# Western Weed Control Conference

# PROCEEDINGS
# 1962

- MARCH 20-22, 1962
- NINETEENTH CONFERENCE
- LAS VEGAS, NEVADA

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This Proceedings is a record of the papers and reports presented at the 1962 Conference in Las Vegas, Nevada on March 20–22. Copies are available from the Business Manager, Edward J. Bowles, 3239 Mayfair Blvd., Fresno 3, California, at $2.00 per copy. The Research Progress Report, including back copies, is also available at the same address at $2.00 per copy.

## PROGRAM AND TABLE OF CONTENTS

### MONDAY, MARCH 19, 1962



### TUESDAY, MARCH 20, 1962

### GENERAL SESSION
Chairman – Lowell S. Jordan



### RESEARCH SECTION
Chairman – V. H. Freed

## EDUCATION and REGULATORY SECTION
Chairman – Louis A, Jensen



## WEDNESDAY, MARCH 21, 1962

## GENERAL SESSION
Chairman – J. Wayne Whitworth

W. R. FURTICK, PRESIDENTIAL ADDRESS
1962
*Western Weed Control Conference*
*Las Vegas, Nevada*

The Western Weed Control Conference has the distinction of being the first weed conference established in the United States. It set the pattern for the later development of four regional conferences, the Northeastern, Northcentral, Southern and Western. The Weed Society of America which is the present national professional society of those working in weed control is an outgrowth of these regional professional conferences.

We are highly indebted to the early efforts of Professors Robbins of the University of California, and Hyslop of Oregon State University and others for their leadership in the establishment of the first Western Weed Control Conference. This conference was called in an effort to promote interest and focus attention on the control of weeds which are such a serious problem in western agriculture.

The conference was established to bring together interested parties dealing in regulatory aspects of weed control with those working on weed control through research, extension, teaching and industry. Since the time of the first pre-World War II weed control conference, there have been many changes in the science and technology of weed control. Along with these astounding advances has been some changes in attitudes and working relationships which may be equally important.

The early days of the weed control field were marked by very limited research endeavors, usually by-products of research projects other than those dealing exclusively with weed control. Much of the work was centered in the departments of agronomy and relied heavily on investigating cultural practices such as crop rotation, competitive cropping, fertility practices and tillage procedures as a means of minimizing the weed competition with various crops.

There was very little extension work dealing strictly with weed control and that also was largely a by-product of extension teaching related to specific crop production. The extension worker dealing exclusively with weed control was unknown. Much of the weed control efforts were in the hands of regulatory agencies in which the introduction and spread of weeds was being fought through quarantines, inspections, seed regulations and similar measures.

The post-World War II introduction of herbicides brought an aura of glamour to the weed control field. The black magic aspects of the new "miracle weed killers" captured the public's imagination and led to rapid expansion in research endeavors of universities and the Agricultural Research Service of the U. S. Department of Agriculture. A heavy investment was made by the American chemical industry in developmental research programs to discover new and more efficient weed killers. The long list of registered herbicides and the even longer and rapidly lengthening list of experimental compounds attests to their success.

The early research by professors in the universities and governmental research workers in A.R.S. was largely of the so-called squirt and measure type. New chemicals were scattered promiscuously on large numbers of crops and weeds in a haphazard manner and the results tabulated. Many irregularities in performance were noted and frequently the research workers in the early developmental period of weed control were not trained in the basic sciences necessary to understand the often erratic action of these new agricultural tools. Frequently the term unexplainable was heard used in relation to the failures or irregularities. This early period has rapidly given way to weed control as a science. Many of the factors involved in the performance of weed killers are now well known. These factors were not even considered only ten years ago. Such things as the physical chemistry of the herbicide as it relates to absorption, translocation and detoxification by plants or to volatilization, soil adsorption, photo decomposition, microbiol break-down, chemical degradation and leaching in the soil all of which are basic considerations today.

Much attention has been focused in recent years on endeavors to explain the method of toxicity or mode of herbicide action from a physiological standpoint for the various herbicides. Although some progress has been made in this direction, we still have made an amazingly small dent after fifteen years of trying to prove how 2,4-D kills a plant.

The changes in research from early efforts of the agronomist to find out whether a chemical killed a given weed without hurting the crop to an increasing emphasis by academic circles on the so-called basic research, which concentrates on explaining the actions of herbicides, has been accompanied by other more subtle changes in the relationships of those interested in weed control. In the early developmental period of chemical weed control there was often marked suspicion between the academic research worker and his colleagues in the chemical industry. This early suspicion was perhaps often justified. Although we may label some of the early researches in chemical weed control as naive compared to present standards, the early endeavors of the chemical industry also might be considered somewhat haphazard and in many cases unethical. Nearly all of the early day fly-by-night peddlers have disappeared. The highly competitive nature of the ag-chemicals business, and government regulations, such as the Miller Bill, which have created an enormous cost in the development of weed killers has insured the development of an ethical, conscientious chemical industry serving agriculture. With these changes in the chemical industry have come the breaking down of barriers between the academic researchers and industry research, development and sales staffs. With few exceptions, the academic research workers door is wide open to the chemical industry colleagues. They are part of the same team necessary to each other in order to get the job done. The same teamwork has developed with the extension and sales staffs of the universities and the chemical industry. Closer working relationships have also been developed with the regulatory agencies since we are dependent on each other for successful functioning. The government regulations on the use of pesticides have created whole new areas of regulatory work related to weed control. In order to get the information necessary to register and recommend chemicals, it requires the teamwork of all, or the expense would be unbearable.

Although these relationships have been developing, I am concerned about the future trends which are now evident in this rapidly growing field. There are a number of trends and differences of opinion on how the responsibilities should be divided between the segments dealing with weed control. Let's examine some of the trends and contemplate where they may lead. Looking at the problems of the chemical industry we see the rapid realization by management that of the pesticides, herbicides offer one of the brightest futures. From the total usage potential herbicides far outdistance any of the rival pesticides. Unlike insect and disease problems, weeds occur on most of the crop acreage as an annual problem that is as dependable as day and night. They are not plagued by the the exasperating here this year, gone next year problems of the insecticide and fungicide industries. They recognize the ultimate herbicide potential is the major portion of the total crop acreage. The only comparable potential in the ag-chemical industry is fertilizer. This realization has been accompanied by the further understanding of the much greater complexity of the problems in launching a herbicide compared to most other pesticides. In herbicides you're dealing with differential toxicity to crop plants. Mistakes can be extremely costly. In addition, you are involved with the total physiology of the plant and the inter relationships to its environment which affects the plant and the pesticide. This on top of the high costs necessitated by safety measures required by law, such as the toxicology of the chemical and the residue information demanded in ever increasing detail such as determining the metabolism of a herbicide has compounded the costliness of herbicide development. The close association of herbicide action to soil, climate, plant environment relationships has made it mandatory that much of the developmental research be conducted in widely varying geographic production regions. This has made it necessary for the chemical industry to depend heavily on cooperative relationships with governmental and academic research staffs in order to make the launching of a new herbicide feasible.

