carried out by the National Farmers Union recently suggested that not more than 5 per cent of farms carried infestations of this density. But as with many other weed infestations today there is often a fluctuating situation in terms of couch dominance in individual crops according to the pattern of weather, a dull wet summer, for instance, allowing couch to gain ascendancy over crop vigour resulting in crop yield losses directly as a result of competition.

There are several advocates today of a cheap partial control system to deal with couch merely to provide suppression of weed growth particularly at the time of crop establishment but this technique must rely a great deal on the rapidity of early crop growth. This approach to "living with couch" could also complicate other husbandry techniques. It could well interfere with potential new systems of broad leaved weed control based on the use of soil acting herbicides which have already been discussed at this Conference.

Harvest Interference

By far the most obvious effect of rhizomatous grass weeds today on the arable farm is that relating to harvest difficulties. Fully mechanised harvesting of potatoes can be seriously hindered by the presence of couch rhizomes in the baulks. A vigorous growth of couch can retard progress at time of cereal harvesting and add to the cost of grain conditioning. The benefits of inbred resistance to shedding and sprouting of grain, a feature of many new cereal varieties, can also be nullified in the presence of these grass weeds when lodging occurs during adverse weather conditions.

Relationship with soil disease

Soil borne disease has always been regarded as a limiting factor in cereal monoculture. Take-all (*Ophiobulus graminis*) is endemic to most soils in this country today.

This fungus disease is not amenable to direct control by fungicides, at least as a practical and economic proposition, but the situation today is such that new varieties and new husbandry techniques adopted in cereal production are capable of off setting the effects of the disease. A fallow period between the harvesting and sowing of spring cereals does allow for an opportunity for root and stubble residues, carriers of the disease, to rot and for the fungus to die down in the soil. The extent of die-back is, however, governed by:

i) weather conditions - a severe winter or a dry winter preventing die-back of the disease by limiting biological activity in the soil

ii) the presence of other hosts for the disease.

Both *Agropyron repens* and *Agrostis gigantea* are carriers of "take-all" the disease being usually present on rhizome internodes.

There are today many instances of long sequences of barley cropping providing yield levels that give profitable financial returns but generally these have remained free of couchgrass contamination. We are also conscious today of a phenomenon known as "Take-all decline" where the effect of the disease on barley or wheat is noticeably reduced after three or four successive crops but the extent of this decline of fungus activity on the cereal plant is again governed by the presence of other hosts for the disease and the effect that these may have on the vigour of the cereal crop. Thus the presence of rhizomatous grass weeds limits the extent of "Take-all decline" and, therefore profitability of cereals is an intensified cropping system.

In many parts of the country, however, more traditional systems of arable cropping sequences involving the introduction of crops, which are non-hosts of "take-all disease, are still the rule rather than the exception. But here again if crops, such as potatoes, sugar beet and peas, are allowed to become infested with couchgrass the principles of crop rotation, allowing for disease decline, are clearly being jeopardised. The interjection of short duration grassland leys, particularly aimed for conservation or seed production purposes, offer opportunities for establishment of perennial weed grasses and often these short leys become excellent cultures for couch.

In areas where cash crops such as potatoes and sugar beet cannot be grown to give profitable returns because of soil, climate or other factors alternative crops to cereals such as field beans are now being exploited. These are crops that do not demand additional capital expenditure on machinery or buildings above those required for cereals. Unfortunately the tolerance of beans will not allow for dosage rates of herbicides, such as simazine, which could be expected to give satisfactory control of *Agropyron repens* or elimination of *Agrostis gigantea*. So that despite being non-host of 'take-all' disease beans or other break-crops, grown in the presence of couch, are often of limited value in reducing the potential of the fungus.

There is, however, one cash crop, which because of its considerable smothering effect when grown in narrow rows, could help to reduce couch grass infestations as well as being a non-host for 'take-all'. This is the background of interest in oil seed rape production in this country today - provided marketing conditions offer a satisfactory financial return.

Soil Pests

So far we have been considering soil born disease. We also have evidence today that the presence of rhizomatous weed grasses can effect the severity of attacks of soil pests such as cereal root eelworm [*Heterodera avenae*]. The oat crop that is striving to overcome competition with couch grass is particularly vulnerable to high soil populations of cereal root eelworm. The degree of freedom from couch in non-susceptible crops will govern the success of any cropping system designed to reduce the yield losses incurred by this pest in cereals.

Foliar Diseases of Cereals

Foliar diseases such as Mildew (*Erysiphe graminis*), Leaf Blotch (*Rhynchosporium Secalis*) and Rust (*Puccinia spp.*) are increasing in intensity and causing serious yield losses in cereals, particularly barley, today. These diseases not only interfere with grain development but also weaken straw which leads to losses at harvest. Although inbred resistance to some of these foliar diseases is now a feature of many modern varieties mutation often results in the development of new physiological races. It is known that soft lush growth in cereals, often brought about by heavy nitrogen dressings is very prone to attacks by foliar disease and that early infection is encouraged by dense foliage growth. Over-seeding is often responsible for such dense growth but the presence of couch grass can also encourage a favourable micro-climate early in the growth season that allows these foliar diseases to thrive and spread. These diseases can survive on the remnants of late unproductive secondary tillers in stubbles post-harvest and are often transmitted to volunteer seedlings (from shed grains) from the debris left by combine harvesters. Stubble hygiene, in terms of the complete destruction of the residues from previous crops is an important consideration when contemplating in-between cereal cropping measures for couch control in the autumn.

Any chemical used for couch control should also be capable of desiccating or killing volunteer cereal plants in order to reduce the carry over of these foliar diseases.

Future Control Techniques

Enough has been recorded to emphasise the significance of rhizomatous grass weeds in arable and in particular in cereal cropping today. Direct competition with crops is probably the least of our worries - the aspects of inter-relationship with disease and pest being of greater importance. We are concerned therefore with the need to <u>eliminate</u> these weed grasses rather than partial arrest of growth. Later in this session we shall hear of technical developments that will ease the problem of couch in potatoes - crops that are identified with selected areas in the country.

When, however, we come to consider the very large acreage farmed in a cereal/grass system - now progressively getting cereal dominant - there is a desperate need for new techniques that will allow for the eradication of couchgrass either between cropping or in the presence of cereals or sown grasses. Any new approach, be it based on chemical alone or a combination of herbicide and cultural techniques will need also to encourage the die-back of disease and pest by promoting rapid death of host crop residues. It is important also that there should remain no trace of residual herbicide activity that could endanger the relationship of crop vigour with disease or pest potential.

There is clearly scope for the close integration of pathological and physiological plant growth interests with the development of herbicides for the control of rhizomatous grass weeds. Agronomists have also a role to play in defining optimum periods for the application of control measures and the sequence of cropping that would fit the pattern of soil, crop and disease requirements. We are dealing with perennial weeds and it is unlikely that short term measures will provide the answer to this serious problem in arable farming today.

SESSION VIII A - PERENNIAL WEEDS IN ARABLE LAND

Discussion of all papers in this session.

Mr. P.J. Boyle asked Mr. C. Parker to comment of the possibility of a new approach to the control of rhizomatous weeds based on the use of chemicals to break dormancy. If weeds could be stimulated by this means the induced flush of shoot growth could easily be destroyed. Mr. Parker replied that he was actively investigating this approach and attempting to devise new techniques to screen chemicals for this purpose.

Mr. J.G. Elliott asked Mr. R.G. Hughes the interval of time necessary to control soil borne fungus diseases. Mr. Hughes replied that a fallow interval between harvesting and sowing of spring cereals could allow root and stubble residues to die back sufficiently for subsequent crop vigour to overcome the effects of the reduced soil borne disease. Widening the interval by sowing early maturing barley would accentuate this but on the other hand, a dry or very cold winter would limit the biological activity causing this die back.

Mr. W. Cowan asked what effects heavy applications of nitrogen, as used by Dr. D. J. Turner, would have on the cereal disease situation. Dr. Turner remarked that he had reported a preliminary investigation of some environmental factors and their effects on couch. He thought it would be premature to relate these results to practical control measures.

Dr. Turner then asked Mr. Hughes whether the frequent removal of couch shoots would have a significant effect in cereal disease incidence. Mr. Hughes replied that it would but he questioned the efficiency of frequent defoliation as a means of control of couch during the limited interval of time available between cereal crops.

Mr. M. Eddowes asked for an explanation of the success of rotary cultivations against couch and asked if timing of the treatments was important and if rotary cultivation could or should be linked with deep ploughing. Mr. Elliott said that he believed it was important not to allow an interval between rotary cultivations which would permit any increase in food reserves. He also believed that deep ploughing would prevent regeneration of weak shoots.

Mr. C.L. Campbell asked whether the effect of EPTC was to kill the rhizomes of couch or merely to suppress growth. He also asked if EPTC could be used after harvest and before sowing winter corn. Mr. D. Bartlett replied that EPTC did result in kill of rhizomes but some survivors usually remained and these were capable of healthy regrowth. Mr. Bartlett was interested in the technique of applying EPTC and then incorporating it in the soil by means of a sprayer mounted on a plough. Barley had only shown temporary symptoms when sown one day after application of EPTC in this way.

The Chairman announced that some corrections should be made to the paper by Messrs. Bartlett & Marks. On p. 568 at the end of the first paragraph.

66	ppm should	read		6.6
18	"	"	"	1.8
12.4	"	"	"	1.24
7.4	"	"	"	0.74

THE FARMER'S FUTURE REQUIREMENTS

R. A. Burton

Wordsley House Farm, Stonnall, Walsall

Mr. Chairman, ladies and gentlemen, when I was asked to give this paper, my brief was to the effect that I should try and project my thoughts well into the future, and to try and give some indication as to how application methods could possibly be developed over the next ten years. I was told I could let my thoughts wander at will, as it would be the responsibility of succeeding speakers to comment on the practicability or otherwise of my suggestions. This arrangement is fortunate from my point of view, as it enables me to be as 'science fiction' minded as I like, with total disregard for practical details. Critics, and I am sure there will be many, are asked to bear this in mind. What I have tried to do is to prepare a paper that will stimulate the more agile minds of research workers even, perhaps, into completely new lines of thought.

At this stage, I think it is necessary to go back to first principles, because it is surprising how many scientists, once they get their heads in the clouds, never return to earth and, after all, it is the application of their efforts, either in, or on, the field itself, that is the measure of their success. They can develop the most marvellous herbicide imaginable, and the finest machine for applying it, but if either of these will only work under laboratory conditions then they are useless.

I think that few would quarrel with the statement that to be worthwhile herbicides should control the maximum number of weeds, as cheaply as possible, with the minimum of effort and the maximum safety to the crop. Cost in this context means not only the cost of the chemical used, but also the cost of application and any resultant damage to the crop, either by the chemical depressing the yield, or by mechanical damage due to the method of application.

On the first two points, it is obvious that if a herbicide could be developed that would either be repelled by the crop or, alternatively, attracted by the weeds, then it would be far more efficient than anything at present available, and there would be relative freedom from danger to the crop by overdosing. It is possible to electrically charge spray particles so that they are attracted by the weeds and repelled by the crop?

The importance of producing a cheap chemical which can be used at very economical rates is, however, of less importance than that of developing methods of application which could very easily be far in advance of present methods. In horticulture in particular most herbicides are applied at the 100 gallons per acre rate, for a variety of reasons. One is that with present equipment, as it performs in the field, a mistake of 10 gallons per acre when calibrating is far less serious than a similar mistake when attempting to apply 30 gallons per acre. Also, most horticultural herbicides seem to act better in the presence of larger quantities of water. Nevertheless, it seems rather ridiculous to use half a ton of water to be able to apply 2 lb. of herbicide efficiently. On my own farm, every year, it takes one man, plus tractor and sprayer, a complete fortnight to apply $2\frac{1}{2}$ cwts. of chemical, simply because it has to be mixed with 75 tons of water. Multiply this over the country and you begin to realise the unnecessary amount of man power and effort involved.

On the agricultural side, the waste of effort per acre is not quite as bad as, normally, concentrations of the order of 150:1 instead of 1000:1 are used. But when you take into account the extra acreage involved, then the total waste of effort is indeed staggering. What I am looking for is a machine that will apply concentrated herbicides accurately, a machine that can apply 1 gallon, or even less, per acre, or a machine that can apply 4 lbs. or less of powder per acre would be ideal.

A machine of this type would mean that a tractor sprayer would be able to do 50 acres per filling, booms could be lengthened, possibly up to 200 ft., and there would be far less mechanical damage to the crop. Some system of keeping the nozzles at a constant height above the crop would have to be devised, but this should not be too difficult. The small two-wheeled horticultural tractors would similarly be able to do about 10 acres per filling. Over the whole country, this one development would result in a tremendous saving in man hours.

