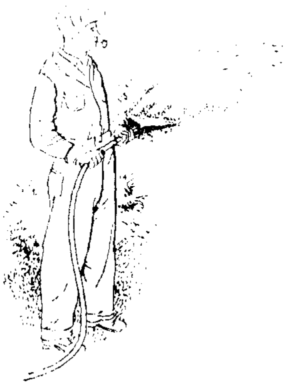

In areas of rapid progress, symposia are especially valuable for reviewing the field, presenting current research results, and looking ahead. This symposium, organized by the Pesticides Subdivision of the Division of Agricultural and Food Chemistry, American Chemical Society, is presented with that aim

HERBICIDES

Chemical Weed Control

C. E. MINARIK, Chemical Corps Biological Laboratories, Camp Detrick, Frederick, Md., and
A. G. NORMAN, Department of Botany, University of Michigan, Ann Arbor, Mich.

Chemical weed control in a diversity of forms has developed greatly during the past few years, in part as a result of the impetus provided by the rapid acceptance of 2,4-D. Further technological advances may well depend on an extension of fundamental research on growth processes in plants. Present uses are essentially empirical, though often dramatically effective. Much can be done to improve retention of herbicidal sprays by plants, to aid entry into particular species, and to understand their subsequent transport and action in the plant. Present herbicides have been selected for high potency and broad toxicity. Compounds of greater specificity, even if of somewhat lower activity, might be preferred in some situations. When selective weed control is practiced it may be possible to incorporate a lower level of responsiveness to the herbicide, in order to make the control of the dominant weed species more effective. For preemergence applications to prevent germination of weed seeds or establishment of weed seedlings, compounds only slowly utilized by the soil population may be required. All these are problems for the chemist in cooperation with workers technically trained in the many other skills which are involved in weed control practices.

HERBICIDE SYMPOSIUM

HERBICIDES are used in a diversity of ways to control undesired vegetation. The goal may be prevention, suppresion, or eradication. The herbicide may be used in a selective manner to minimize competition between weeds and crop, or so to change the ecological balance that tall herbaceous or woody species are eliminated without injury to a grassy cover. Or it may be used nonselectively to bring about rapid kill of some particular weed, without concern as to effects on other plants adjacent. The requirements of the chemicals to be used for these many purposes, and the precautions to be adopted in their distribution are varied.

A whole new field of technology has developed during the past few years as a result of the spectacular accomplishments of the recently introduced chemical herbicides. It is a field which involves the association and cooperation of workers with very different trainings and experience. It is hardly true to say that weed control was a borderline field. More correctly it might be likened to a neglected or relatively unexplored area which has now been penetrated by parties of chemists, physiologists, botanists, microbiologists, engineers, agronomists, and horticulturists moving in from different starting points. They have found their joint interests, and in meeting have gained strength.

This is not to imply that the use of chemicals for eradicating weeds is of itself really a new development; even selective usage in cereals has long been known. It was primarily the discovery and introduction of 2,4-D that gave great impetus to research and development in weed control from the synthesis and screening of candidate organic compounds to the large scale production and practical field use of a number of new herbicides. The vital and outstanding differences which these in general exhibit in comparison with those employed earlier are high potency and the ability to be transported within plants to a remote organ there to affect some growth process. Many could properly be classified as growth inhibitors

More to Come

April 15 Issue

Chemical Methods of Brush Control
R. H. Beatty, American Chemical Paint Co.

Preemergence Methods of Weed Control
D. E. Wolf, E. I. du Pont de Nemours & Co., Inc.

Survey of Contact Herbicides
L. M. Stahler, Bureau of Plant Industry, USDA

April 29 Issue

Mechanisms of Action of 2,4-D
R. L. Weintraub, Chemical Corps Biological Laboratories

Survey of Formulation of Herbicides
J. A. Kelly, The Dow Chemical Co.

Critical Aspects of Herbicide Residues in Soil
R. J. Aldrich, New Jersey Agricultural Experiment Station

and as such are peculiar in causing this inhibitory response in higher plants without apparent effect at comparable concentrations on animals or microorganisms.

The multimillion dollar herbicide industry is in great measure based on the efforts of plant physiologists and biochemists who were working on the fundamental problems of plant growth as affected by natural plant hormones and organic chemicals possessing similar growth-modifying properties. The dividends from basic research are often great, as in this case. That the developments may lie in an unexpected direction should be borne in mind by those responsible for the direction of further research in the herbicide field. Much that is being done is of the nature of routine empirical testing, which might be described as the gambler's approach. If technological advances are to continue, a certain percentage of the effort should go into long-term fundamental research from which other new and different developments may arise. The chemical industry cannot afford to leave this to the uncoordinated efforts of universities and governmental agencies, most of which also are too empirically minded.

Contact of Herbicide with Plant

It is first necessary to bring the herbicide in contact with the plant. The problems of distribution have been troublesome, and considerable improvement may yet be expected. This is particularly the field of the engineer who needs, however, considerable guidance from the agronomist or horticulturist. It is an outstanding characteristic of most of the newer herbicides that they can be applied effectively as sprays at rather low volume rates. Too great a degree of atomization is undesirable, in that drift of fine droplets may take place with injury to adjacent vegetation. To avoid this the nozzles are now usually operated at a lower liquid pressure than was formerly the case, and considerable advances have been made in nozzle design to secure uniformity of coverage.