Some of the trends in the universities and the Agricultural Research Service are creating some concern among the chemical industry as to whether this cooperative relationship will continue to function and if it does not, what alternatives are left. This trend is the rapid shift of emphasis in all academic research towards the so-called basic or fundamental type research. This research is a very necessary ingredient to the development of the fundamental knowledge which will be necessary to make many of the advances in all areas of biological research. However, in order to get the total job done, which is necessary to solve the problems of American agriculture, developmental research cannot be neglected. Someone is going to have to do it. The question is, who? I think it highly desirable from the standpoint of the American farmer and from the chemical industry that this task be done by the state university. From the farmer's standpoint this gives him an unbiased source of information and from the standpoint of the chemical industry it is almost impossible to think of the costs involved if developmental research had to be done by them at each local level. There also is the problem of getting the confidence of the farmers where all of the research is entirely industry motivated.

I am sure there is real concern by the chemical industry as to whether there will be adequate developmental research conducted by the universities in the future to fulfill the need. From the universities' standpoint, I feel there is presently considerable difference of opinion as to who should do the developmental research or whether it should be done by the universities. Some feel that this is an integral function of the weed control research unit in the university. Others feel this is a matter that should be delegated to extension as part of the extension program. Some university people feel developmental research is something that should be left to the chemical industry and they should not trouble themselves since it does not lend itself to highly scientific publication and professional prestige which is necessary to get the salary advancement and professional stature desired.

I feel that it is going to be imperative that we face this problem squarely and keep our employers, the American farmer, in mind when we do this. Whether the job is a team-work approach between research, extension and industry or whether it is worked out as a function of research servicing all levels from studying the physical chemistry and the physiological relationships to the on-farm demonstrations necessary for adoption is immaterial. It is my plea in closing that we all endeavor to work as a team whether we be be research workers in universities, government or industry, extension personnel, salesmen or representing a regulatory agency. We must work together to solve the problem most effectively and efficiently in the interest of American agriculture. As this conference program develops, I hope we will get most insight into the problems facing modern weed control and some insights on how these solutions will be met.

# GOVERNMENT REGISTRATION REQUIREMENTS FOR PESTICIDES

J. RAY BARRON, JR.
AMERICAN CYANAMID CO.

As you know, there has been a great deal of publicity concerning the use of pesticides, as well as antibiotics and drugs, in the production of our wholesome and abundant food supply. Chemicals in foods have suddenly assumed great importance in the public mind. This has been accomplished through publicity channels of which some has been good but a great deal of the publicity has been alarming. We first read and heard about the alarms issued on cranberries through the use of aminotriazole; secondly, diethylstilbestrol in chickens; third, the Kefauver hearings on drugs in general; and finally, milk contamination certain uses of insecticides and in the treatment of dairy cattle for control of mastitis. There should be no alarm, for industry is aware of the need for a wholesome and abundant food supply, and there are federal and state laws to control nearly every chemical now going into the production, storage, packaging, preservation and transportation of foods.

Today, I would like to first discuss the fundamentals of the Federal Laws in which we deal in registering our pesticide chemicals. Secondly, I would like to show the interrelationship of the Miller Pesticides Amendment to the Food, Drug and Cosmetic Act and the Federal Insecticide, Fungicide, and Rodenticide Act; and third, discuss how the Food Additives Amendment affects the registration of pesticide chemicals.

Since the subject of pesticide registrations can become involved, I have prepared slides to aid in following the discussion more easily. In reviewing Federal Laws we must deal with laws pertaining to both FDA and USDA requirements.

## REVIEW OF FEDERAL LAWS

### Food and Drug Administration

Food and Drug Act of 1906

Food, Drug and Cosmetic Act of 1938

- Miller Pesticide Amendment – 1954
- Food Additives Amendment – 1958

Under the FDA, the first law was enacted in 1906, and it was known as the Food and Drug Act. The Act of 1906 was, in general, to halt the exposure of the general public to filth, rotten foods and misleading claims. However, at that time it was apparent some chemicals were necessary in the production of food and should be allowed if certain safeguards were provided.

The Food, Drug and Cosmetic Act was passed in 1938 which authorized the Secretary of Agriculture to limit, by regulation, the amount of pesticide which can remain in foods.

In 1954, Public 518 or as it is more popularly referred to, the Miller Amendment, was passed by the 83rd Congress. This Amendment empowers the Secretary, Department of Health, Education and Welfare to establish tolerances of pesticidal residues in or on raw agricultural commodities moving in interstate commerce and to obtain registration for such pesticides under FIFRA.

The Food Additives Amendment was enacted on September 8, 1958. This amendment empowers the Secretary of the Department of Health, Education and Welfare to establish residue tolerances in or on processed foods. Under the Act of 1938 it was the job of FDA to prove an additive safe. The new law places the burden of proof on the manufacturer.

There is still another amendment to the Act which is not included in the slide; this is the Color Additive Amendment that was enacted in July 1960. This new law can make it necessary to establish the safety of almost any coloring ingredient used in or on a food, drug or cosmetic. In testimony during the hearings, the National Agricultural Chemicals Association requested that pesticides be exempted from the color law since they are already regulated by the Miller Amendment. The request was so granted and is written into the new law.

### United States Department of Agriculture (USDA)

Insecticide Act of 1910

Insecticide, Fungicide and Rodenticide Act – 1947

Amendment of August 1959 – Defoliants, Desiccants, Plant Regulators, Nematocides

The first specific Federal Insecticide Law was passed in 1910 and covered only insecticides and fungicides. The present Federal Insecticide, Fungicide and Rodenticide Act was enacted in 1947. It provided for regulation of labeling and marketing of insecticides, fungicides, herbicides, and rodenticides. The act was amended in August 1959 and subjects defoliants, desiccants, plant regulators and nematocides to the same laws and regulatory controls as insecticides, fungicides, herbicides and rodenticides. The law refers to all of these chemicals as economic poisons or pesticides.

### FIFRA (Federal Insecticide, Fungicide, and Rodenticide Act)

**Regulates** Labeling and marketing of pesticides

**Design** Protect user – physical injury, economic loss
Protect public – injury, exposure or contact

**Prohibits** Interstate marketing – adulterated, misbranded, non-registered

Now, let's take a more detailed look at the mechanics of FIFRA. The act regulates the labeling and marketing of pesticides and is designed to protect the user from physical injury or economic loss. It also intends to protect the public from injury, exposure or contact with pesticides in the transportation or storage, while held for sale, or after application.

The act prohibits the interstate marketing of products which are adulterated or misbranded or which have not been registered with the USDA.

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### Application to Register – New Product

Statement of Composition

Copy of labeling – claims, directions for use

Request additional data – efficacy, mammalian toxicity

Reject registration – poor data, not in compliance with the Miller Amendment

Before a new product is registered, an application must be submitted to the USDA. The application must contain a statement of composition of the product to be offered for sale and a copy of labeling including all claims and directions for use, efficacy, residue data and a copy of analytical procedure, and mammalian toxicity. The USDA may request additional data if they find that the original data is not adequate. In addition, they may not grant registration on the basis of poor data or on the basis that the application is not in compliance with the Miller Amendment. The above procedure is referred to as registration on the basis of no residue at harvest. Usually, the USDA consults with FDA over residue data with applications which are submitted in this manner. The USDA usually requires 2 – 4 weeks to review data in such applications.