In future years as well, it seems highly probable that tractor marks across a crop, or indeed any mechanical damage to a standing crop, will not be acceptable, in which case it is obvious that better methods of aerial spraying than those in use at present will have to be found. This would, I think, be a possible use for a hover-craft.

Safety is the next problem to be tackled and here we have the twin problems of drift over neighbouring fields and the safety margin of the crop being sprayed. As herbicides have got more complex and selective, the safety margin seems to have got narrower. Primarily, of course, this is a matter of sprayer efficiency and careful calibration, but we still have the problem of overlapping. On horticultural crops overlapping poses relatively few problems, as it is usually possible to arrange the overlap between between rows; in fact, by using the rows as markers it is virtually possible to eliminate it altogether. In agriculture, this is a much more serious problem and, as I envisage the use of much wider booms than at present, the problem will become even more acute. Is it possible to have automatic nozzles that shut off immediately they are over land that has been sprayed? Or is it possible to have expanding and contracting booms so that there will be no overlap and no strip that has been missed? These again should be automatic and could possibly be worked via radio-active tracers energising a geiger counter, or fluorescent tracers on a photo-electric cell.

Whereas under or overlapping is a problem that affects a farmer on his own land, drift is a problem that affects his neighbours. Despite the official view that drift is becoming of less importance, I speak with some feeling on this matter after being asked to act as assessor on a drift claim that was eventually settled for well over a thousand pounds. If we are going to move to an era of more concentrated herbicides, then it follows that any drift will be potentially more dangerous. How are we going to combat this?

At the present moment the only advice seems to be to use coarser droplets, which again means using more water if we are to get efficient coverage. Is it possible to use magnetic traction, as is done in flow production paint spraying? Is it possible to use some method whereby the spray is attracted to the ground? Alternatively, is it possible to put some form of barrier round the field being sprayed to act as a deterrent to drifting, such as electrical waves, wireless waves, or even sound waves?

On a slightly more practical note, has any thought ever been given to producing antidotes for herbicides so that when drifting occurs over susceptible crops they can be washed clean or, alternatively, is there anything that can be sprayed on susceptible crops to immunise them against drift? I am sure there must be thousands of glass-house and fruit growers who are in predominantly agricultural areas who would be greatly relieved if it was possible to apply an immunising spray.

The foregoing remarks have tended to apply to the application of herbicides to growing crops. I would now like to turn to the question of pre-emergence herbicides. These, at the moment, are used both as overall sprays and as band sprays. With regard to the attachment of band sprayers to seed drills, I must confess to being prejudiced against them. I know that theoretically this is the ideal method, but I dislike them for two reasons. Firstly, you are trying to do two distinct yet rather precise jobs at one and the same moment of time, both of which are subject to various faults and breakdowns, which means that any single breakdown brings both jobs to a halt, or - what invariably happens - the operator continues in the full knowledge that he is not doing as good a job as he should. Secondly, if a pre-emergence spray is going to be used, I prefer to see it used over all the ground and thus do away completely with cultivations.

One of the drawbacks to most of the pre-emergence sprays in use at the present time is the fact that at the recommended rates the ground is not kept clean for the total duration of the crop. Admittedly, the crop is enabled to establish itself in a relatively weed-free environment, but what I may be allowed to call the 'clean period' would be better if it was longer. If the concentration is increased to get this effect, then invariably the crop itself is damaged. Would it be possible to have a herbicide incorporated in some form of minute capsules that would progressively disintegrate over a long period thus giving a longer weed-free environment? A further development on these lines would of course be a seed dressing that would inhibit weed growth within six inches of the germinating seed. Just imagine what this would mean to the spring cereal grower.

So far I have been dealing with possible developments in what I might call the middle distant future. I would now like to turn to some of our present-day problems that I hope will be solved in the immediate future. With regard to machinery for applying herbicides, what I am looking for is a machine that I can set to apply precisely x gallons per acre evenly and accurately. What I invariably get is a machine that applies x gallons plus or minus a rather wide variation, in fact a variation that either kills the crop or fails to control the weeds. With present herbicides this is far too slap-dash.

My own solution at the moment is to calibrate each machine at the beginning of each season by using pure water and running the tractor in a set gear at a known engine speed. The drivers are then instructed to travel in that gear and at that speed and no other. How much easier it would be if we could move a lever on the machine itself and know exactly the output to expect. Next we have the problem of efficient mixing. Certain herbicides in common use are applied as suspensions, which means that once the mix has been made, agitation must be constant, otherwise there is settling out. This, of course, means that there is very uneven distribution. Please could we have formulations that, once mixed, will stay mixed.

Sprayer booms are another problem. Is it possible to have booms that will shut off progressively so that we do not get fairly large areas that are inevitably overlapped or missed completely in our irregular fields, and is it possible to fix booms on a kind of gimbal arrangement so that the distance of the nozzles from the ground is constant.

With regard to herbicides themselves, is it really too much to hope that we shall eventually get a herbicide to kill a minimum of 90 per cent of the weeds with no damage to the crop, even when it is grossly overdosed? Furthermore, for the horticulturalists and the sugar-beet growers, can we have a herbicide which is not so dependant on weather conditions as those at present available. With particular reference to pre-emergence sprays, can we have some that we can either put on at heavier rates or some that will at least last all the growing season but at the same time will not leave unwanted residues in the ground for the following year. What I have in mind is a formulation that will break down when subjected to normal winter weather conditions of temperature and humidity - for example, after 72 hours continuous frost.

I would now like to turn to the question of cost. Some of my suggestions have been talked about for years, but invariably the same answer has been given by the engineers, i.e. we could supply such a machine but the cost would be prohibitive. Has anyone ever given serious thought to this problem and worked out the cost of a really efficient machine, as opposed to our present ones?

To take some very rough figures - the cost of the average farm sprayer is in the region of £200 - £300 and that machine will have a through-put of something like £6,000 worth of chemicals during its useful life. In other words, the cost of the machine is something less than 5 per cent of the cost of the chemicals it applies. I think this puts cost into a better perspective and will make it more readily appreciated that a relatively small increase in machine efficiency would result in an appreciably larger cash saving in chemicals.

It will have become obvious by now that I have a very strong bias towards reducing the volume applied per acre, as long as the herbicide can be applied safely and efficiently. I have already discussed the question of safety with regard to the environment but it must always be remembered that if higher concentrations are to be used we may find ourselves dealing with chemicals that could be dangerous to the user. At the moment most herbicides are extremely safe from the operator's point of view. It is important that they should remain so and the operator's safety should be of prime importance when new types of sprayers are being developed.

This leads to the last point I wish to underline with regard to ultra low volume application. I have tended to stress the problems of actually applying the herbicides, but if we are to get highly concentrated chemicals, we shall undoubtedly get chemical problems and biological problems. In point of fact, I regard this problem of ultra low volume as one which will only be solved by a three-pronged attack from engineers, chemists and biologists, all working together.

Finally, gentlemen, what of the far distant future? The ultimate, of course, would be a weed-free environment where no sprays would be needed, but before we reach that goal I eventually expect to see a remote- controlled machine, floating over the crop so that there is no mechanical damage, and spraying or dusting a herbicide that is 100 per cent successful under all weather conditions, with no drifting and no damage at all to the crop even when applied at ten times the recommended rates. I only hope that the few suggestions I have been able to incorporate in this paper will have the effect, as I stated at the beginning, of stimulating others.

APPLICATION - THE BIOLOGISTS' REQUIREMENTS

J. Holroyd

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At the present time, a large variety of both foliar and soil-acting herbicides are available which can be used in widely differing situations. They may be 'contact' herbicides with fairly localised activity, or they may move freely in the plant and act at a distance from the site of entry. They may be formulated as emulsions, solutions, wettable powders or granules.

Foliar-acting herbicides may be applied to the foliage of fully exposed weeds or to a complex canopy of crop and weed foliage in which the weeds are partially or wholly shielded. The foliage may be of any shape, orientation and wettability. Soil-acting herbicides may be applied to soil surfaces which range from relatively smooth seed-beds, to whose which are cloddy and uneven and even ridged as in a potato crop. Thus there is a vast complex of interacting factors related to the plants, the soils, the herbicides, the type of application, the weather conditions before, during and after the application, etc. which governs the effectiveness of any herbicide treatment. However the optimum result should be the maximum kill of the weeds in a relatively short time, with maximum selectivity if a crop is present and a minimum of drift. Inevitably each herbicide and crop and weed situation will have different application requirements for this optimum effect and thus any generalised answer must be a compromise.

The chief objective of this paper is to discuss some of the more important characteristics of plants and herbicides and how they inter-relate with the characteristics of different forms of application (principally liquid sprays) which can be modified by the engineer, and to attempt to state the requirements for achieving the most satisfactory compromise.

Consider firstly the application of herbicides which are either dissolved or suspended in a diluent - generally water. The application is in the form of a spray and the controllable characteristics of a spray are:-

a) the size of the individual droplets and the proportion of droplets of droplets of different sizes,

b) the velocity of the droplets,

c) the angle of incidence of the droplets,

d) the volume rate, and

e) the distribution of the droplets over the target area.

It is important to emphasize that it is the nature of these characteristics at the point of impact of the spray with its target which is important, not at some position between the outlet and the target. Thus measurements made under the still air conditions of the laboratory may be vastly changed under field conditions.

The situations in which herbicides are applied may be divided into two main types. In one they are applied post-emergence to foliage and in the other pre-emergence to the soil.

FOLIAR APPLICATIONS

The amount of spray retained by plant foliage is of primary importance as it determines the dose of herbicide available to affect the plant as a whole. This amount retained depends on the actual leaf area of the plant and its arrangement with respect to the degree of overlapping of the leaves and the angle of incidence of the spray. In addition the proportion of intercepted spray droplets which is actually retained depends on many characteristics of the foliage as well as of the spray.

a) Droplet size

The size of droplets influences their retention by plant surfaces and a closely related factor is the surface tension of the liquid of which they are composed. Thus Brunskill (1957) working with pea leaves, which are relatively difficult to wet, showed that droplets with a surface tension of 45-50 dynes/cm and 250-350 μ in diameter bounced off, whereas at a slightly lower surface tension (40-45 dynes/cm) there was a sharp rise in the number retained.

On the other hand smaller droplets of 80-95 μ diameter with a surface tension of 72 dynes/cm were almost completely retained.

Bengtsson(1957, 1961) also found that droplet size was particularly important when plants with difficult-to-wet leaves were sprayed or sprays with a high surface tension used. Generally small droplets were retained more readily than large droplets. Some species such as Chenopodium album which has difficult to wet leaves, were affected more by sprays of smaller droplets, whereas Sinapis spp and Galeopsis spp were more or less equally affected irrespective of the droplet size of the spray.

Even when spray droplets are completely retained they may cover a relatively small proportion of the leaf surface. Carleton et al. (1960) calculated that at a volume rate of 10 U.S. gal/ac and a droplet diameter of 200 μ only 0.13 acres of plant surface is covered if the contact angle is 90°. They also calculated that there may be 5 - 20 acres of plant surface per acre of land. If the droplet diameter is reduced to 20 μ then 1.33 acres would be covered. This is still only 7 - 27% of the plant surface. However with more wettable leaves and/or liquids with low surface tension the droplets tend to spread out on the leaf surface and have a larger area of contact.

b) The velocity of the droplets

Brunskill in his experiments found that as their velocity was increased the proportion of droplets retained also increased. This will be most important for relatively small droplets whose kinetic energy is small and where there is a danger of their being swept round the leaf surface without actually impacting.

c) Angle of incidence

Brunskill found that as the angle of incidence of the droplets was increased the number retained decreased. Thus the more erect the leaf the less likely it is to retain spray droplets unless and 'angled' jet is used. This probably provides part of the explanation why a number of workers have found that 'angled' sprays of barban are more effective than normal perpendicular sprays for the control of Avena fatua (Gull et al., 1959, Friesen & Henne, 1959, Carder, 1960 and Bingham, 1960). Another factor is that the leaf sheath of the A. fatua is more retentive than the rest of the leaf, in addition to being more exposed to the 'angled' spray. Parker (1966) has also found an 'angled' spray to be more effective on Allium vineale due to the greater amount of herbicide retained.

d) Volume rate

Volume rate is generally fairly closely related to droplet size as at normal pressures and rates of work droplet sizes tend to be larger at higher volume rates. Thus fewer of these larger droplets will be retained, at higher volume rates by the less readily wetted leaves, and the concentration of herbicide in the droplets which are retained will be less with a consequent reduction in the total amount of herbicide retained.