A somewhat neglected topic has been the determination of the amount of herbicide intercepted by and actually retained on the surface of the vegetation. The growth habit of the plant may be important in this respect. The total leaf surface and the angle at which the leaves are borne are of significance, but of much greater consequence is the nature of the cuticular surface. With many species only a small fraction of the spray droplets that are intercepted by the plants actually are retained. It has been shown by high speed motion pictures that aqueous droplets frequently bounce like balls or coalesce and run down the veinal channels and drop off at the base of the leaf, particularly if there is a heavy waxy layer or bloom. Oil solutions or emulsions may behave very differently, and often appear to be far more inhibitory than aqueous sprays. There is a much higher level of retention. Frequently spreading and immediate tissue entry may be observed. The behavior of aqueous formulations can be improved with respect to some species by introduction of wetting agents or surface active agents. These may enhance retention and cause the droplets to spread on the leaf surface.

Much remains for the formulation chemist to investigate, in the direction of specific adjuvants and formulations designed to be of maximum effectiveness on a particular weed or group of weeds. This will call for parallel quantitative studies of interception and retention on species and combinations of interest. Some of the observed cases of differential action may in a sense be fortuitous, based not on degrees of responsiveness to the herbicide, but instead on behavior following droplet impingement, so that in fact the retained dosages are of very different orders of magnitude.

Entry of Herbicide into Tissues

The next group of problems belong to the physiologist and center round the actual entry of the herbicide into the tissues of the plant. Many organic compounds, varying greatly in molecular size, are able to enter the plant readily and quickly through the leaf surfaces. Whether the stomata are essential or are involved at all seems controversial at present. There is some evidence that nonpolar compounds are able to penetrate more readily than polar compounds. Dust preparations of 2,4-D have been shown to be effective, though somewhat undesirable because of drift hazard.

The problems of absorption are dealt with by Crafts (*1*). There is a paucity of information available on root entry. Some of the newer herbicides, such as 3-(*p*-chlorophenyl) 1,1-dimethylurea (CMU), and isopropyl *N*-phenylcarbamate (IPC), may be particularly effective when applied to the soil to be taken up by the roots of responsive species. It cannot be assumed that roots and leaves are identical in matters of entry. Herbicides are being selected primarily on the basis of tests involving top application. Perhaps the time is ripe for a search for active compounds that rapidly penetrate root tissues and the adsorption of which is not affected by continued presentation at a low concentration, a circumstance that may well be expected in the soil. Indeed, screening techniques with these objectives are now beginning to be used in a number of laboratories. There is some indication that the root absorbs polar more readily than nonpolar compounds in contrast to the leaf. Root presentation through soil application also involves the microbiologist and soil scientist. The former must interest himself in the stability of the compound in the presence of the soil population and in its effects on soil microbial functions. The latter may be concerned with possible interactions with the clay minerals or organic colloids, and its mobility if exposed to leaching rain.

Transport of Herbicide within Plant

Once in the plant, the transport of the herbicide from the point of entry to those organs or tissues in which the desired responses take place is of great importance. This topic has received a good deal of attention from physiologists without having reached complete clarification. The use of isotopically tagged compounds is likely to be of considerable aid in this type of study. For rapid translocation the herbicide must be soluble in the plant sap and capable of moving in the phloem. It is generally agreed that 2,4-D, when applied to the foliage, is transported by mass flow of photosynthate to those organs or tissues that are actively growing, without chemical combination during the period of transport. The 2,4-D has been recovered from portions of the plant remote from the point of application (*3, 4*), thus substantiating the view that the herbicide itself and not a stimulus induced by it is translocated to the responsive region.

Transport in the xylem takes place when herbicides are absorbed by the roots, and subsequent distribution through the plant is fairly uniform, being influenced mostly by the rate of transpiration or water loss from leaf and stem surfaces. Cooperation between formulation chemist and physiologist may succeed in affecting the transportability of the herbicide, as well as its entry, by the presence of adjuvants or coagents.

Mode of Action

A diversity of chemical structures is represented in the newer herbicidal chemicals and it is inconceivable that compounds as different as 2,4-D, maleic hydrazide, isopropyl *N*-phenylcarbamate, and trichloroacetate, for example, could have a common mode of action. The nature of the composite response that results in lethality in each case may well be entirely different. Though not in any way vital in the empirical search for active compounds with herbicidal properties, knowledge of the processes involved might well provide a basis for the synthesis of more active compounds or the more effective use of those now known. There is indeed some possibility that this will not be accomplished until much more information is available about the endogenous growth hormones and their role in the normal physiology of plants. Certainly growth regulators typified by 2,4-D appear able in some responses to function as substitutes for the native hormones, or at least to act by participation in the same mechanism by which the native hormone operates.