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### Experimental Permits

For Experimental Use Only

Name and composition

Approximate quantity to be shipped

% Total quantity supplied without cost

Acute toxicity

The act provides, also, for registering pesticides for experimental use. This is a very important phase in registrations and I wish to emphasize the attention that we must give to it under present laws. In shipping a new pesticide to a federal or state experiment station, we are not obliged by law to register our label with the USDA. However, if the chemical is shipped to a customer for testing, we must register our label and submit an application for registration giving such information as name and composition of the pesticide to be shipped, approximate quantity to be shipped, percent of the total quantity supplied without cost, and data on the acute toxicity of the pesticide.

### Proposed Experimental Program

Label copy

Food or feed contamination

Use around food or feed?

Chemical analysis only?

Show residues not hazardous or
temporary tolerance

In addition, it is necessary to include, in the application the proposed experimental program giving such information as the pest and the crop or animals to be treated, the number of acres or animals to be treated, etc. We must also indicate whether or not the use will be around food or feed, or if the crop that is to be treated will be used for chemical analyses or show that residues will not be hazardous. If residues are expected to be present, then the applicant must submit a petition under the Miller Amendment proposing a temporary tolerance.

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### Miller Amendment – FDC Act

**Purpose** Protect public from harmful residues

**Provision** Commodity adulterated if bears pesticide chemical which is unsafe

Safety not formally cleared

Pesticide present in excessive amounts

Petitioning for tolerance or exemption

Register under FIFRA before filing petition

Now let's take a more detailed look at the mechanics of the Miller Amendment under the Food, Drug and Cosmetic Act. The purpose of this amendment is to protect the public from harmful pesticide residues. It provides that a raw agricultural commodity is ;ed adulterated if it bears any pesticide chemical which is unsafe. As an example, the pesticide chemical whose safety has not been formerly cleared, or which is present in excessive amounts, would be considered unsafe. It also provides for petitioning for a residue tolerance on a raw agricultural commodity or an exemption from an established tolerance and finally, it provides for the registration under FIFRA before filing such a petition.

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**Petitioning Procedure**

**A. Name, chemical identity, and composition**

Chemical and physical properties

Complete quantitative formula of product

Stability and known impurities

Now what is the petitioning procedure which we must follow under the Miller Amendment? The procedure is prescribed by regulations, and the format should be followed in detail and data submitted in a concise and clear manner. In Section A, the name, chemical identity and composition of the pesticide must be submitted. This includes chemical and physical properties, complete quantitative formula of the product containing the chemical a and stability data, including known impurities. Stability data is most important from the standpoiht of efficacy and hazard to the user. In other words, if the chemical is known to be unstable over a short period of time, impurities may affect the efficacy of the product and be injurious to the consumer in handling the chemical as compared to the parent chemical.

**B. Amount, frequency and time of application**

Usefulness against pests

Label – dosage and schedule must correspond to directions for use.

Yields – flavor – phytotoxicity

**C. Full reports of investigations – respect to safety**

Acute and chronic toxicity

The amount, frequency and time of application make up Section B of the petition. Here we must show the usefulness of the pesticide against various pests. The product label is included, and the dosage and schedule in which the efficacy data is obtained must correspond to the directions for use on the label. Other information which must be included in this section of the petition are crop yields, effect of the pesticide on flavor, if any, and information pertaining to phytotoxicity. The USDA requires replicated tests to determine the effectiveness of the product and that tests be conducted in at least three different areas in the United States on the same crop and against the same pest. Difference in climatic conditions can affect the performance of the product against the pest for which it is intended for use.

In Section C of the petition, we must submit full reports of investigations made with respect to the safety of the pesticide chemical. The Miller Pesticide Amendment provides that 1-year feeding studies are generally required on one animal species and 1-year feeding studies on a second animal species. It is not possible to design a single test program that will apply to every pesticide in all of its applications; for example, in the case of organic phosphate insecticides, 90-day subactue feeding tests may be conducted and in many cases, when we review the results of these studies with FDA, they have agreed that

2-year chronic feeding studies are not necessary to comply with the Miller Amendment in supporting a proposed residue tolerance. This is an important factor in view of the costs of 2-year feeding studies in one animal species and 1-year animal feeding studies on the second species. These costs run $80,000 and if, after two-year studies are complete and upon autopsy, certain organs from the animals may appear abnormal, these organs have to be sectioned and each tissue studied microscopically. If this is required, an additional 5 to 10 thousand dollars is expended.

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**D. Results of tests on the amount of residue remaining – description of analytical methods**

Critical for tolerances

Tolerances set on amount of residue – not on highest figure permissable from health standpoint

Crops of limited acreage

Exaggerated dosages

Results of tests on the amount of residue remaining and a complete description of analytical methods go into Section D of the petition. This information is probably the most critical of the data that goes into a petition from the standpoint of obtaining a residue tolerance. Many petitions have been rejected on the basis of the residue data and analytical procedures. The analytical procedure must be sensitive enough and this is usually determined on the basis of the no-effect level found in chronic feeding studies.

Residue tolerances are set on the amount of residue found on the raw agricultural commodity, and not on the highest figure permissible from the health standpoint. For example, if a residue of a certain pesticide would be safe at 50 ppm, but only 2 ppm residue would result from a certain recommended use of the pesticide, the tolerance for that use would be set at 2 ppm rather than at 50 ppm.

The costs to develop an analytical method and compile residue data to clear a pesticide under the Miller Amendment ranges from $10,000 to $150,000, depending on the complexity of the chemical. In addition, it has been determined that to compile the necessary residue data on treated commodities, costs can run $400,000 to $500,000. The figure determined by the pesticide industry is $388,000. You can understand that in crops of limited acreage why management would turn down research dollars to develop information to clear such crops under the Miller Amendment.

Both Food and Drug and USDA have been urging applicants to furnish residue data for pesticides when the chemical is applied well above the normal dosage that would be recommended. This is to determine what the residue might be in the event a grower erred by using using a stronger dosage than shown on the label. It is understood that, with some pesticides, it is impossible to go too far beyond the normal level since phytotoxicity would occur. This is usually shown in the data on efficacy contained in Section B of the petition.

**E. Practicable methods for removing residue exceeding any proposed tolerance**

Description of method

**F. Proposed tolerance for the pesticide**

**G. Reasonable ground in support of petition**

Summarize data in entire petition

Benefits when used in agriculture

Tolerance proposed – no health hazard

Where residues of the pesticide chemical exceed any proposed tolerance, the petitioner must show practical methods for removing the residue in Section E of the petition. Such a method is only needed in cases where the residue exceeds any proposed tolerance.

In Section F we must list the proposed tolerance for the pesticide and list the specified crops.

Finally, in Section G we give the reasonable ground in support of the petition which includes a summary of all the data given in the petition, the benefits when used in agriculture, and show the tolerance that is proposed will not create a hazard to the public health.

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**Tolerance-Setting Process – Miller Amendment**

1. Registration of product with USDA
2. Submit 2 copies of petition to FDA,
   1 copy to USDA
   Certified check – $2500 +
3. Filing FDA (15 days)
4. USDA certification – FDA (30 days + 30 days)
   Usefulness
   Opinion on residues

We have, so far, had a look at what the requirements are under FIFRA and the Miller Pesticide Amendment, and now I would like to show just what the tolerance-setting process is under the Miller Amendment. First of all, we must register the product with the USDA. A A petition cannot be filed, unless this has been accomplished. Secondly, we submit two copies of the petition to Food and Drug and one copy to the USDA. Along with our covering letter to FDA, we submit a certified check in the amount of $2500. This check covers the filing fees plus the time spent by personnel in the FDA in reviewing data. Additional fees are required depending on the number of tolerances that are being proposed in the petition as well as the number of crops for which tolerances are requested. The third step in the tolerance-setting process is the actual filing of the petition by FDA. They have 15 days to do so after receipt of the petition. Then, after the petition has been filed, the USDA has within 30 days to certify usefulness to FDA as well as give an opinion as to the amount of residue that will remain when used as directed on the label. The amendment provides that if USDA is unable to accomplish this within 30 days, they can take an addit additional 30 days to complete the action.