More easily wetted leaves may also retain less herbicide if they are sprayed at a volume rate which results in excessive 'run-off'. Holly (1952, 1960) and Blackman et al., (1958) have shown that the relationship between volume rate and the amount of herbicide retained varies with different species with consequent implications regarding selectivity. But this is an aspect which has not been greatly exploited.

e) The distribution of the droplets over the target area

Behrens (1957) working with solutions of 2,4,5-T attributed more importance to droplet spacing than to droplet size or spray volume and herbicidal concentration and found that a spacing of 0.12 in equivalent to a deposition of 72 droplets/in^2 was the widest spacing at which maximum herbicidal activity was maintained on cotton and mesquite. It is surprising that the distance was so small for 2,4,5-T is a translocated herbicide. Other species and other herbicides may give very different results, and there is obviously a need for more work on this aspect.

Situations in which foliar herbicides are used

There are two main situations in which foliar applications are used. In one the weeds are on their own and in the other the weeds and crop are together.

a) Weeds in the absence of a crop

When there is no crop present to complicate matters highest degree of herbicidal activity is required. This will be obtained by an application giving optimum cover of the foliage with maximum retention of the droplets, irrespective of whether the herbicide has contact activity only or is translocated, although, of course, complete cover is of more importance with the contact herbicide. Theoretically the application should be an evenly distributed spray of relatively small droplets, for this will achieve maximum penetration and be most completely retained by the foliage. In practice the situation is more complex, for if for example the leaves are angled towards the stem, it will probably be more advantageous to wet the leaves to run off so that the herbicide runs down the stems killing the plant above the point of contact. Hence the more effective kill with dinoseb at high volume rates.

Translocated herbicides are less critical and their effects are more closely related to the total amount of herbicide retained by the plant. However, effective cover is still important.

In practice, of course, plenty of herbicide is applied in the hope of getting complete kill,but in so doing 3 - 4 times more herbicide is used than would be necessary, if application methods were more efficient.

b) Crop and weed foliage together

When the crop and the weeds are growing together the situation is complicated by the added factor of competition between the crop and the weeds. Thus a poorly growing crop provides less competition but the weeds are more fully exposed, and receive a larger proportion of the herbicide. Conversely, in a vigorously growing crop, although competition may be severe, the weeds may receive relatively little herbicide. Hebblethwaite and Richards (1966) using a variety of spraying machines and nozzle types found that weeds under a vigorous cereal crop received as little as 20 - 30% of the herbicide applied. Ideally, therefore, the herbicide should be applied before the crop canopy protects the weeds or a spray should be used which readily penetrates the crop canopy. Small droplets will tend to penetrate the canopy more effectively but these are also the most readily retained by, for example, a less readily wetted crop such as a cereal. Possibly a mixture of larger and smaller droplets as produced by present machines is the most efficient type of spray, particularly where there is a mixture of leaf surfaces, but there is no information as to what the proportions should be or the limits thereof. On present knowledge, however, where the crop foliage is less readily wetted than the weed foliage, large droplets may be satisfactory as differential retention will help selectivity.

Where the weed foliage is less readily wetted it is probably most satisfactory to choose maximum retention i.e. smaller droplets, and rely on the intrinsic selectivity of the herbicide.

SOIL APPLICATIONS

When a herbicide is applied to the soil surface it has to reach a plant surface (either a root or a shoot) penetrate the plant surface and be transported within the plant to the site of action before it can be effective. Transport from the soil surface is generally as a solution in water provided by rain or irrigation. However, while at the surface there may be loss due to adsorption, volatilisation and chemical or microbiological breakdown and although these factors may be thought to be relatively independent of the type of application, very little research work has been done to investigate this aspect.

Is the retention of a volatile herbicide by soil influenced by the volume rate or droplet size? It seems possible, for example, that smaller droplets of a spray containing a volatile herbicide such as tri-allate may penetrate further into the smaller interstices of a dry soil surface and thus be less exposed and liable to loss by volatilisation, before the herbicide is incorporated.

Distribution

Distribution on the soil surface will, however, be important but there is little information on the minimum distance between droplets on the soil surface for maximum effectiveness. This will be influenced by the type of herbicide (soluble or insoluble, volatile or non-volatile) and mode of action (active at the site of entry or at a distance). Horowitz (1966) stressed the importance of uniform distribution, for in his work with granules of dichlobenil he found that although the phytotoxic area produced by grouping several granules together or using granules containing a higher concentration of active material, was increased, the increase was not proportional to the amount of herbicide applied. In one experiment he placed granules containing 7.5%, 15% and 25% dichlobenil on air dry soil, and after overhead watering found that the ratios of the respective areas of phytotoxicity were 1:1.5:2.5 (using ryegrass as the test crop). Thus on a given area the effectiveness of the same dose of herbicide was increased as the concentration of herbicide in each granule was decreased i.e. the more even the application the greater the effectiveness. Dichlobenil, although volatile, has a relatively localised activity on root growth (Massini, 1961) and thus uniform distribution is important.

Lyndsay and Hartley (1966) found that MCPA affected only the roots of peas and barley with which it came in direct contact, and growth continued when a portion of the root system was in a herbicide-free environment. In contrast they found that atratone killed plants whether available to the whole or to only a portion of the root system. Other herbicides in this category which are active at a distance from the site of entry, are other triazines, substituted ureas, uracils etc. Wettasinghe (1966) has also shown that it is the total amount of a triazine in contact with a particular root system which is important, and not its distribution. However, in practice if a pre-emergence application is uneven, seedlings may be relatively well developed and thus more resistant before they come into contact with the herbicide.

Again, therefore, even distribution of the herbicide is required although no guidance can be given as to how even it must be for the maximum effectiveness of the various types of herbicide.

A further complication in applications to the soil surface is topography. Uniform application will be very difficult where the surface is very uneven. An extreme example is the potato ridge. The dose actually applied to the sides of the ridge will be much less than that applied to the bottom of the ridge (unless an 'angled' spray is used) and in loose or dry soil conditions, this uneven distribution may be further accentuated by erosion of the ridge.

Incorporation

Incorporation of the herbicide with the soil can be classed as part of application for it reduces loss by volatilization and also brings the herbicide into closer proximity with either the roots and rhizomes of perennial weeds or with weed seeds. There is again little published information on how complete the initial distribution of the herbicide in the soil needs to be. No doubt the volatility of the herbicide, and soil conditions are important factors, but even with a volatile herbicide such as tri-allate it has been found that the more efficient the mixing the better the control of wild oats, and at the right dose, the less damage to the crop (Holroyd, 1964). In these same experiments the distribution of both P_{32} and Saturn yellow in the soil was examined after incorporation with the soil, using standard farm implements such as harrows and rotary cultivators; and the distribution was found to be very uneven indeed. However, at the same time examination of the initial distribution of spray on the soil surface showed that this varied by a factor of 2 although similar portions of the spray swathe were sampled.

This was considerably better than the distribution which Nation (1966) found under a cereal crop when he examined the deposition given by a number of farm sprayers. Using sampling areas of 8 in^2 he found that the deposit varied from 0 to 4 times the intended application rate.

Can subsequent soil mixing with a suitable implement - designed for the job - compensate for an initially poor distribution? Is the initial distribution relatively unimportant? This is an aspect which needs investigation.

PHYSICAL FACTORS

As a biologist I have been considering the condition of the spray pattern and its constituent droplets at the point of impact with their target, but the engineer has to get them to this point from the outlet. This, of course, presents problems. Beginning with the spray boom itself there is the difficulty of boom whip and bounce. The spray droplets themselves in travelling from the outlet to the target are subjected to the environmental conditions. Air movement in particular can distort the still air pattern of distribution and give uneven deposition in addition to causing actual loss of the smaller droplets by drift. The size of the droplets may be still further reduced by evaporation particularly under conditions of low humidity and high temperature. The smaller the droplets the greater the loss due to the higher surface to volume ratio.

POSSIBLE REMEDIES

There are various possible remedies. Drift may be reduced by increasing the droplet size and reducing the number of small satelites as in the vibra-jet or vibra-boom. The number of small satelites can also be reduced by formulation using gelatinous additives such as 'Norbak' or invert emulsions such as in the bifluid system. But large droplets are not always wanted, as has been indicated, particularly for foliar applications. However, they may be satisfactory for soil applications where the potential target area is less. Thus 20 gal/ac distributed evenly as 200 μ droplets would have a density of approximately 3460 per in^2.

The exposure of the spray droplets to the environmental conditions could be reduced by shortening the outlet to target distance or increasing the outlet to target speed. The ultimate would be to apply soil acting herbicides below the soil surface. Some work on this has already begun in the United States (Wooten & McWhorter (1961), Wooten et al. (1966)). This technique has much to commend it for it not only avoids the vagaries of the above ground environment but also puts the herbicide where it is likely to be most effective, particularly on perennial weeds. This is particularly true of the relatively insoluble herbicides. With volatile herbicides, it avoids the necessity for incorporation and makes an attrubute of their volatility. It is worth remembering that a new method of application may increase the effective control of a difficult weed as much as an entirely new herbicide.

CONCLUSIONS

Herbicides have made very striking advances during the last few years and we can control many more weeds in most crops, but there have not been similar advances in application machinery. It is worth remembering that a new method of application may increase the effective control of a difficult weed as much as an entirely new herbicide. This is not entirely the engineers fault for biologists have failed to give him definite limits to which he could work, and to state precisely just what is required for the maximum effectiveness of many of these herbicides. Unfortunately ours is still a rather inexact science, and one of the things the biologist requires in turn is more sophisticated application equipment for experimental purposes. Thus we need a means of producing droplets of known sizes, which is more efficient and easier to use than the spinning disc, and also a means of producing sprays composed of chosen mixtures of various sized droplets. For soil work a method is required for placing herbicides below the soil surface in various ways.

The W.R.O. has a number of joint projects with the National Institute of Agricultural Engineering at Silsoe which if suitably supported should help to solve some of these problems, but there is still a great need for very much more research on the many aspects of the application of herbicides and in this the biologists, the physicists and the engineers should all play major parts.

References

BENGTSSON, A. (1957) Effects of drop size on the activity of two selective herbicides. Proc. 4th int. Congr. Crop Prot., 67-68.

BENGTSSON, A. (1961) [The influence of droplet size on the effects of herbicides.] Växtodling, 17, 149.

BEHRENS, R. (1957) Influence of various components on the effectiveness of 2,4,5-T sprays. Weeds, 5, (3), 183-96.

BINGHAM, H.E. (1960) Barban for wild oat control. Proc. 17th N. Cent. Weed Control Conf., 1960, 42-3.

BLACKMAN, G.E., BRUCE, R.S. AND HOLLY, K. (1958) Studies in the principles of phytotoxicity V. Inter-relationships between specific differences in spray retention and selective toxicity. J. exp. Bot., 9, (26), 175-205.

BRUNSKILL, R.T. (1957) Physical factors affecting the retention of spray droplets on leaf surfaces. Proc. 3rd Br. Weed Control Conf., 593-603.

CARDER, A.C. (1960) Barban as a post-emergence herbicide for wild oat control in spring wheat. Res. Rep. 17th N. cent. Weed Control Conf., 70-1.

CARLETON, W.M., LILJEDAHL, L.A., IRONS, F., HEDDEN, O.K. & BRAZEE, R.D. (1960) The development of equipment in the application of agricultural chemicals. Proc. Symp. The nature and fate of chemicals applied to soils, plants and animals. agric. Res. Serv., U.S. Dep. Agric. 20-9, 70-84.

FRIESEN, G. & HENNE, R.C. (1959) Comparison of several nozzle types on the effectiveness of S-847 (Carbyne) on wild oats. Res. Rep.west. Sect. Nat. Weed Comm. Can., 123.

GULL, P.W. et al. (1959) Results of field trials with barban on the control of wild oats in wheat, barley and flax. Proc. jt Meet. 16th N. cent and 10th west. Can. Weed Control Conf., 51.

HEBBLETHWAITE, P. & RICHARDSON, P. (1966) Spray recovery in cereals. Weed Res., 6, (1), 84-5.

HOLLY, K. (1952) The effects of volume application rate on the activity of 2,4-dichlorophenoxyacetic acid and 2-methyl-4-chloro-phenoxyacetic acid. J. Sci. Fd Agric. 3, (7), 308-12.

HOLLY, K. (1960) Pot experiments with new herbicides for the control of Wild Oats. Prof. 5th Br. Weed Con. Conf., 533-41.

HOLROYD, J. (1964) Field investigations concerning the selective phytotoxicity of di-allate to *Avena* spp. in wheat and barley. Weed Res., 4,(2), 142-66.

HOROWITZ, M. (1966) Experiments with granules of dichlobenil under glasshouse conditions. Weed Res., 6,(2), 91-103.

LYNDSAY, R.V. & HARTLEY, G.S. (1966) Studies of the response of plants to root-applied herbicides. 2. Further observations on the effect of localized application. Weed Res., 6 (3), 221-32.

MASSINI, P. (1961) Movement of 2,6-dichlorobenzonitrile in soils and in plants in relation to its physical properties. Weed Res., 1, (2), 142-6.