The newer herbicides are, in general, compounds both of high potency and broad activity or toxicity. They have been selected by tests that would bring out chemicals with just these characteristics. As general-purpose herbicides for eradication or suppression, they are excellent, but they are somewhat less satisfactory where selectivity is required. The field men have devoted great efforts to the investigation of the precise conditions of employment that permit those potent compounds to be used selectively or without injury to a crop or to adjacent vegetation. Frequently the conditions are critical and the margin between effective dosage and a level at which deleterious effects develop may be narrow. It says much for the ingenuity of these agronomists and horticulturists that such successful results have been achieved. From the point of view of the chemical industry it is good in that volume production of a relatively few compounds is achieved. However, this situation may well change.

It is becoming rapidly apparent that plant species differ greatly in responsiveness and that the ranking of candidate compounds in order of potency on one plant may not hold on another. Moreover, there may have been too great a stress on extreme potency because in field application labor costs usually far exceed the cost of the herbicide. Developments in the field of brush control well exemplify the remarkable specificities that are encountered. Thus 2,4-D, though highly inhibitory to many herbaceous plants, both annual and perennial, did not prove effective in killing some of the woody species that are troublesome along utility right of way, roadsides, and railroad banks. 2,4,5-T, on the other hand, proved inhibitory or toxic to many of these and the combination of 2,4-D and 2,4,5-T, usually in the ester form, is finding wide use. 2,4,5-T is also far more effective than 2,4-D in control of wild blackberry and raspberry. Chemical control of brush is rapidly replacing mechanical methods because, although the initial cost may be somewhat higher, maintenance in subsequent years is relatively simple.

Many other examples of specificity in response could be cited, yet these have turned up almost incidentally and not as a result of deliberate search. Perhaps the first was the finding that the Irish potato is almost unaffected by concentrations of 2,4-D that are lethal on many other broad-leaved species; 2,4,5-T, on the other hand, causes growth inhibition and induces many morphological aberrations (*2*). This difference does not hold for other solanaceous plants. Many, such as the tomato, are most sensitive to 2,4-D, but others, such as the horse nettle, resemble the potato in being far more responsive to 2,4,5-T.

Looking ahead therefore, an intensive search for and exploitation of specificities in responsiveness may be expected, that will call for the partnership of chemists and field men. In some cases differential or selective properties may also be required; compounds to which the crop plant will be unresponsive and the dominant weed highly susceptible will be sought. The total annual requirement for such chemicals may be only a few tons, but their usefulness will be such that the chemical industry will find it profitable to supply them.

Varietal differences in crop responsiveness to some herbicides are now well recognized. These are founded in genetic differences and can be studied on a genetic basis. The range is usually not too broad—the varieties seem to differ mainly in the threshold concentrations that cause injury. The differences can be overcome by moderate changes in concentration. No species have yet been found with varieties ranging from wholly susceptible to wholly unresponsive, as in the case with disease reaction. This possibility cannot, however, be excluded. There is an important implication in these findings. The plant breeder may well be able to incorporate in the crop a lower level of responsiveness to a particular herbicide, in order to broaden the gap between the crop and the dominant weed competitors.

Special Problems

The search for compounds having specific effectiveness in inhibiting the germination of weed seeds and the development of weed seedlings may likewise become an important part of the work of those concerned with pre-emergence weed control. This also is a field that must involve the microbiologist to a much greater extent than has heretofore been the case. Pre-emergence applications have been found to be somewhat undependable, or, expressing it differently, the effectiveness of such applications seems to be considerably affected by climatic conditions which in part are operative through influence on microbial activities in the soil.

There is also the matter of special formulations for soil application, a topic which as yet has not received much attention from the chemist. The herbicide is likely to be most effective if it remains in the superficial layers. Too ready mobility may be undesirable, though there must be sufficient solubility to produce the physiological response in the seedling. This also brings up the subject of residual effects. Persistence or disappearance of a herbicide from soil depends on the activity of the soil population. The incorporation into the soil of chemicals with structures that are frequently completely foreign to the normal economy presents some complex biochemical and microecological problems. In practice, second or later applications of a particular compound may give less effective weed control than the initial treatment.

Additional topics requiring a chemical approach or of interest to the chemist could be cited. However, we must recognize the vigor and initiative that have been displayed by the agricultural chemical industry in the development of new herbicides and the effectiveness of the cooperation between technically trained men in rather unrelated fields in waging war on weeds.

Literature Cited

(1) Crafts, A. S., J. Agr. Food Chem., **1**, 51 (1953).
(2) Ennis, W. B., Jr., Swanson, C. P., Allard, R. W., and Boyd, F. T., *Bot. Gaz.*, **107**, 568–74 (1946).
(3) Holley, R. W., Boyle, F. P., and Hand, D. B., *Arch. Biochem.*, **27**, 143–51 (1950).
(4) Weintraub, R. L., Brown, J. W., and Yeatman, J. N., *Science*, **111**, 493–5 (1950).

Received for review November 7, 1952. Accepted January 23, 1953. Presented before the Division of Agricultural and Food Chemistry, Symposium on the Formulation and Action of Herbicides, at the 122nd Meeting of the American Chemical Society, *Atlantic City, N. J.*