5. FDA order in **Federal Register** (90 days).
   Tolerance
   Exemption
   or
   Petition withdrawn
   Supplement (additional data)
   Refer to Advisory Committee
6. USDA – registration of label
   Maximum time: 135 – 165 days

The next step is to wait up to 90 days for the FDA to publish an order in the **Federal Register** establishing a tolerance for the pesticide chemical on various crops. They can, also, issue an order exempting the pesticide from a tolerance. FDA may also find there is insufficient data in the petition to grant a tolerance and, therefore, the petitioner is asked to withdraw the petition without prejudice for future filing, or submit the petition with additional data, or refer the petition to an Advisory Committee. If the petition is withdrawn, the petitioner has 6 months to re-file his petition. If he fails to do so, he must submit the petition for re-filing along with a certified check for $2500. If FDA grants a tolerance for the pesticide, then the USDA completes its action by registering the label.

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### Food Additive Amendment – FDC Act

**Provision** Petitioning for tolerance or exemption for processed food commodities

**Pesticides** Involved if residues exceed tolerance established on raw agricultural commodity

A word or two about the Food Additives Amendment as it pertains to pesticides. This amendment provides for the establishment of tolerances for chemicals in or on processed food commodities.

Pesticides are involved to the extent that if, for example, a residue tolerance has been established on oranges, as provided for in the Miller Amendment, the residue in the processed commodity derived from oranges cannot exceed the residue tolerance on oranges. In other words, if the residue tolerance on oranges for a specific pesticide is 5 ppm, citrus pulp derived from oranges must not have a residue of more than 5 ppm. If the residue in citrus pulp is in excess of 5 ppm for a specific pesticide, then the manufacturer must determine if residues of the pesticide will appear in edible tissues and milk.

As in the case of the Miller Amendment, we are required to follow a specific format in preparing a Food Additive Petition. It is similar to the Miller Amendment and since we have gone over this already, I will not repeat.

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### Petition Procedure

Submit 3 copies of petition to FDA

Filing FDA (15 days)

FDA order in Federal Register (90 days + 90 days)

Register label with USDA

Maximum time: 105 – 195 days – FAA
135 – 165 days – MA

In submitting a Food Additive Petition, 3 copies go to FDA. A copy of the covering letter goes to the USDA to alert them of the submission. FDA is required to file the petition within 15 days and from that date, they have within 90 days to publish an order establishing a tolerance, or an exemption from a tolerance, in the **Federal Register.** However, they are permitted to take another 90 days to make their decision if, after the first 90 days, they are unable to complete a review of the data in the petition. After a tolerance is established, we submit labeling to the USDA to register uses that cover processed commodities.

The maximum time required to process a Food Additive Petition is 105 – 195 days as compared to 135 – 165 days for a Pesticide Petition under the Miller Amendment.

What about the farmer, grower, and food processor when it comes to knowing specific tolerances for approximately 100 pesticides already in this category, and yet not have excessive residues on crops at harvest? The farmer and grower cannot be expected to know the tolerance for every pesticide, nor can they be expected to run chemical analyses on their crops at the time of harvest. The same applies to the food processor, though it is possible for his staff, if available, to analyze for residues on his raw commodities. The answer and advice we in industry, as well as federal and state agencies, can provide the farmer, grower and food processor is to carefully read and follow the directions for use and limitations on labels of federally registered products. FDA, in their Leaflet No. 6, "Protecting Crops and Consumers," states, "the grower will be safe if he follows these three simple rules:

1. Use a pesticide only on the crops for which it is recommended by the manufacturer on the registered label.
2. Use the pesticide in the amounts specified on the label.
3. Apply the pesticide only at the time specified on the label."

The grower of forage crops is encountering problems with respect to pesticide residues appearing in milk. He has recently been asked to sign a guarantee as to the pesticides used during the season. The grower has been reluctant to sign such guarantee, because of his neighbor across the road may have used a pesticide which drifted onto his forage crop. This particular pesticide may not have been federally registered on forage and, therefore, any residues of such pesticide found would be in violation. This problem is real, and exists, but it cannot be ignored if we are going to have strict enforcement of the law of zero tolerances or no residues in milk. If the problem is ignored, or avoided, then there can be serious economic problems developing. Some possible solutions would be:

1. For FDA to set numerical tolerances of pesticides in milk, or
2. For FDA to establish a blanket regulation to permit drifting of pesticides to other crops providing good agricultural practice is followed, or
3. For FDA to set tolerances for pesticides on forage crops, although they may not be adequate in controlling pests of forage crops.

I have gone over federal laws as they affect the registration of pesticide chemicals, and you will agree that we in industry are well regulated and the consumer well protected. We do not need further legislation or do we need the adverse publicity given in the past over chemicals in foods which have cast doubt on the position of the chemical industries relative to the protection of public health. We are convinced that the technological advances over the past 15 years to human welfare of the use of chemicals in food production, storage, processing and packaging is fully demonstrated. How else could the conquest of disease, increased longevity, generally improved public health and the high standards of living enjoyed in the United States be possible without the creative, responsible application of chemicals at every stage of food production from the farm to the ultimate consumer? Federal laws must not hinder the technological advancements in food production and processing, but they should bring encouragement in an atmosphere of understanding, free of prejudice, suspicion and harassment. Political consideration must not hinder industry if we are to con-continue our scientific advancements in food production for the expected future increase in population. The public or consumer must be presented more of the facts of chemical advancements in food production.

In closing, let me say that the chemical industry supported present federal laws before and after their enactment. However, after government agencies and industry operated and gained experience working under them, it became apparent to industry that certain modifications appeared necessary. We are hopeful that modifications can be made, within reason, in order that scientific advancements may continue, so that we people in America can always eat well, feel well, live longer and to enable peoples of the world to continue to look to us as leaders in scientific knowledge of food production.

## REGULATORY PROBLEMS DUE TO CHANGING TECHNOLOGY IN WEED CONTROL

By DUDLEY F. ZOLLER

Nevada Department of Agriculture

From the proceedings of prior conferences it appears that the 1950 conference was the last meeting to schedule a good deal of its agenda to problems in regulatory weed control. The conference adopted a resolution asking for Federal-State cooperation on control of poisonous and noxious weeds. We have precedence for this relationship in our Federal-State Barberry Control Project. Subsequently several bills were introduced in Congress and received the support of the conference. Some enabling legislation was effected providing the framework for this cooperation, but appropriations have not been authorized which would allow coordination of the State regulatory pest control projects on public lands. Currently SB457 – introduced in 1961 is now in the Congressional hopper.

A survey of the 13 conference members was made to determine if a legal basis for effective regional weed control exists in the Western U.S. Three states – Arizona, New Mexico, and Idaho are without legislative authority; although Idaho is charged with the responsibility, it lacks the enabling legislation. Most states in our region have placed considerable responsibility at the local county or weed district level, with some type of formal organization to control most or all of its areas.