NATION, H. (1966) Personal communication.

PARKER, C. (1966) Pot experiments with new herbicides on *Allium vineale L.*, Proc. 8th Br. Weed Con. Conf., 553-62.

WETTASINGHE, T.H. (1966) Studies on the relative toxicities of substituted s-triazines. PhD. Thesis, Reading University.

WOOTEN, O.B. & McWhorter, C.G. (1961) A device for subsurface application of herbicides. Weeds, 9, (1), 36-41.

WOOTEN, O.B., HOLSTUN, J.T. & BAKER, R.S. (1966) Knife injection for the application of EPTC. Weeds, 14, (1), 92-3.

CAN THE ENGINEER MEET THESE REQUIREMENTS?

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I would first of all congratulate Mr. Burton and Mr. Holroyd on their excellent papers which will give us much to think about and discuss. Both papers have stressed the need for equipment which is simple and fool-proof to operate but I think we all appreciate that the accurate application of chemicals can be a very complex business. It is inevitable that a number of the proposals in the two papers call for investigation on the part of the chemist and botanist before the engineer can decide which path to take because the position is continually changing as a result of new chemical discoveries. Also, weeds which were a problem a few years ago have been replaced by new weed problems requiring different treatment and rates of application.

Dealing with the purely mechanical side of Mr. Burton's paper, whether we shall see sprayers in ten years time with 200 ft. booms applying chemicals at the rate of one gallon per acre will depend very much on whether by that time we have developed a nozzle which can produce droplets of a completely uniform size and distribution and at the same time control spray drift on such low rates. If this can be achieved then I think it is highly possible the chemist would be prepared to recommend the use of chemicals in a more concentrated form than at the present time, without the risk of scorching and varying results. I can see some problem in the use of very wide booms on other than fairly level ground and large fields but we are all the time seeing farming units getting larger and the size of fields increasing by the removal of hedges and ditches. Spray booms of 60 - 80 ft. are becoming more common in certain areas at the present time and, given the right field conditions, I believe it would be possible to meet Mr. Burton's requirements to construct wider booms incorporating a levelling device, telescopic adjustment for width and at the same time as the booms were withdrawn, on and off valves which could be automatically operated to progressively switch off the nozzles. This would certainly call for some form of marking and, whilst I think there may be some problem in the use of radio active tracers from the safety angle, the use of fluorescent tracers in conjunction with a photo-electric cell could be an answer to the problem.

Mr. Burton has suggested the use of Hovercraft for carrying a sprayer and I have no doubt that with the commercial development of this form of transport, the Hovercraft could prove extremely useful, particularly where difficult terrain is encountered, but I believe this would more likely be a contractor's machine rather than one to be found on the majority of farms.

There is one point I would like to make here which was referred to by both speakers and that is, the popular demand for a crop sprayer has been for a comparatively low priced machine but a sprayer of the type suggested by Mr. Burton would be costly to manufacture and the capital cost I feel would only be justified on very large farms with a large spraying programme and also as a contractor's machine. Certainly a machine of this type would require a considerable amount of research and development from the engineering point of view and the cost involved would have to be weighed very carefully against the potential market.

I have commented on the need for development of the nozzle to produce uniform droplets and, coupled with this, we have the problem of spray drift. I do not agree with Mr. Burton that the official view is to play this down as it is my experience that more and more attention is being brought to bear on this problem.

Three main suggestions have been put forward for the control of drift, two of which are already in practice but, firstly, Mr. Burton has asked if drift cannot be controlled by magnetic attraction. Frankly, I do not know if any work has been carried out in this direction other than the use of electrically charged particles of dust, but I am wondering if Mr. Holroyd may be able to tell us whether this aspect has been considered by any of the research institutes. This would certainly be a case for the chemist, botanist and engineer getting together and I feel that this suggestion is worthy of further research.

Secondly, Mr. Holroyd has pointed out that another method of controlling drift is for the outlet to target distance to be reduced. With existing nozzles this would involve the fitting of more nozzles per boom with a lower output per nozzle to compensate but in doing this at low application rates there would probably still be a reduced problem of the small fine droplets created by the nozzle. Also the correct setting of the height of the boom is more critical and the risk of striping would be greater. Nevertheless this is a method which can be successfully employed.

Thirdly, we come to the method which is most generally used today of a nozzle, whether creating spray droplets by hydraulic or mechanical means, operating at very low pressures and giving a fairly coarse droplet size. Mr. Holroyd has pointed to the fact that the larger droplets apart from reducing drift enable a better distribution to be obtained and result in less loss through evaporation, but suffers from the disadvantage of run-off. I feel this technique can still be further developed towards a greater uniformity of droplet size and evenness of distribution. It would be interesting to hear if the tendency to run-off could not be reduced by the incorporation in the chemical of an agent to improve surface tension.

Mr. Holroyd has referred to the possibility that it may be necessary to mix residual herbicides in the soil to obtain maximum effect. I would think this might be very well done with a rotavator, though whether the chemical should be sprayed on or injected behind a tine would be a case for experiment. Some years ago my own company was concerned in the construction of a machine with Messrs. Rotary Hoes Limited for the application of dust for the control of eel-worm in potatoes and a considerable improvement was obtained in the results by injecting the dust in a band behind a tine, followed immediately by rotavating. This reduced the loss of material to the minimum and gave a very even distribution in the soil.

Mr. Burton has asked if it is not possible to have a machine which could adjust the rate of application by the movement of one lever. With the present requirements for droplet size and drift control, it is particularly necessary to keep the pressure at the nozzle constant. I feel this would be a fairly difficult requirement as any adjustment to the rate of application, apart from varying the speed of travel, would require adjustment to the size of orifice of the nozzle. As presumably the rate of application would not be likely to vary on any given job, possibly the simplest and cheapest method will remain the separate changing or adjustment of the nozzles.

Very briefly, on the problems of mixing the chemicals and agitation, I feel there should be some agreement where hydraulic agitation is used on the amount of by-pass required from the pump to ensure adequate mixing of the heavy suspensions. Too often a low to medium volume machine is used at the maximum output from the pump instead of one with greater capacity, leaving little or nothing for agitation.

In closing, I realise I have only dealt very briefly with a few of the problems raised. It is possible that new techniques such as herbicide pre-treatment followed by direct sowing will be considerably developed in the next few years, having a profound effect on the development of equipment and the spraying programme for weed control.

Finally, I would fully endorse the view expressed by the previous speakers of the need for greater research into the problems of application and that the maximum achievement will only be obtained by the chemist, botanist and engineer working jointly on these problems.

Discussion

Mr. J. Holroyd commented that the difference in activity between large and small droplets on mustard referred to in his paper was not due to retention on the leaves but to differences in distribution on the plant or over the target area.

Mr. R. Howes referred to the question of settlement of wettable powders which had been raised by Mr. Burton and Mr. Allman. He said that agitation should not be stopped for lunch but inevitably stoppages occurred due to breakdowns. However, if the wettable powder was ground finer and better dispersed, it would eventually settle to a harder cake. He himself thought that, with the cooperation of the engineer to produce better agitation during spraying, a more flocculated powder which settled faster but to a softer cake so that it was more easily redispersed after stoppages would be the answer.

Miss H. M. Hughes asked if there were any reasons why chemical sprays could not be dyed to assist in marking and control of drift. Dr. G. S. Hartley said that it was very much appreciated within the industry that it would be useful to make deposits and spray drift strongly coloured. The problem had been closely looked at and the difficulty was essentially economic. One was covering very large areas at great dilution and the cost of the necessary dyestuffs or pigments greatly exceeded the cost of active ingredient.

Mr. J. J. North commented that spraying machinery was used for the application of chemicals other than herbicides and these might have different biological requirements. In the future other chemicals might be applied at the same time as herbicides.

Mr. Maynard said that the cost of machinery had been estimated at 5 per cent of the total cost of spraying, but that in fact machinery costs were frequently recorded as low as one per cent of the total cost.

Miss H. M. Hughes asked about the possibilities of using carriers other than water. There were various industrial waste materials that could be used and that would be better than water for spraying minute quantities safely over large areas. Mr. R. Howes said that the cost of solid and other industrial waste would always be higher than that of water since it would have to be distributed ready mixed from central points and the cost of road transport could never compare with piping water at 1/6d. to 2/6d. per thousand gallons to the grower.

Mr. J. Love referred to the fact that mention was made in Mr. Burton's paper of seed dressing. His organisation had used charcoal on strawberries as a protectant. Could not some protectant be used on seeds such as the gell being developed for direct seed sowing. This would give protection to the plumule as it came up through the residual herbicide and to the radicel which would go below. He asked what developments there were in this. Dr. G. S. Hartley replied that deliberate protection of sown seed by a band of finely divided active charcoal had been tried. It was technially very successful except that the small proportion of weed seeds under the band also survived and these were the most important. For a low-value agricultural crop the method was too expensive. Protection of the seed by a dry coating had also been tried but in this case the radicle very soon emerged from the protected region and it was the radicle, more than the seed, that was vulnerable.

In closing the discussion, the Chairman, Mr. C. J. Moss, said that he was quite a new-comer to this work and the most important impression he had gained was the need for more work in this field. Mr. Holroyd had said that herbicides had been very striking advances during the last few years. We must not be pessimistic about progress because there were a lot of difficulties; because we did not have Hover-craft or 200 ft. booms, we should not lose sight of the good that herbicides were already doing. The difference in ten years was very striking. Great advances had been made although perhaps these advances had been those most easily made with comparatively unsophisticated equipment.

On the application side, Mr. Moss said it might be necessary to go to more sophisticated equipment. It was true that in many parts of agriculture and horticulture progress could not continue at the present rate with equipment that cost merely one per cent of the chemicals or other materials employed. Very much more money might have to be spent. Mr. Burton had given a figure of £6,000 for the cost of chemicals. If ten per cent of that could be saved per annum by more efficient application by a completely different approach to the problem of the manufacture of spraying and other equipment it would be well worthwhile.

In farming, more than ever, continued Mr. Moss, we had to stop looking at the cost of one part of a job and saying that it was too expensive; we had to look at the problem in the round. When you were dealing with £6,000 worth of chemicals it might be economical to spend £1,000 on application equipment. The lesson was becoming clear in many parts of agriculture and horticulture.

Professor Galbraith in his recent Reith lecture had said that it was possible to predict that a mission would land safely on the moon in a few years' time. It was not yet known how this would be done but that it would be done was practically certain! Mr. Moss said he felt we could be equally certain that we could make good progress in the application of herbicides. As with Professor Galbraith, he could not predict the ways in which we were going to do this but he was certain that we could make progress even with the present limitations of money and staff. Space programmes cost thousands of millions of pounds but there were only limited resources available to spend on spraying and other agricultural problems.

At Silsoe, they had started to collaborate with manufacturers and with the Weed Research Organisation on the incorporation of herbicides in soil and studies of sprays and spraying. Much of the work had only just started. Again, manufacturers had done much work to solve some of the problems in the industry. He predicted that we should certainly ask the farmer to pay more for equipment; it would be more economic in the long run for him to do so.

Collaboration was a most important factor, continued Mr. Moss. There was hardly a field of agricultural research today which did not involve collaboration between widely different types of men: engineers, scientists, manufacturers and, he added, farmers and growers. We had to keep our heads in the clouds sometimes but we did need our farming friends to help keep our feet on the ground! He would like to ask for collaboration not only from manufacturers and sister research institutes but also from farmers who could look into the future and tell them what things were needed most.

Mr. Moss expressed himself disappointed in one respect because he had hoped one or two points would have been emphasised in discussion. The resources were not available to tackle all the problems; they had to try to pick a small number. He had hoped that a number of the problems that it was most important to tackle would have been emphasised.

RECENT DEVELOPMENTS AND INVESTIGATIONS IN THE CHEMICAL CONTROL OF AQUATIC WEEDS IN THE NETHERLANDS

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INTRODUCTION AND SURVEY

The first stage in the chemical control of aquatic weeds in the Netherlands was the application of leaf sprays against emergent and some floating species, for example, 15 to 20 kg/ha of dalapon, mainly against grasses, and 2 kg/ha of MCPA or 2,4-D as amine salt, mainly against broad leaved water weeds. These treatments, applied on a small scale since about 1959, have been passed by the Dutch government since 1964. However, in permanently water carrying ditches, dalapon may only be used without a wetting agent because of fish toxicity. For the same reason ester-formulations of auxin-type herbicides may not be used. Another treatment, passed since 1964, is the application of diuron on temporarily dry ditch bottoms at a dose of 6 to 12 kg/ha.

Although commonly applied in certain regions nowadays, the above mentioned treatments did not solve the problems for the major part of our ditches in our polders. Here the control of the emergent and floating vegetation generally results in increased development of submerged weeds such as _Elodea_, _Ceratophyllum_ and _Potamogeton_ species.

Investigations during the years 1961-1964 have shown that higher submerged and also some floating and emerging aquatic weeds can be controlled by applying 0.4 to 0.8 ppm paraquat in the ditch water. Several species are also susceptible to diquat but on average its effect is less favourable and as a rule much more regrowth takes place from rhizomes. Since 1965 paraquat may be used as indicated but without the usual wetting agent which is too toxic to fish. Diquat has not yet been submitted for approval. Unfortunately paraquat does not solve the problem in most of the Dutch polder ditches because the higher submerged aquatic weeds, controlled by paraquat, are generally replaced by filamentous and other multicellular algae (_Vaucheria_ spp., _Enteromorpha_ spp., _Hydrodictyon_, etc.) often clogging the ditches to the same extent or even worse. Only _Cladophora_ spp. are susceptible to and can be well controlled by paraquat and diquat.

After it was found that diuron was not only an effective algicide, but also an excellent, though slow acting, herbicide against higher submerged aquatic weeds, in 1965 and 1966 we concentrated on the possible application of this total herbicide for the maintenance of polder ditches. The investigations were carried out by a research team of specialists, which had studied the consequences of paraquat and diquat applications in ditches in former years. It was found that 0.4 ppm diuron in the ditch water may give complete control of all noxious submerged higher aquatic weeds as well as algae and it is to be expected that this dose will be passed for use in polder ditches in due time.

Two other closely related herbicides are still under investigation for the control of submerged and other aquatic weeds, dichlobenil and chlorthiamid. It has been found that 1 ppm of both herbicides in the ditch water may sufficiently control most higher aquatics and that they are more effective than any other chemical against _Equisetum fluviatile_, but they completely fail against algae.

Although the dose of a herbicide against submerged weeds should be expressed in ppm or grams per cubic metre of ditch water, it has been found that for shallow ditches the dose should be based on a minimum depth of 50 cm. Therefore the lowest dose per ha of ditch surface for paraquat and diuron (0.4 ppm) should be 2 kg, for dichlobenil and chlorthiamid (1 ppm) 5 kg.

FACTORS TO BE CONSIDERED

Toxicity

A herbicide used in ditches containing fish and from which cattle drink should have a very low toxicity to mammals, birds, fishes and fish food organisms. Before starting an experiment we should be certain that cattle can freely drink the treated water. The maximum concentration of a herbicide in a ditch should be at least 10 times lower than the LD 50 found for the most susceptible fishes and fish food organisms in laboratory tests at our Fishery Institute at Ijmuiden. No detrimental effect on the macro- and micro-fauna as a whole may be found in treated ditches. Then it should also be taken into account that ditch water is often used in irrigation or watering and in preparing sprays of pesticides. All these points and others have been studied by the above mentioned official research team.

Oxygen content in ditch water

More oxygen dissolves in water as the temperature is lower. The direct result of killing submerged weeds by herbicides is that the oxygen production by photosynthesis is stopped. Later oxygen is used in the decomposition of the dead plant material. As a result the control of a dense ditch vegetation may cause completely anaerobic conditions bringing about fish mortality. For this reason it is better to apply herbicides in ditches as early as possible.

Anaerobic conditions also prevail under a dense cover of floating Lemnaceae under which most submerged leaves die of light deficiency.

Fish food

None of the before mentioned herbicide applications were harmful to fish food organisms as a whole. As a rule more and larger food organisms developed in the plankton after a herbicide treatment.

Persistence

An important property of a herbicide against submerged weeds is its persistence in ditch water. It is generally accepted that herbicides in the soil and in ditch water are broken down by microbial metabolism. This goes for herbicides with low as well as with high persistence. At normal dosages an approximately exponential decrease of the concentration with time was found in model experiments for the following list of herbicides. The models were aquaria containing water, bottom soil and mud as well as the macro- and micro-flora and -fauna from a ditch. At 18°C the following data were found for half life:

Herbicide	Initial concentration	Half life
paraquat and diquat	0.2 to 2 ppm	0.6 days
dalapon	20 ppm	25 days
2,4-D amine salt	2 ppm	40 days
diuron	0.2 ppm	17 days
	0.4 ppm	48 days
	0.8 ppm	70 days
aminotriazole	10 ppm	300 days

The very low persistence of paraquat and diquat goes with a rapid herbicidal action. These properties enable their application in slightly flowing water.

All other herbicides in this list are very persistent and act slowly. The same goes for dichlobenil and chlorthiamid, for which no figures have as yet been found for half life in aquaria. For diuron, contrary to paraquat and diquat, a higher persistence was found with a higher initial concentration. This may be caused by inhibition of the microbial breakdown by the herbicide itself.

Water movement

Slowly acting herbicides, used against submerged weeds, can easily be displaced with the treated ditch water before they are sufficiently absorbed by the weeds to be controlled. Such too early displacement may even occur in ditches presumably containing completely stagnant water. However, we found that completely stagnant water is very rare in our polders. Water movement may be caused by (a) the wind blowing along the surface water and a compensating counter current deeper in the ditch, (b) ascending water, (c) pumping.

Unpredicted water movement rarely disturbed the effect of paraquat and diquat in test plots screened off by single fences of hardboard, and here these herbicides disappeared at about the same rate as in the above-mentioned model experiments. The persistent herbicides, on the contrary, disappeared much more rapidly in the test plots in the ditches compared to the models, and moreover most irregularly, even in completely successful experiments protected as well as possible from water movement. This means that not only the test plot of at least 200 (better 500) m length received a certain treatment, but also two adjoining buffer plots of 50 m, all being screened off by hardboard fences. Even these precautions did not always prevent a too rapid dilution in the test plot, shown by the analyses of the prevailing concentrations in bio-assay.

APPLICATION

Time of application

As a rule aquatic weeds are most susceptible to herbicides when growing rapidly. Besides it may be important that a fairly large leaf and stem surface is developed to take up sufficient herbicide. The greater number of submerged and other aquatic weeds attain this condition at the end of June and the beginning of July, which on average is the best time for paraquat applications. Probably the best time for dichlobenil and chlorthiamid is about one month earlier. With diuron excellent results have been achieved from the end of February onwards. This enables applications in early spring which may be important in keeping the oxygen content in the ditch water sufficiently high for fish life.

Elodea canadensis and *nuttallii* may be found in a fresh green susceptible stage throughout the year. At the same time, however, it may be found with black stems and withered leaves in other ditches. This unsusceptible condition may change at any time to a susceptible one by rapid regrowth from the black stems.

In ditches, usually filling up with *Elodea* in May, a paraquat application in April should be considered when the right stage of development occurs. In such cases a second treatment in July may be needed against later developing species. This, however, will not be necessary after early treatment with diuron.

Methods of application

Diuron, dichlobenil and chlorthiamid may be used as granules, which are sown like fertilizers, or as wettable powders. Normally wettable powders are sprayed with water, but they may also be sown after mixing with a 10-fold quantity of moist sand, which is cheaper than granules.

In our experiments liquids were applied with a propane knapsack-sprayer, which for leaf sprays was equipped with a portable boom with Birchmeier Helico Sapphire whirling nozzles and for spraying a jet directly into the water with a spray lance with a single nozzle without a whirling device. For the application of paraquat as a leaf spray, the just-mentioned nozzles were equipped with perforated whirling devices which I developed for very coarse droplets to prevent drift. In practice self-propelled motor equipment will be used as a rule, either with a carried spray boom or with one or two spray guns.

Against submerged weeds the rapidly acting and non-persistent paraquat should be thoroughly mixed through the ditch profile. In ditches up to 4 m wide this is best achieved by spraying deep into the water with a single jet under high pressure, moved regularly at 30 to 50 cm along each ditch bank.

METHOD USED IN INDICATING CHANGES IN DITCH VEGETATION

Coverage-scale HOOGERS

In this scale, developed by our vegetation specialist (Hoogers) the ditch areas covered by different species are indicated by single symbols, as follows:

- = not found	4 = 35-45%
: = less than 1%	5 = 45-55%
+ = 1-4%	6 = 55-65%
1 = 5-15%	7 = 65-75%
2 = 15-25%	8 = 75-90%
3 = 25-35%	9 = 90-100%

As a rule, the area covered is estimated once a month for (a) floating species, (b) submerged species, (c) species at the bottom. Accordingly the total of figures for a ditch vegetation at a certain moment may well exceed the number 9. One species, however, is never evaluated with a symbol over 9.

"Time-tables"

By plotting the figures for the various species found through the year on a horizontal scale, the months being indicated by their first letter, a "time-table" is obtained giving a clear picture of the changes in the vegetation, affected or not by a herbicide treatment. This is illustrated by the following time-table of an experiment on river clay in 1965. It shows the figures in ditches treated with 0.2, 0.4 and 0.8 ppm diuron respectively on 21 April and in an untreated ditch (check) on three higher submerged weeds and the filamentous alga Vaucheria sp. The treatment is indicated by a vertical line. The check was partly cleaned by hand at the end of July.

Time-table of an experiment in ditches with diuron

		A	M	J	J	A	S	O	N	D
CHECK	Spirodela polyrhiza	-	2	7	9'	6	9		8	:
	Lemna trisulca	:	:	:	:'	:	:		-	-
	Elodea nuttallii	6	7	3	3'	2	1		:	+
	Vaucheria	2	:	-	-'	-	-		-	-
					') partly cleaned					
DIURON										
0.2 ppm	Spirodela polyrhiza	-	-	:	+	6	7	7	1	-
	Lemna trisulca	+	-	-	-	:	:	:	-	:
	Elodea nuttallii	:	:	-	-	:	:	:	+	+
	Vaucheria	:	-	-	-	-	-	:	-	:
0.4 ppm	Spirodela polyrhiza	-	-	+	7	9	9	6	1	-
	Lemna trisulca	3	:	-	-	-	-	-	-	-
	Elodea nuttallii	3	:	-	-	-	-	-	-	-
	Vaucheria	2	-	-	-	-	-	-	-	:
0.8 ppm	Spirodela polyrhiza	-	-	-	:	:	:	+	+	-
	Lemna trisulca	:	1	:	-	-	-	-	:	:
	Elodea nuttallii	3	:	-	-	-	-	-	-	:
	Vaucheria	+	:	-	-	-	-	-	:	+
		treatment								

The vegetation in the four ditches was not quite the same before the application of diuron on 21 April, but a more uniform series of ditches is rarely found and the effect of the different treatments is clear, which is all we can hope for.

Spirodela has never been found in untreated ditches before May. In May it appears in the "check", attaining an area covered of about 70% (symbol 7).in June and of about 100% (symbol 9) in July. In the treatments with 0.2 and 0.4 ppm diuron it was first observed in June, attaining a high area covered in August and July respectively. Only the treatment with 0.8 ppm diuron showed actual control of Spirodela. Here this species was first seen in July, attaining a maximum area covered of 1-4% (symbol +) in October and November. In December it completely disappeared from the water surface, which is quite normal. Earlier small brown disks have been formed, which sink to the bottom before the plants die. Next May these disks (curions) develop into new plants.

In this experiment 0.4 ppm diuron was successful against the other submerged species but failed against Spirodela. This may have been partly caused by a more or less dormant and therefore less susceptible stage at the time of application. However, analyses of the diuron concentrations showed that the ditch water was diluted too rapidly, which also may have caused the failure of this treatment against this species. In other experiments it was found that 0.4 ppm diuron may completely control all important submerged weeds, Spirodela included, even when applied at the end of February or the beginning of March.

In the check plot Elodea nuttallii (the untidy looking Elodea, mistaken for the "tidy" Elodea canadensis until recently) lost ground as the surface became covered with Spirodela. This is normally found for all submerged species, and it is most probable that Lemna trisulca and Elodea should have rapidly increased in the treatment with 0.2 ppm diuron without Spirodela.

The filamentous alga Vaucheria also disappeared in the check as soon as Spirodela developed but this was partly a seasonal effect. Vaucheria reappeared here at the beginning of the next year (not on this time-table), and in the other ditches in October, November or December.

TREATMENTS RECENTLY DEVELOPED

Paraquat

This non-persistent, rapidly acting herbicide may be applied in ditches only as Gramoxone-ZU, a 20% solution without the usual wetting agent, as follows:

1. Jet-sprayed directly into the ditch water against submerged weeds, up to a depth of 50 cm in a dose of 10 l/ha of Gramoxone-ZU, and for a greater depth 2 l/ha more for each 10 cm. On average the best time for application is the end of June and the beginning of July. Usually ditches treated at this time will remain sufficiently clean until winter, but filamentous and other multicellular algae are not controlled excepting Cladophora spp.
2. As a leaf spray on a developing cover of Lemnaceae at a dose of 2 l/ha of Gramoxone-ZU, adding the less toxic wetting agent Agral.
3. As a leaf spray on emerging vegetation about one month before mechanical cleaning in a dose of 5 l/ha of Gramoxone-ZU, adding Agral. The effect chiefly is "chemical mowing"; only a few species are killed, but other species will regrow from rhizomes etc. In shallow ditches susceptible submerged and floating species may also be more or less controlled.
4. As a leaf spray mentioned under 3 on mainly floating Stratiotes aloides and Sparganium erectum, killing these species completely.