The trend is supervision or technical assistance at the state level although certain projects may be handled directly at the state level, such as Ragweed control in Oregon, which incidentally is a unique project in that it is the only weed in the west being controlled as a public health problem.

If we were to single out the desirable features among state programs, we would mention the multi-purpose principle of Colorado's pest control districts in which they are apparently geared for a developed program whether it is an insect, weed, or plant disease without duplication of organization. While California provides for consolidation of services none has done so to date. Some other states would greatly enjoy the resources of finance and personnel that California is able to put into its pest control efforts.

Utah's organization is highlighted with its State and County advisory boards well represented by different interests and this seems particularly desirable in evaluating its programs and coordinating them to its research, education, and regulatory effort.

In this connection, I might mention the small but vociferous group of preservationists usually known as conservationists who are beginning to make themselves felt in many legislatures and more particularly in Congress with the current proposed Wilderness Bill. Perhaps the Wyoming experience with 2,4-D on Big Sage, with attendant destruction of moose browse, points up the need for careful evaluation of the effects of large herbicide projects in the light of multiple interest; for recreation and wildlife are becoming a major resource in areas historically considered to have marginal single usage. The Oregon roadside weed program modified its brush control from broadcast spraying to painting cuts with 2,4-D; but not before receiving criticism because of the resulting lack of beauty of dead plants throughout the roadside landscape.

Our state departments have been rather single use minded ie, policies have been formulated in the light of the responsibility charged by their legislatures and like the federal agencies perhaps we had no choice. I think we must admit some of the services our legislatures have saddled us with may be hard to justify on the basis of our original legislative purpose. More and more our functions must rely on cooperation and coordination with other agencies and public interest groups as our land areas develop to its highest use. More and more our problems will deal with the activities of people. In 38 years the population of the U.S. will double and 30% of that increase will find its livelihood in the southwest desert areas. This increase means over 54 million people will be dodging cactus plants.

We asked the states what influence the new herbicides and the Miller amendment had on their regulatory programs to which question we had a variety of succinct responses. All have used a great deal more caution in following the manufacturers label recommendations, particularly ATA. The new herbicides have been a tremendous impetus to far greater chemically treated acreages – 50 million acres nation-wide in 1959 – and have sparked the public interest in chemical weed control to allow increased budget appropriations for the current effort being exercised by the states. It has provided the attitude whereby we can now learn to live profitably with these noxious weeds by the use of available herbicides. Our battle cry of eradication has been modified to effective control, and we should still rely on cultural control when propitious. I wonder how many control agencies have on their capital outlay inventories a good old tractor and disk?

Certain analytical problems on residues exist to the dismay of the dairy industry and enthusiasms of herbicides proponents may have created false panaceas as to an herbicide potential, but these can be resolved through research and education.

All states and the federal government now have seed laws, and these are powerful prevention tools. Quarantine measures, and I know this has been a dirty word in Oregon, have augmented prevention in dissemination of weed seeds in the harvesting, movement, and sale of feed, farm machinery, seed screening and manures in some of our states. Five states – New Mexico, Arizona, Colorado, Oregon and Washington – exercise no quarantine enforcement or lack legislative authority in connection with their weed control activities; and three others, Wyoming, Montana, and Nevada have authority but seldom use it. We were unable to inquire as to the reasons for this. California probably utilizes this tool to a greater advantage than the other states.

Uniform control of noxious weeds has not been simple due to climate, soil, species variation, and cropping practices. We still need greater know-how and even utilization of available information so that a regional concept may find common ground to extend responsibilities from the Federal government to the private land owner. Because 7/8 of all Federal lands administered by nine different agencies occur in our eleven western states, and this amounts to approximately 408,420,000 acres, the need for congressional recognition of closer cooperation at least in the western region is vital.

There is as yet no provision for authority to control weeds nationally by the Pest Control Division of the Department of Agriculture. With increased demand for beneficial use of water, greater recognition of noxious weed control as a part of national conservation should also have increased congressional recognition.

Now to be consistent with our need for closer cooperation and coordination with our federal agencies, I'd like to call upon Mr. Max Bridge, Range and Forestry Officer with the Bureau of Land Management to speak on the federal viewpoint.

## CROP-WEED ECOLOGY IN WEED RESEARCH

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When we consider the challenges of weeds that have been met by the development of control practices, we find that the results of plant ecology research have played a major part in the solution of these problems and have uncovered new lines of approach to weed control. Many effective weed control practices exploit known differences in the ecological characteristics of crops and weeds. The success achieved with these methods depends on knowledge of plant ecology.

Conversely, many of our failures or shortcomings in weed control technology may be attributed to ignorance of the biological interactions of the crop we wish to grow and weeds we wish to destroy. Accurate information about the biological capabilities, or more simply about the growth characteristics and habitat requirements of crops and weeds is essential to ultimate control of weeds. Careful characterization of the nature and extent of weed competition in major crops is essential to the development of suitable control methods, including a realistic appraisal of the role of the more expensive herbicides.

Recently I drew up a new project proposal in which the major objective will be to characterize the competitive or interference effects of annual weeds on corn and soybeans. Today I will present some of the more important findings which have led us to concentrate research effort on this problem, and indicate the more promising leads which should be investigated. But before proceeding on this, a few definitions and comments are needed.

Definitions of weeds are numerous and sometimes unprintable. For our purposes plant species may be considered weeds when their exclusion from the artificially maintained habitat becomes a major problem in crop production. Weeds then, are plants that possess ecological adaptations which enable them to grow, survive and even flourish in the same habitat as the crop, despite a sequence of agronomic practices designed to favor crop growth. Of these adaptations, seed dormancy and germination play major roles. In fact, an annual weed as contrasted to an annual crop plant, is merely a species with dormant seeds which germinate only under a narrow range of environmental conditions. In contrast, the rapid and predictable germination of crop seeds is an adaptation of major importance in the successful establishment of crops.

Plant ecology may be translated literally as "the study of plant organisms at home" From an ecological viewpoint, crop production creates open or at least disturbed habitats, in which crop and weeds have initially a more or less equal chance for germination and establishment. The techniques of crop production associated with planting are designed to favor the crop, but in practice they may be ineffective against well adapted weed species. Thus the agronomic practices may merely set the stage for competition between crop and weeds.

Plant competition is a natural force whereby the crop and weed plants tend to attain maximum growth and yield, each at the expense of the other. The term is the subject of some discussion in ecological circles particularly as it applies to the ecology of crops and weeds. Competition may be used by some ecologists to describe the relationships between plants growing together which lead to the death of some and the survival of others. In this sense it covers a wide range of phenomena, implies that competition is always for things in short supply, and suggests a period of growth of greater duration than is found in annual crops. A British research worker, Dr. Harper, has suggested the term "Interference" to cover all the negative aspects of plant relationships in communities. This term is quite descriptive of the effects of annual weeds on row crops such as corn and soybeans, and of the effects of these crops on weeds.

Interference is operative both above and below ground and includes a wide range of effects and factors of the environment. Above ground, shading effects are of major importance both directly and indirectly as they modify plant growth and subsequent competitive advantage in the utilization of moisture and nutrients, below ground.

In humid regions such as Great Britain, the supply of plant nutrients is very often the major factor which must be shared by crops and weeds. In the dry climate of Western Canada, where Pavlychenko did his classic work, soil moisture quickly becomes limiting to plant growth and governs the patterns of plant competition or interference. In Iowa we may encounter both conditions in the same season. While patterns of interference may vary, the outcome usually may be described in one of these three ways: (1) crop and weeds grow and mature in state of mutual suppression, with variable crop yield reductions; (2) the weeds suppress crop growth to the point where little if any crop return is realized; and (3) the crop suppresses the weeds, and the resultant crop yield reductions may be significant but in no way a crop failure.

Each of these three conditions is found in crop production. The first is found commonly in cereal crops, particularly where no selective herbicide is available to control weeds. The second is the ultimate in crop neglect and I shall mention it no more. The third condition is a logical consequence of row crop cultures, that not only permit but virtually demand effective weed control methods via cultivation. A few comments now about crop-weed interference or competition in the row crop cultures of the mid West, where corn is the climax vegetation and where soybeans are rapidly invading the oat fields. Why are we concerned about weed competition, anyway?

In conducting these experiments the major probjems were those associated with the establishment and maintenance of suitable weed infestations. In the work with corn we used infestations of *Setaria lutescens* (yellow foxtail) almost exclusively and only recently have begun to use other foxtails, including the giant foxtail *Setaria faberii.* Variations in seasonal rainfall and growing conditions were encountered with years and locations, and were anticipated in the design and execution of the experiments. Major agronomic variables which were controlled or modified, included corn plant populations, weed populations, a available soil nutrients, crop varieties and the duration of competition between crops and weeds. Of these variables, corn plant populations and size of competing foxtail infestations were of major importance since the relative numbers of each determined in large part the outcome of interference. In experiments to assess the average losses due to weeds, we have used infestations which approximated closely those found in commercial fields. For other studies, infestations of up to a ton of mature dry weeds were sometimes necessary.

We have been concerned primarily with the factors of soil moisture and available nitrogen as they modify the competitive effects of weeds on corn yields. Shading effects were present, but only recently have we begun to evaluate this component. Actually, shading is a one way effect with corn and foxtail communities since foxtail never shades corn. The shading effects of corn on foxtail however, determined the growth and interference potential of the foxtail infestations.

Competition between corn and foxtail for nitrogen and water did not follow the same sequence or reach the same degree of severity in all experiments. But, under all conditions encountered, nitrogen fertilizer applications greatly minimized the competitive effects of foxtail on corn, and particularly where soil moisture was limiting. Supplemental irrigation water offset the competitive effects of foxtail when nitrogen levels were adequate or high, but not when nitrogen was in short supply.

Seasonal distribution of rainfall in Iowa follows a typical pattern of adequate soil moisture from spring until early July, a dry period in late July and August, and fall rains in late August and September. Competition for moisture was confined generally to the dry periods in summer. Foxtail infestations which grew with the corn until early July and were then removed prior to the onset of dry weather did not reduce corn yields except under conditions of very low nitrogen. The extent of competition between corn and foxtail during the dry periods was determined, however, by the growth of foxtail and corn prior to the onset of drought. Thus available nitrogen and moisture in the spring determined the severity of competition for moisture later in the summer. In this connection, nitrogen had relatively little effect on the growth of foxtail compared with its effect on the growth and vigor of the corn plants.

The patterns of foxtail growth and resulting corn yield reductions indicated the final outcome of corn-foxtail competition was conditioned not only by individual factors of soil nitrogen, soil moisture, corn plant populations and degree of foxtail infestation, but also by the interactions of all four. The effects of nitrogen fertilizer in minimizing foxtail interference varied within corn plant populations; corn plant populations in turn determined to a considerable degree the growth and competing potential of the foxtail. Observed corn yields suggested that competition among corn plants, as well as that from foxtail, determined the extent of corn yield reductions at high population levels. In general, for each season and habitat encountered, maximum yield reductions were obtained at that corn plant population which produced maximum yields under weed-free conditions.

Separation of the effects of nitrogen and water remains a major research problem in this work. Substitution of nodulating and non-nodulating isogenic lines of soybeans for foxtail, the use of dwarf corn to eliminate the effects of differential shading, varying nitrogen availability with soil applications of ground corn cobs and fertilizer, and the careful use of irrigation water and plastic ground covers are promising approaches. Preliminary experiments have revealed some new problems. Results to date suggest that shading effects of corn are most serious at higher levels of soil nitrogen and water.

Experiments with ordinary nodulating soybeans and annual weeds have revealed some interesting differences in the patterns of competition as contrasted with those observed in corn. The effects of nitrogen fertilizer were very slight and were evidenced only by slightly better weed growth and somewhat higher bean yield losses where beans and weeds followed heavily fertilized corn in the rotation. The shading effects of soybeans on weeds was quite pronounced with soybean plant stands of 9 or more per foot of row. Competition for moisture during the dry periods of summer was a major factor in determining the outcome of soybean weed competition. Bean yield reductions were greatest in seasons which had a wet spring and a dry summer. When plastic ground covers were used to create dry conditions over the entire season, growth of soybeans and foxtail was reduced and yields lowered, but the losses due to weed competition were negligible. A complicating factor in soybean-weed competition studies was the occurrence of early fall rains which resulted an increase in soybean seed size and yield, thus masking some of the effects of earlier weed competition.

My interpretations of this research have emphasized the interference or competition among plants resulting from a limited supply of one or more of the macro factors of the environment. We have been concerned with the autecology of weeds and crops and have assessed some of the end results of synecology. Crop yield reductions were not often spectacular and crop failures never resulted from weed competition, even on land which had grown corn for ten years without any nitrogen fertilizer treatment. We have noted the tangled inter-relationships of plant stand, nitrogen and water availability and the shading effects of corn on foxtail. I have indicated some of the techniques which may improve future experiments.

Any discussion of crop-weed ecology would be incomplete without a consideration of those possible conditions wherein the effects of one plant on another may be due to factors other than competition for moisture and nutrients and to the interference effects of shading. Evidence on this controversial point is conflicting, incomplete and insufficient to warrant firm conclusions. There seems little doubt that plant root exudates and the products of plant residue decay are present in the soil. Whether or not such materials are toxic, or directly beneficial to other plants has not been proven as a widely occurring phenomenon, excluding the special examples such as legumes which fix nitrogen and the desert shrubs which inhibit seedling development in close proximity to the parent plant.

We have not as yet studied this aspect of crop-weed ecology, but we have noted some results which need further explanation, and which may be the result of such inter-actions. For example, corn yield reductions are not directly proportional to the increased levels of foxtail infestation. This has been observed under a range of experimental conditions. It may be due simply to the effects of heavy shading. Occasionally, weed infestations which were left in association with corn until early July resulted in significant yield increases. This positive effect of weeds on corn may be merely on the distribution of corn roots during extremely wet soil conditions in the early spring and summer. In experiments with soybeans and green foxtail, when soil moisture was limiting for the entire season, moderate weed infestations did not reduce soybean yields appreciably. If nothing else, this suggests that some concepts of water utilization and sharing may need modification.