Diuron

This slow acting and very persistent herbicide is the most promising one for the maintenance of polder ditches, controlling both higher submerged and other aquatic weeds and algae. However, it has not yet been passed by the Dutch authorities. It is sold as Karmex, an 80% wettable powder or as granules. The dose for ditches is 2 kg/ha diuron up to a depth of 50 cm, and 0.4 kg more for each 10 cm. In deeper ponds where dilution by water movement is not possible, a lower dose may suffice. Excellent results have been obtained from the end of February onwards.

Dichlobenil and chlorthiamid

These closely related, slow acting and persistent chemicals have not been passed for use in ditches. Dichlobenil is available as Casoron, a 50% wettable powder and in 7.5% granules; chlorthiamid as Prefix, a 75% wettable powder and in 7.5% granules. The dose is 5 kg/ha of active ingredient up to a depth of 50 cm, and 1 kg/ha more for each 10 cm. Good results have been obtained from applications at the end of May and the beginning of June, earlier treatments having been insufficiently investigated.

Reference

HOOGERS, B.J. De groeicyclus van waterplanten. (summary: The development of aquatic plants during the year). Jaarboek I.B.S. 1966. Mededeling I.B.S. No.316.

Discussion

The Chairman (Mr. J.V. Spalding) in opening the discussion on Dr. van der Weij's and other reports presented, announced that agreement had now been reached between the Ministry of Agriculture, Fisheries and Food, the River Authorities and other interested bodies on a Code of Practice covering the safety aspects of chemicals in aquatic situations. The use of herbicides in these situations would now be covered by the Pesticides Safety Precautions Scheme and the Ministry would issue recommendation sheets on individual herbicides which had been cleared for use.

Mr. F.N. Midmer said that he was interested in Dr. van der Weij's work with diuron in Holland since this chemical had not been used in Great Britain. It looked as though diuron could be useful in controlling water weeds on which paraquat had a short-term effect. Dr. van der Weij replied that diuron was not in large-scale use in Holland and that care was required because of its persistence. Experiments were being carried out on a divided polder and they had noted an increase in fish food organisms. Mr. A.F.J. Wheeler asked how early in the season diuron could be used since early treatments prevent deoxygenation. Dr. van der Weij replied that good results had been obtained from February-March applications. Diuron granules had been put through holes in ice on the water and good control obtained in the summer. He thought treatments should not be applied later than April. Mr. R.C. Jennings asked if effective use of diuron was confined to static water and Dr. van der Weij replied that there was little experience in Holland in flowing water.

Mr. Midmer said that with increased use of water in drainage ditches for spray irrigation we must be concerned about the residual effects of either paraquat or diuron affecting crops that are sprayed. Mr. Wheeler said that with channel irrigation, after the use of either diquat or paraquat, the water can be used immediately. In the case of overhead irrigation, water should not be used until at least 10 days after treatment; there was a very wide margin of caution in this recommendation.

Mr. Midmer said that he had been involved with the helicopter treatments carried out over the last few years and was most interested because of the saving in time. Difficulties did arise, however, due to wires close to the channels, particularly those going across them. Dr. van der Weij commented that the difficulty with aeroplane application was pilot fatigue, and said that they were going to try spraying with a single jet from the air since this may prove more successful.

Mr. E.P. Whitaker commented that investigations which have taken place so far indicated that some triazines, particularly simazine and atrazine, give good control of algae and some submerged aquatic weeds. He asked if Dr. van der Weij had any experience of the use of triazines as aquatic herbicides. Dr. van der Weij replied that experience in Holland was limited and was so far confined to the laboratory. A few trials had indicated that atrazine was promising in this respect.

Mr. Whitaker asked if there had been successful treatment of limited areas of large lakes with diquat or did the concentration have to be sufficient to treat the whole lake. Mr. Wheeler said that sectors of an enclosed area of water can be successfully treated and, in fact, it has been recommended that, for example, one-third of the area should be treated if there is any question of reduced oxygen content of the water. The diffusion of the chemical frequently gives excellent control of the whole area. Mr. J.F. Newman commented that the Chichester experiment was done in three parts. Treatments were applied according to the direction of the wind; the drift of surface is in the direction of the wind so that for a light wind the effect extends far beyond the area of treatment. Weed control was obtained with 0.1 ppm. active diquat. Failures can be induced when something lying in the water absorbs the paraquat or diquat before the herbicides have taken effect. This can happen with the crust of calcium carbonate on plants, where there is a lot of suspended organic matter in the water or a thick growth of algae on the surface of the water.

Mr. Wheeler remarked that he was puzzled by the very few occasions where *Elodea canadensis* appeared to be uncontrolled. It appeared that this occurred when water was particularly hard and it had been suggested from the U.S.A. that the formation of a crust of calcium carbonate on *E. canadensis* prevents uptake of the chemical. Dr. van der Weij said that their experience with *E. canadensis* is that it can always be very easily controlled when in the active stage but when dormant it is impossible to kill it with any chemical. Mr. J.W. Mackenzie said that in the U.S.A. their experience had been that with the use of diquat in field trials in California six months' control was obtained using an active concentration of 0.05 ppm. whereas in Florida a minimum active concentration of 0.5 ppm. was required in order to achieve success. Field observations in Florida tended to show that water flow and density of infestation in relation to diquat concentration affect results on *E. canadensis*. Dr. van der Weij commented that there were two kinds of *E. canadensis* in Holland but their susceptibility was the same. Where there is dense growth a higher dosage applied with a strong jet into the water gives good results. He mentioned that in Holland diquat was not used for the control of water weeds because paraquat gave better results. Very few plants are more susceptible to diquat and a higher concentration of paraquat gives a longer lasting effect.

PROBLEMS IN THE PERSISTENCE OF HERBICIDES IN PLANTS AND SOILS

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The persistence of herbicides in plants, soils, and other segments of the environment has come under increased scrutiny in recent years. Strengthened guides and requirements for pesticide labelling and use in Great Britain and the United States can be attributed largely to the increased awareness of potential hazards associated with use of pesticides, including herbicides. The lay-man as well as the scientist has expressed concern. Herbicides have not been discussed with the equal fervour nor categorized in the same hazardous group as DDT and related insecticides. Nevertheless, we often do not have suitable answers to questions raised on persistence of herbicides and their metabolites. Concern over unanswered questions has stimulated more thorough investigations of pathways, mechanisms, and rates of decomposition of herbicides in plants and soils. There prevails also the desire of the scientist, the inquiring mind, to know more, to understand, to explore new uncharted realms.

The guidelines that are desirable to establish for this discussion are practical in nature, but fundamental concepts and principles may be utilized for interpreting results and projecting possible problem areas. The objectives are to discuss (a) practical problems that have arisen as a consequence of herbicide persistence in plants and soils, (b) potential residue problems to anticipate and to avoid, and (c) research problems associated with herbicide residues.

When a herbicide is introduced into an agricultural ecosystem, only a part of it reaches the target plant; and still less reaches the site of action to exert its effects on the undesirable species. Desirable plants are exposed to the herbicide during and after application. Soils are sprayed directly, or herbicide residues on leaves are transported to the soil by rain water. The relatively large quantity of herbicides that must be applied to insure small quantities at the site of action in the undesirable plant is conducive to the development of persistence problems. Our technology presently limits a high level of efficiency. Therefore, a major goal of research should be one of reducing the amount of herbicide required for weed control by increasing the efficiency of application.

PERSISTENCE IN PLANTS

When herbicides are present on the surface of plants, several processes are thought to account for disappearance: volatilization, photodecomposition, chemical reactions, absorption by plants, and movement in solution or suspension in rain water. The assumption that these processes occur appears realistic, but supporting data for some of them are scarce. Rates of disappearance are influenced by air temperature, solar radiation, wind, and rainfall.

Within the plant, herbicide molecules may remain unchanged or they may be degraded by enzyme catalyzed reactions and by non-enzymatic chemical processes such as hydrolysis, oxidation, and reduction. Formation of complexes and adsorption to non-physicological sites may also occur, but chemical change of the herbicide does not necessarily follow; hydrolytic and ion exchange reactions often yield the parent compound. A thorough review of the metabolic fate of herbicides in plants was published recently (Swanson, 1965).

Translocation of herbicides in plants has been extensively investigated. Rate, distance, direction, and extent of movement vary among herbicides and plants. A few herbicides translocate readily in the phloem, some move sparingly and others move not at all. Most are readily translocated from roots to leaves in the xylem. Phloem-mobile herbicides are often translocated into food storage organs or tissues with high metabolic activity. Herbicides that move upward in the xylem usually accumulate in the leaves.

The ultimate result of translocation is one of reducing the herbicide concentration in one or more tissues or organs of the plant and increasing it in others. Little is known about degradation rates of herbicides among plant tissues and organs, but some differences have been observed.

Exudation of herbicides from roots sometimes occurs but is not presently considered a major pathway of loss.

Many of the common herbicides disappear rapidly from plants, but there are notable exceptions. Dalapon, for example, accumulates and persists for long periods, in some plants at least (Foy, 1961); but I know of no residue problems attributable to this persistence.

A few herbicides persist in seeds of sprayed plants. Typical 2,4-D response was observed in cotton seedlings grown from seeds of treated plants (McIlrath, et al, 1951). Phytotoxic symptoms of dalapon were transmitted to the third generation of wheat after preplanting applications of 4 lb/ac of the herbicide to the first generation (Foy, 1961). Dalapon and the closely related 2,3-dichloroisobutyric acid cause male sterility in cotton plants by inducing non-dehiscent anthers (Scott, 1961), an effect of some potential, perhaps, to plant breeders in hybrid seed production.

In several instances where persistence and metabolic fate of herbicides in plants have been investigated, the capability of a plant to metabolize a herbicide rapidly is associated with resistance. Herbicides are often used for weed control in those crop plants having mechanisms for rapid detoxication. Therefore, we have a built-in device for reducing problems associated with persistence in plants. This same built-in device is operative during development of herbicides because plants that metabolize experimental compounds are more likely to be selected as tolerant species than those without the metabolic capability.

That partial metabolism of a few herbicides produces compounds toxic to plants is now well-known (Wain, 1955). In such cases, plants in which the butyric acid 2,4-DB and related herbicides are used for weed control, the resistant plants, presumably retain the parent compound. Slow enzymatic degradation, dilution in the plant as size increases, and probably other mechanisms account for reduction and disappearance of residues by harvest.

The need for herbicides in crop production usually is most urgent at planting or soon after; and usually a single application, or at most two or three, fulfills the need. Massive and frequent applications are unnecessary. For many herbicide uses, the time lapse between application and harvest is sufficient for reduction of residues to non-detectable levels. In others, residues persist to harvest but apparently pose no significant hazard to animals and man. Chemical industry has played a major role in research on disappearance rates of herbicides from plants.

Practical problems associated with herbicide persistence in plants have been rare. One such problem was encountered with amitrole residues in cranberries in the United States in 1959. According to available reports, residues occurred only on berries from plants that had been sprayed at times other than prescribed on the label and recommended by weed control specialists. Some berries were removed from the market. Preceding action by the U.S. Food and Drug Administration, methods of detecting amitrole had been improved and metabolites, hitherto undetectable, were measured, increasing the total recovery value. Although the pharmacological significance of the residues was questionable, they exceeded the zero tolerance, established by law for all chemicals exhibiting carcinogenic properties in laboratory animals.

In forage production, herbicides such as 2,4-D are often needed most urgently during the grazing season. Although 2,4-D disappears rapidly (within a few days) from most plants, some restrictions on grazing sprayed pastures have been necessary in the United States to prevent residues in milk. By law, no pesticide residues of any kind are allowed in milk. A recent study indicated that less than 0.01 ppm of 2,4-D was found in milk when grazing of cows on pastures sprayed with double the usual rate was delayed for 1 week (Klingman et al., 1966). Residue analyses of forage in the same experiment showed that about 9 per cent of total 2,4-D applied as the butyl ester and about 30 per cent of that applied as the ethylhexyl ester remained after 7 days.

Recent joint actions by the U.S. Departments of Agriculture and Health, Education, and Welfare established general guidelines for strengthening controls over pesticides in foods. One aspect of this new action involves tolerances of residues that occur inadvertently in agricultural products. Inadvertent residues may occur in rotational crops growing in soil containing persistent residues, or they may be deposited on plants by drift from adjacent sprayed areas. The decision has been made that tolerances will be required for such residues in raw agricultural products. Specific mechanisms and responsibilities for establishing tolerances have not been clarified. Since the probability of problems of this type is not great with herbicides for phytotoxicity often foretells the presence of carry-over residues or drifting herbicide sprays, an awareness of its possible occurrence should be maintained.