Future research in crop-weed ecology must be concerned with a clearer assessment of the role of the soil microflora in the growth relationships of crops and weeds. Research has already demonstrated the important role of soil microflora both in the inactivation and sometimes in the activation of pre-emergence and soil sterilant herbicides. Further progress in this area might aid in the development of new herbicides needed for the growing of true crop monocultures, and at the same time provide information perhaps vital to the maintenance of such crop monocultures in full production.

A broad approach to weed control must encompass the biology of the weeds as well as the physiology, biochemistry and technology of the methods used to control them. Investigations of this sort demand a greater share of research time and effort than is presently being done. However, present trends in weed control research indicate that such efforts are being expanded and without any sacrifice of existing programs in herbicide research. In focusing attention to the need for research in weed biology, I have no wish or intention to detract from or to minimize the importance of herbicide research in all its aspects. Indeed, herbicides are so widely used that they are an integral part of the normal environment of weeds and a potent factor in weed ecology. Let us work from that premise.

I have then, assigned to or implied for crop-weed ecology, a central role in weed research. This is not to infer that all weed research should be concerned with ecology, but as long as weeds grow in the same fields as crops, research in plant ecology will be an integral and vital part of weed control.

# VEGETATIVE MANIPULATION FOR MULTIPLE BENEFITS

## The Arizona Watershed Program

By Joseph J. Arnold
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The Arizona Watershed Program, a program of vegetative manipulation for multiple benefits, is in a large measure a program of controlling weeds on a large scale, if one accepts the broad definition of a weed as a "plant out of place". The primary objective of the program is aimed at recovering a greater percentage of precipitation falling on the State's watersheds by reducing evapo-transpiration losses. Toward this objective conversion of worthless, or "weed" vegetation types using large quantities of water to more valuable vegetation types using smaller quantities of water, is being tried out on pilot watersheds.

Besides increasing water yields, the Arizona Watershed Program is directed toward such other multiple benefits as increasing production of high quality timber, increasing forage and browse for game and livestock, reducing erosion, reducing wildfires and improving conditions for fishing and other forms of recreation.

Guided by recommendations of nationally recognized scientists, who examined Arizona watersheds in 1956, the Program has advanced rapidly through the energetic cooperation of many Federal, State and private agencies. Following are some of the practices being tested:

### Patch Cutting of High Mountain Mixed Conifer Forests

Clear cut logging in patches appears to be the most promising method of harvesting products from mixed conifer forests, the spruce-fir-aspen-pine stands of high elevations. Not only does clear cutting in patches produce wood products from a forest type so far unused in Arizona, it also provides openings where accumulation of snow and rain recharges springs and streams. Experimental patch cutting is already producing important increases in water yields.

When reseeded with grasses, clear cut patches provide such additional benefits as more forage and browse for livestock and game.

Released by the removal of overstory trees, understory shrub species, such as locust, may need to be controlled through chemical treatments as a maintenance measure.

### Thinning of Ponderosa Pine Forests

The best sources of Arizona's high-value commercial saw-log timber are the remaining open stands of virgin ponderosa pine. But continued production of high quality timber requires the weeding or thinning of thousands of cut-over acres now choked with dense stands of young trees making little growth.

When combined with pruning, thinning not only increases growth and quality of timer, but also increases forage and browse, improves forests for recreation, and possibly increases water yields. Taking trees down to 7 or 8 inches in diameter, Arizona's new pulp mill will help accelerate the tremendous job of thinning overstocked stands of pine.

Prescribed burning, applied during late fall and early winter by reducing excess forest debris and inflammable fuels, helps protect pine forests against destructive wildfires that usually occur in summer.

Chemicals are playing an ever-increasing role in the management of pine forests when one considers the chemical fire suppressants used to help control forest fires, chemicals used to help debark trees for pulp, and herbicides used to control invading stands of oak and alligator juniper.

### Conversion of Pinyon-Juniper

Of fourteen and a half million acres of pinyon-juniper woodlands in the State, close to a million acres have been cleared by cabling, bulldozing, burning, hand-chopping and chemical treatments. Test applications of chemicals like fenuron show considerable promise in controlling alligator juniper, a sprouting species.

Although juniper control primarily increases forage and browse for livestock and game and reduces erosion, possibilities of increasing water yields are being closely watched by the Forest Service, Geological Survey and Bureau of Indian Affairs.

### Conversion of Chaparrel Brush

Conversion of dense chaparral brush areas to a more palatable forage cover not only increases grazing values and reduces erosion, but also shows promise of increasing water yields.

With the aid of herbicides used to control resprouting, an experimental watershed on the Tonto National Forest has been producing seven times more water since it was burned over by wildfire. Sediment yields also increased. With the help of chemical dessicants, controlled burning of contour strips under normally low fire hazard conditions is now being tested as a means of reducing wildfires and resultant erosion, while at the same time increasing forage and water yields. Chemical fire suppressants are being used to keep controlled burning to desired limits.

Root plowing followed by reseeding is showing considerable promise in the conversion of chaparral to grass in areas having gentle slopes and deep soils. Maintenance of established grass stands against re-invasions of brush species may require periodic chemical treatments.

### Control of Phreatophytes

The most extravagant users of water are trees lining creeks and dry washes from the top of the watersheds to the downstream dams.

Several agencies are studying the use of water by salt cedar and are developing mechanical and chemical methods for controlling this species.

The wasteful use of water by cottonwoods and effects of control are being studied by the Geological Survey in cooperation with the State Land Department and Salt River Project. The Bureau of Indian Affairs has recently treated some 500 acres of cottonwoods on the Fort Apache Indian Reservation by chemical injections with the Cornell probe.

Considerable acreages of mesquite have been dozed, root-plowed or treated with chemicals by airplanes in the southern part of the State.

Treatments of phreatophytes will be of particular importance if increases in water yields yields from the higher watersheds are to reach the dams located at lower elevations.

The Arizona Watershed Program, a cooperative attempt to manipulate different vegetation types for multiple benefits, depends upon the efforts and talents of many individuals and agencies. Successful manipulation will likely depend on no one method, but rather a combination of methods, using burning, mechanical and chemical treatments.

This program has produced consumer demand for your services – and for your products.

# FOREWORD

The importance of soil applied herbicides continues to grow with increasing use of such chemicals and the introduction of new materials. The complexity of factors governing the effectiveness of herbicides used in this manner is becoming ever more apparent. The present symposium is an outgrowth of this interest in this phase of weed work.

Various investigators have worked on the problem of the relationship of chemicals in soil, but in recent years a much larger group have become concerned with this type of research. One of the difficulties in such research has been the lack of delineation of some of biological and physical principles involved. The contributors to the symposium while attempting to set forth some of these principles do not delude themselves by thinking that they have solved all of the problems. Rather, it is their hope that the information will suggest points of departure for more decisive research on the problems.

# THE SOIL BEHAVIOR OF HERBICIDES AS INFLUENCED BY THEIR PHYSICAL PROPERTIES

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The number of herbicides for application to the soil increases every year. It has been found that a higher degree of selectivity and a longer period of weed control may be achieved with chemicals applied to the soil in contrast to those applied to foliage (32,45). However, those chemicals applied to the soil are more subject to varied degrees of changes in environment which determine the effectiveness of the treatment than are those chemicals applied to foliage of plants (19, 32). For this reason, it is becoming of paramount importance to develop a basic understanding of the laws and principles governing the behavior of these chemicals. A thorough understanding of such phenomena would permit the development of a more rational use program for these chemicals and the attaining of a higher degree of effectiveness under more varied conditions.