PERSISTENCE IN SOILS

Soil applications of herbicides are far more frequent than applications to foliage; and persistence in soils in relation to weed control, crop injury, effects on beneficial soil microorganisms, and possible accumulation in soils has been thoroughly investigated for several herbicides and has received token attention, at least, for most that have reached commercial use. Many research papers are now being published in this area, and several reviews are available (Fletcher, 1960; Holly, 1962; Sheets and Harris, 1965; Sheets et al., 1964; van der Zweep, 1960; and others).

As in plants, loss of herbicides from soils proceeds, or is influenced, by one or more of several processes: volatilization, photodecomposition, microbial decomposition, adsorption, leaching, and uptake and metabolism in plants. The occurrence and relative importance of specific processes determine the soil life of a herbicide. Soil characteristics and properties and environmental factors influence the processes, often determine which one predominates, and may retard or inhibit one or more of the processes completely.

Soil characteristics and properties that directly and indirectly influence persistence are types of clay minerals, amounts of clay minerals, organic matter content, structure, texture, pH, temperature, moisture, and aeration. Several environmental variables influence persistence: rainfall and irrigation (intensity, frequency, and duration), temperature, solar radiation, and wind. The interrelations of the soil characteristics and properties, environmental factors, and the processes involved in the loss of herbicides in soils have been discussed in detail

(Sheets, et al., 1964; van der Zweep, 1960; and others).

Problems have been encountered much more frequently from persistence of herbicides in soils than from persistence in plants. Effects on beneficial soil microbes which have been, generally, minor and of short duration, is the subject of a discussion by Dr. W.W. Fletcher later in this Conference.

Solvents, surfactants, other herbicides, insecticides, bacterial inhibitors, and adsorbents alter persistence of herbicides in soils. Some herbicides, chlorpropham for example, that have desirable phytotoxic and selective properties, disappear from soil too rapidly under many conditions to maintain adequate weed control through a critical period. Scientists in at least one laboratory in the United States are presently seeking methods of extending the effective soil life of chlorpropham (Kaufman, 1965). Sodium and potassium azide effectively retarded microbial decomposition in soil perfusion columns; but in greenhouse pot tests, results were inconclusive. Other workers have shown that the persistence of EPTC in soil was influenced by the solvent used in application (Danielson, et al., 1961). Additional study of these and similar approaches seems desirable to develop suitable field procedures for extending persistence in soils for 2 to 4 weeks. The concept appears valid.

In modern agricultural practices, the same crop is often sprayed with more than one pesticide and sometimes with several. Herbicides may be applied to soils containing insecticide residues from control programmes of the same or preceding years. Some attention has been given to persistence of herbicides in the presence of other herbicides and other pesticides in soils. Kaufman (1966) found that dalapon applied to soil with amitrole persisted longer than dalapon applied alone, but dalapon had no effect on amitrole loss. In soil perfusion columns, 2,4-D was completely decomposed in 20 days as determined by chloride ion liberation (Kaufman, 1965). Under the same experimental conditions, chloride ion was not released from dicamba. If,however, dicamba was added to soil perfusion columns adapted to 2,4-D, chloride ion was released from dicamba. Recently, Corbin (1966) observed rapid decarboxylation of dicamba in a crude soil system without prior enrichment with 2,4-D. The explanation of these two divergent observations is presently unclear.

In recent studies by Kaufman and Kearney (1966), carbaryl, a methyl carbamate insecticide, inhibited microbial degradation of chlorpropham in soil perfusion columns and extended herbicidal activity in a silty clay loam soil under greenhouse conditions. A purified enzyme from soil microorganisms that catalyze the hydrolysis of chlorpropham was inhibited by several methyl carbamates. This result suggests a method for influencing or regulating the persistence of chlorpropham in soils. Such results also provoke thought that interactions may now be occurring unnoticed or may develop in the future when new herbicides and residues of other pesticides are present together in soils.

Certain adsorbents can be used to reduce residual activity of herbicides. Transplants of strawberry, cabbage, privet, and forsythia were protected from simazine residues in soils when the moist roots were dipped in activated charcoal before setting (Ahrens, 1965). However, charcoal does not reduce persistence of herbicides; it renders them inactive through adsorption. Adsorption may actually increase persistence by reducing availability of herbicides to soil microorganisms.

Injury to non-treated susceptible crops grown in rotation with sprayed crops constitutes a significant problem associated with persistence of herbicides in soils. A review on this subject, with special reference to problems encountered in the United States, was recently published in Residue Reviews (Sheets and Harris, 1965).

Phytotoxic effects from several herbicides have been observed in field and greenhouse tests 6 months or more after application. Reports of carry-over problems have been more frequent for atrazine than for any other herbicide; however, atrazine is the most widely used s-triazine. A recent survey in Canada documented the extent and degree of injury to sugar beets from persisting atrazine residues in Southwestern Ontario (Frank, 1966). In the United States injury to cereals, soybeans, sugar beet, and tobacco have been observed from atrazine carry-over. These hazards have been recognized, and label directions and recommendations advise against planting sensitive crops in fields the season after corn that has been sprayed with atrazine.

Carry-over problems or persistence of sufficient time to suggest a potential hazard have been observed with several other herbicides: dichlobenil, diphenamid, diuron, fenac, monuron, neburon, picloram, propazine, simazine, and 2,3,6-TBA. Problems in crop production have not been encountered with each of them. A few problems have been observed, and knowledge of the behaviour and persistence patterns has allowed use without much hazard or damage.

The season after application, concentrations of several herbicides in soils may be near the threshold level to sensitive plants. Research and experience have taught that careful attention to rates, methods, and uniformity of application permits use without damage to many rotational crops. However, sporadic residue problems develop from improper application. The solution is one of educating the farmers and dealers who advise farmers; weed specialists need to stress good equipment and proper application.

Disappearance curves vary for different herbicides, soils, and climates. A lag phase during which the herbicide concentration remains fairly constant often precedes rapid microbial decomposition. Once decomposition reaches a maximum rate, regardless of the importance of biodegradability in the loss of a herbicide from soil, disappearance appears to proceed, in most situations, at an ever decreasing rate. However, when carry-over from one season to the next occurs, the concentration is low; and accumulation in surface soils to any substantial degree does not occur. Phytotoxicity of herbicides provides a built-in warning of accumulation in soils. A major need for the efficient use of many of the herbicides that persist for several months in soils is data on response of rotational crops to low levels of residues. With such data rotational schemes with little or no hazard could be devised. The farmer is limited in his choice of rotational crops, but production can continue and advantage can be taken of the benefits derived from the herbicide.

At depths below the plough-layer, environmental conditions, soil properties and mineral nutrient levels may be much less favourable to development and growth of soil microorganisms than in surface soil. Although adequate data are not available to consider this problem, one may logically suggest that microbial decomposition of herbicides in subsoil environments is slower than in surface soils. Atrazine and simazine,usually considered to be relatively immobile in soils, have been detected at depths of 1.5 to 2 feet under some soil and climatic conditions (Burnside et al., 1963).

Water soluble herbicides that are not strongly adsorbed such as fenac and 2,3,6-TBA have been detected at soil depths of 2 to 5 feet (Phillips, 1959; Dowler et al., 1963). These herbicides are also not readily decomposed by soil microbes and persist for 1 to 3 years in some soils. Fenac, 2,3,6-TBA, and some related herbicides appear more likely to accumulate in subsoil than atrazine, diuron, diphenamid and others. However, acreage treated with fenac and 2,3,6-TBA is not great, and continuous use on the same soil is rare. On the other hand, atrazine is used extensively each year and is often applied to the same soil annually or once every two years. Burnside et al., (1963) expressed concern about possible accumulation of atrazine in subsoils of semi-arid Nebraska. More research is needed in both humid and arid climates to adequately appraise the situation.

CONTAMINATION OF NON-TARGET AREAS

Contamination of non-target areas with herbicides can arise from drift during spray operations, especially aerial applications, or by transport of the phytotoxic chemicals as solutes or suspensions in water or by vapour movement.

In practical research with herbicides, as with other research, need determines directions and objectives. Most critical needs, based on the judgment of men in decision-making positions, are attended first. In the development and testing of herbicides, therefore, residue aspects that are first investigated are concentrations in plant parts that become food for man or domestic animals and disappearance rates of herbicides from agricultural soils. The needs that provoke these studies are obvious.

We have been only mildly concerned about problems that present only minor hazards or are only of indirect interest to man. For example, we have not, at least not until very recently, been especially concerned with movement of herbicide residues from soils into streams, lakes, and ground water, with disposition rates in non-agricultural soils, or with effects of herbicides on biota of non-target environs. Application of heavy rates of herbicides for control of weeds in non-crop lands is a common practice and has been for many years. This is not necessarily a bad practice; but applications to large acreages or oft-repeated applications involving high rates on limited acreages could create environmental pollution problems. Also, inadvertent residues in fish, game, and other wild life could develop as an undesirable side effect.

Herbicide spraying has not created environmental pollution problems usually associated with DDT and certain other chlorinated hydrocarbon insecticides. Yet a few herbicides appear to approach or equal DDT in soil persistence. Perhaps we are fortunate. Certainly, little claim can be made to our ability to predict or foretell, but several things work in our favour. In contrast to insecticides which are selected and developed because they are toxic to animals, herbicides are plant toxicants; and the critical processes in plants that are interrupted or inhibited by herbicides may be different, or completely absent, in animals. Because herbicides are plant toxicants, persistent soil residues are usually always discovered before a product is marketed. Thus major problems are averted. Most herbicides are biologically degraded and disappear within 6 to 12 months after application; most are fixed or adsorbed to soil and are relatively insoluble in water. These properties collectively contribute to the low probability for wide distribution in the environment. There are perhaps some exceptions. Salts of fenac and 2,3,6-TBA are fairly soluble in water, are somewhat resistant to biological degradation, and are generally not strongly adsorbed to soil. Hence, movement may occur under certain conditions. Rates of application and use patterns, however, are such that only limited problems, at most, could develop.

Movement of 2,4-D and atrazine in wash-off water from field plots was investigated in the Southeastern United States (White, et al., 1965; Barnet, et al., 1966). The plots, with a 5 to 7 per cent slope, were cultivated and left fallow. The lowest rainfall intensity and duration represented a storm frequency of 1 year. Significant amounts of both herbicides were removed from the plots, but 2,4-D was lost in much greater quantities than atrazine. An ester formulation of 2,4-D was removed in much greater quantities than an amine salt form. Losses of herbicides were greatest during early stages of rain storms.

Although storms with the intensity and duration of those used in these studies occur on the average of once a year only, the results, nevertheless, indicate that surface run-off waters remove herbicides from sprayed fields and provide a means of transport of toxicant from the site of application to unsprayed streams and lakes.

Movement of atrazine from one field to another has created some minor problems for farmers. Tobacco, tomatoes, and peanuts located topographically below corn fields have been injured. Therefore, in some situations another cautionary statement may be necessary in our advice to farmers.

RESEARCH NEEDS AND CONCLUSIONS

Several specific problems needing further investigation have been suggested or alluded to during the discussion. Let us now summarize them and suggest a few more.

Industrial and, in some cases, public supported laboratories must continue residue and persistence studies in plants and toxicological investigations with new herbicides to insure human safety. Study of the parent compound alone is not enough; we must also know if hazardous metabolites are produced or persist in plants and in soils.

Mechanisms of degradation of herbicides on plant surfaces under the natural environment have not been investigated thoroughly. What roles do solar radiation, rainfall, and plant chemistry play in weathering of herbicide deposits on plants?

Herbicides are formulated and applied with several different diluents and carriers, and surfactants and other additives are almost universally employed in spray solutions to improve spreading and wetting of leaf surfaces and sequentially to increase penetration and plant response. We have virtually no data on the influence of diluents, carriers, and surfactants on persistence of herbicides in and on plants. Observations suggest that there are important effects in some cases. For example, when oil is the carrier, residues of atrazine on plants are apparently greater than when water is used. Expanded studies in this area are desirable.

Combinations of herbicides are now employed to control several weeds growing in association where a single chemical is not effective on all species. Also, some synergistic combinations are promising. What possible influence does one component of a combination have on the persistence of the other?

As new herbicides of the growth regulating type are developed, we should watch for persistence in seeds and possible detrimental effects on germination and growth and development of seedlings.

Additional crop response data are needed for several selective and highly effective herbicides that remain active in the soil for several months. Knowledge of crop tolerance would permit rotational sequences of crops and herbicides that would minimize hazards to rotational crops from carry-over residues. Another aspect of this problem involves the potential for inadvertent residues in non-treated crops in a rotation. Therefore, if a herbicide is known to persist from one season to the next, the question of undesirable residues in rotational crops could be raised. Although the likelihood for this occurrence is not great, we should have some research data to show residue levels or their absence in the raw agricultural commodities from tolerant non-treated, rotational crops that follow use of a persistent herbicide in a crop rotation.

Some evidence suggests that tolerant crops may play a role in disappearance of herbicides from soils (Sikka and Davis, 1966). The magnitude, importance, and utility of this pathway of loss needs to be determined.

Much is yet to be learned about the interactions between herbicides, soil properties, and climatological and meteorological factors. These investigations have relevance to practical investigations designed to improve weed control practices, to tests of persistence, decomposition, and movement in soils, and to studies on movement from agricultural soils into unsprayed sites.

Movement of herbicides into subsoil horizons and the potential for contamination of ground water need investigation.

Although precise regulation of herbicide persistence under field conditions is not presently a reasonable objective for Weed Scientists, the extension of residual activity of some highly effective and selective herbicides for a few weeks appears to be a feasible goal. Some success has been realized already by utilization of granular formulations and by employment of special application methods such as incorporation, injection, and layering of herbicides in soils. Another approach, that of delaying adaptation of microorganisms that decompose herbicides or temporarily inhibiting proliferation of microbes that are already adapted, remains promising although a few attempts in the last 10 years generally have been, from a practical point of view, unsuccessful.

We should also explore our information resources and maintain an alert and open mind for approaches to shorten the residual life of those highly effective and selective herbicides that possess some hazardous potential from persistence from one season to the next.

As acreages sprayed with herbicides increase, effects on plants and animals in adjacent, unsprayed sites will need study. Pathways and processes of movement in the environment are already important for several herbicides: 2,4-D, atrazine, trifluralin, and others. We must engage the cooperative efforts of scientists in Ecology, Zoology, Botany, and Chemistry to study effectively the many ramifications of movement and distribution in the environment for expertise in these fields is essential to understanding the total problem.

Persistence of herbicides is both good and bad. Persistence is good when weed control is maintained throughout the crop season and in soil sterilization projects when growth is retarded for 2 years; it is bad when rotational crops are injured and when residues in plants prevent grazing treated areas or utilizing other agricultural products. Our job of learning has a two-fold purpose: to utilize the good aspects of persistence and to eliminate the bad aspects from weed control practices.

References

AHRENS, J.F. (1965) Improving herbicide selectivity in horticultural crops with activated carbon. Proc. NEast Weed Control Conf., 19, 366-367.

BARNETT, A.P., HAUSER, E.W., WHITE, A.W. and HOLLADAY, J.H. (1966) Loss of 2,4-D in washoff from cultivated fallow land. Weeds (in press).

BURNSIDE, O.C., FENSTER, C.R. and WICKS, G.A. (1963) Dissipation and leaching of monuron, simazine, and atrazine in Nebraska soils. Weeds 11, 209-213.

CORBIN, F.T. (1966) North Carolina State University, Raleigh, N.C., personal communication.

DANIELSON, L.L., GENTNER, W.A. and JANSEN, L.L. (1961) Persistence of soil-incorporated EPTC and other carbamates. Weeds 9, 463-476.

DOWLER, C.C., SAND, P.F. and ROBINSON, E.L. (1963) The effect of soil type on preplanting soil-incorporated herbicides for witchweed control. Weeds 11, 276-279.

FLETCHER, W.W. (1960) The effect of herbicides on soil micro-organisms in "Herbicides and the Soil", ed. E.K. Woodford and G.R. Sagar, Blackwell Scientific Publications, Oxford, England. pp. 20-62.

FOY, C.L. (1961) Adsorption, distribution and metabolism of 2,2-dichloropropionic acid in relation to phytotoxicity. II. Distribution and metabolic fate on dalapon in plants. Plant Physiol. 36, 698-709.

FRANK, R. (1966) Atrazine carry-over in production of sugar beets in Southwestern Ontario. Weeds 14, 82-85.

HOLLY, K. (1962) Herbicides acting through the soil - a review. Proc. Sixth British Weed Control Conf. pp. 467-477.

KAUFMAN, D.D. (1965) Agricultural Research Service, U.S. Department of Agriculture, Beltsville, Maryland. Unpublished results.

KAUFMAN, D.D. and KEARNEY, P.C. (1966) Microbial degradation of carbamate pesticide combinations. Research paper presented at the 1966 (Sept.) meeting of the American Chemical Society, New York, N.Y.

KLINGMAN, D.L., GORDON, C.H., YIP, G. and BURCHFIELD, H.P. (1966) Residues in the forage and in milk from cows grazing forage treated with esters of 2,4-D. Weeds 14, 164-167.

McILRATH, W.J., ERGLE, D.R. and DUNLAP, A.A. (1951) Persistence of 2,4-D stimulus in cotton plants with reference to its transmission to the seed. Bot. Gaz. 112, 511-518.

PHILLIPS, W.M. (1959) Residual herbicidal activity of some chloro-substituted benzoic acids in soils. Weeds 7, 284-294.

SCOTT, R.A., Jr. (1961) Mechanisms and reversal of gametocide response in cotton. Plant Physiol. 36, 529-538.

SHEETS, T.J. and HARRIS, C.I. (1965) Herbicide residues in soils and their phytotoxicities to crops grown in rotations. Residue Reviews 11, 119-140.

SHEETS, T.J., HARRIS, C.I., KAUFMAN, D.D. and KEARNEY, P.C. (1964) Fate of herbicides in soils. Proc. NEast Weed Control Conf. 18, 21-31.

SIKKA, H.C. and DAVIS, D.E. (1966) Dissipation of atrazine from soil by corn, sorghum, and Johnsongrass. Weeds 14, 289-293.

SWANSON, C.R. (1965) Metabolic fate of herbicides in plants. ARS 34-66, U.S. Department of Agriculture.

VAN DER ZWEEP, W. (1960) The persistence of some important herbicides in soil in "Herbicides and the Soil", ed. E.K. Woodford and G.R. Sagar, Blackwell Scientific Publications, Oxford, England. pp. 79-88.

WAIN, R.L. (1955) A new approach to selective weed control. Ann. Appl. Biol. 42, 151-157

WHITE, A.L., Jr., BARNETT, A.P., WRIGHT, B.G., TYSON, B.L. and others (1965) Atrazine losses from soils by runoff and erosion. Southern Piedmont Conservation Research Center, U.S. Department of Agriculture, Watkinsville, Georgia. Unpublished data.

SESSION IX A - PERSISTENCE OF HERBICIDES IN PLANTS AND SOIL

Discussion

Dr. R.J. Hance enquired if Dr. Sheets knew of any evidence for the non-biological decomposition in soil of any other herbicides besides the azido-triazines whose non-biological reduction in the soil had been referred to in a paper earlier in the Conference. Dr. T.J. Sheets replied that data published several years ago indicated that sesone could be hydrolysed non-biologically in the soil. There is also a suspicion that there may be slight non-biological hydrolyses of certain substituted ureas and chloro-s-triazines in the soil. Dr. J.M. Osgerby commented that the persistence of the phosphorylated triazine WL 8535 mentioned in the paper by Hocombe et al. has been studied at Shell Research Ltd. Decomposition was shown conclusively to be by chemical hydrolysis and soil microorganisms play no part in the process.

Dr. W. van der Zweep asked for comment on the rate of breakdown of herbicides in both soil and water in aquatic environments as compared with the situation after terrestrial applications. Dr. T.J. Sheets said that a paper had been published on the decomposition of substituted ureas in aquatic environments. Some data had been collected in the U.S.A. on the breakdown of 2,4-D in water and it is more persistent there than in soil.

Mr. P. Bracey reported agreement between the experiments reported by Hocombe et al., in which herbicides lasted longer in soils in the laboratory and greenhouse, and commercial applications of chlorpropham under glass. Lower dosage rates have to be used under glass, although more rapid breakdown would be expected under the conditions of higher temperatures, moisture and high organic soil content. Dr. W. van der Zweep verified that in Holland chlorpropham applications under glass can be made at reduced rates as compared with field applications and have not then shown any soil residue problem. Mr. S.D. Hocombe commented that the long persistence periods in the greenhouse experiments were surprising in view of the attempts to keep the soil both warm and moist. For herbicide evaluation this abnormally long persistence is a disadvantage because the answers are required as quickly as possible. Attempts are in progress to accelerate the breakdown of herbicides in soil in the greenhouse and laboratory by the addition of microbiological nutrients. There is evidence from several laboratories that this can result in a gradual increase in rate of disappearance of herbicides from soils. Dr. T.J. Sheets suggested that water relations in the soil may be critical through alterations to the aerobic conditions therein. Dr. R.H. Schieferstein added that storage of soils in an air dried state prior to setting up experiments can greatly effect the outcome of persistence studies, compared to use of fresh field soils or soils stored in a biologically viable condition. This might partially explain the relatively long persistence in the experiments under discussion. Mr. Bracey contributed another example of a possible change in breakdown rate. Fenuron used in plums may cause defoliation but this is avoided by the use of old chopped hay as a mulch which may be encouraging rapid breakdown.

Dr. B.J. Heywood enquired whether there are any known cases of acceleration of breakdown of a pesticide through the addition of another pesticide in plants or soil, to which Dr. T.J. Sheets gave a negative answer. A second question from Dr. Heywood asked about the mechanism involved in the reduction of the rate of breakdown of herbicides in the presence of other pesticides. Dr. Sheets replied that in the case of carbaryl there is clear evidence of inhibition of microbial enzymes.

Dr. E. Grossbard asked Dr. Sheets if he had any evidence on the effect of soil storage conditions involving drying or freezing on the activity of microorganisms and hence on herbicide persistence in experiments in which the soil is used subsequently. Dr. T.J. Sheets replied that there was a need for further study but that his former colleague Dr. Kaufman did not regard this as a problem as long as some microorganisms survived. However, some specific groups of organisms might be more sensitive to drying or freezing. Dr. M.H.B. Hayes observed that the work of Birch in East Africa, which has been well substantiated, had shown that the rate of decomposition of soil organic matter in soils which had been air-dried or even oven-dried and then rewetted was greatly accelerated. This evidence is obviously contrary to experience with herbicides, where it would appear that air drying of soils prior to herbicide addition delays the rate of decomposition of the herbicide. Prof. E.W. Russell added that the principal reason for the Birch effect is that drying kills many microorganisms and the flush of activity is due to the decomposition of these dead organisms. It could be expected that drying a soil might kill off the organisms adapted to decomposing the herbicide and hence increase the persistence of herbicides reapplied after drying. Dr. E. Grossbard stated that she had done a great deal of work on the effect of freezing of soil at $-15^{\circ}C$. Sometimes there was an increase of microbial numbers and this finding is supported by work by Jenkinson and others who showed a flush in CO_2 production after storage of soil at $-15^{\circ}C$. This does not mean that microorganisms grew vigorously at sub freezing temperatures. The effect is probably a physico-chemical on the soil colloids, releasing large numbers of microbial propagules as compared with soil stored at normal temperatures. On the other hand under certain conditions microbial numbers fell as one might anticipate, thus providing dead microbial bodies as an additional substrate on which the survivors could multiply when soil is thawed. Hence use of soil which has been stored in a frozen state for experiments involving a period of incubation following storage may give a different and perhaps misleading picture because of resultant changes in the composition of the soil microflora.

Mr. J.M. Way pointed out that delayed expression of damage in plants to which auxin-type compounds had been applied, or in the next generation, has often been taken as evidence for the long term persistence of the active compound. However, many of the effects could be explained on the basis of morphogenetic disturbances occurring at the time of application of the compound or soon after. Mr. J.J. North enquired whether residues in plant tissue are likely to be more important in plants perennating by vegetative means than in plants reproducing by seed. Dalapon used in the autumn in potatoes for the control of *Phragmites*, seriously affected the growth of seed tubers taken from the crop. Normal pigmentation of sprout growth was affected and a high percentage of "wilding" type plants produced. Dr.T.J. Sheets replied that research by Foy in California indicated that dalapon persisted for extended times in the vegetative tissues of cotton plants. It is known that dalapon is rapidly degraded in soils where conditions favour growth and proliferation of microorganisms. Therefore it can be presumed that any carry-over effects of dalapon are probably attributable to persistence in plant tissues with subsequent possibilities for reincorporation of the herbicide in the soil.

Dr. E.C.S. Little asked whether Mr. Kirkland could suggest a technique whereby MCPA might be safely applied in plantation crops so as to kill the weeds without risk to the crop. Perhaps rapid decomposition could be ensured by addition of microorganisms with the spray. Mr. K. Kirkland replied that this was possible but he doubted the practical value as MCPA at 3 lb/ac does not normally persist in the soil after 3 weeks.