It has been established that the type of soil to which the chemical is applied, the amount of moisture in the soil and received following treatment and various other factors may determine the ultimate biological effectiveness of the chemical (18, 20, 26, 43, 45, 46, 50). The interaction of a chemical with these factors of the environment may be adduced to be due to the physical and chemical properties of the material applied (19). This may be accepted as a general premise from which it is then possible to derive a logical explanation for the observed behavior of the chemical. It is the purpose here to examine some of the observed behavior patterns of the chemicals and from them to adduce chemical and physical explanations for the characteristic behavior.

The interest in understanding the behavior of chemicals in the soil stems from the concern for obtaining the highest degree of effectiveness with an application of the chemical. This focuses attention on those phenomena which may limit biological effectiveness of the treatment through reducing the effective concentration of the chemical. Experience has shown that there are five major means by which the effective concentration may be reduced. They are: adsorption, leaching, volatilization, microbiological breakdown, and chemical breakdown (2,4,5,7,26, 43,47,55). For purposes of this discussion, the sixth manner by which an effective concentration of the chemical may be reduced, namely: removal of the chemical by plants is excluded. With any given chemical, any two or more of these factors may be operative simultaneously. However, the knowledge of this field has not attained a sufficiently sophisticated state to permit examination of more than one process at a time. It must be kept in mind that there is an interplay of these processes such that one may affect another. This is particularly true in the case of adsorption which appears to play a dominant role in the leaching and vaporization processes. Each of the processes is determined basically by the chemical and physical properties of the compound with which we are dealing.

In the ordinary course of events, chemicals are applied to the soil and then at the end of a finite time their effectiveness is evaluated. Because there may be a lapse between time of application and when the weeds germinate and the young plant exposed to the chemical, the rate at which the effective concentration of the chemical is being reduced by various factors is of importance. Certain of the processes are sufficiently slow that the rate or velocity of the loss due to this process may be measured. However, in other cases such as adsorption the rate is sufficiently rapid that velocity measurements are meaningless. One might consider, therefore, that adsorption nearly instantaneously removes a certain amount of chemical from the soil solution.

It is the ultimate objective in any scientific investigation to start from a general principle or law of general validity and to adduce or predict events in the specific case. The fundamental concept used in this report is that the interaction of the chemical with its environment is a function of its chemical and physical properties. To describe these interactions, thermodynamic and kinetic concepts were applied to determine not only the extent but also the rate at which a particular event is occurring. However, the tendency for certain of these events to occur may be described in terms of the chemical properties and composition of the material in question.

Thus, examination of the structural formula of the chemical often will suggest the possibility of certain reactions. This is not an infallible guide nor does it hold in all cases. However, knowledge of the structure of a compound permits application of some of the solubility rules or organic chemistry and thus is useful in predicting the probable behavior of the chemical.

The solubility of a compound in water is of utmost importance in soil behavior as this property often will determine the rate at which the chemical will leach and is also related to adsorption of the compound by soil constituents. The structure of a compound can give some indication as to the adsorbability of the material (22,24). For example, compounds belonging to the open chair series of organic chemicals would not be expected to be adsorped as strongly as the aromatic compounds which possess strong van der Waal forces. If, on the other hand the chain compound contained a functional group that may react with soil constituents, the adsorption may be manifold greater. This latter case is particularly evident in the case of the heterocyclic compound 3-amino 1,2,4-triazole where the amino group is apparently absorbed on the sites at which ammonia and nitrogen become attached. In the breakdown of chemicals, the bond energy involved in the functional group most likely to be attacked is of importance. For example, if an ester or an amide derivative of a compound had equal biological activity, it would be expected that the amide would have a longer residual life in the soil. This arises out of the fact that the bond energy of the amide is greater than that of the ester, consequently hydrolysis of the ester proceeds with much more facility than the hydrolysis of an amide. Ionizable functional groups, particularly those capable of salt formation are also responsible in markedly modifying the behavior of the chemical in the soil.

**Adsorption**

The adsorption of chemicals by soil has long been recognized as a factor in the biological activity of soil applied pesticides. Adsorption of herbicides, such as arsenic, by soils was described many years ago (45). Sorption of a compound by a solid surface is a complex phenomena that may consist of nonspecific adsorption which is due merely to the general attraction of the surface and molecules for one another or it may involve chemisorption in which bonds between the chemical and solid surface are established (27). In most of the considerations given to the adsorption process here, it is assumed that we are dealing principally with nonspecific adsorption except where noted.

The adsorption process is an equilibrium process wherein the system of the chemical either in solution or in vapor state comes to equilibrium with the chemical adsorbed on the surface of the soil constituent (30).

$$(1) \quad \underset{\text{(equil. conc.)}}{\text{Chemical}} + \text{Soil} - (\text{Chemical})_X\ \text{Soil} + \text{Chemical}$$

In a specified system at a given temperature and pressure and concentration, the ratio of the amount of chemical adsorbed to that in the equilibrium solution is a constant as shown in equation 2.

$$(2) \quad K = \frac{[\text{Chemical (adsorbed)}]}{[\text{Chemical (equil. conc)}]}$$

This constant ratio is not a meaningful constant because the activity of the chemical, the chemical soil complex and the soil has not yet been specified. If these activities (A) had been specified as indicated in the equation 3, a thermodynamic equilibrium constant is obtained.

$$(3) \quad K = \frac{A\ (\text{Chemical})_X\ \text{Soil}}{A\ \text{Chem. in Sol.}\ A\ \text{soil}}$$

Using the relationship developed in equation 3, it is possible to write an equation for the free energy of the adsorption reaction which is the driving force of the reaction as shown in equation 4.

$$(4) \qquad \Delta G^\circ = -RT \ln K$$

The superscript of the free energy ($\Delta G^\circ$) in equation 4 indicates that this is obtained under standard conditions which is the reference point used to determine the free energy at any other temperature or under any other condition. The standard conditions are usually at 25° C, one atmosphere of pressure and when the reactants are at unit activity. In order to determine the free energy under other conditions, it is necessary to make use of the relationship given in equation 5.

$$(5) \qquad \Delta G = \Delta G^\circ + RT \ln \frac{\text{A (Chemical Soil)}}{\text{A Chem. in sol. A soil}}$$

Turning now to the matter of activities, convention specifies that under standard conditions of 25° C and one atmosphere of pressure, solid substances have unit activity. Thus, in a heterogeneous system of soil and chemical either in solution or vapor phase, the soil surface is considered to have an activity of unity. Similarly the complex ($\text{Chemical}_x$ Soil) formed as indicated in equation 1 is an insoluble solid and its activity is taken as unity. On this basis, we then write equation 6 in the form given below.

$$(6) \qquad \Delta G^\circ = -RT \ln \frac{1}{\text{A Chem. in Sol.}}$$

This may be written then as shown in equation 7.

$$(7) \qquad \Delta G^\circ = RT \ln \text{A Chem.}$$

Since, in most instances very dilute solutions are being dealt with, it may be assumed that the activity is approached by the molality of the solution and that the molarity is a close approximation of the molality. In which case we then obtain the following equation 7a.

$$(7a) \qquad \Delta G^\circ = RT \ln \text{M Chem.}$$

It has been shown that the adsorption reaction is one of extent i.e. fractional area covered (30). It therefore becomes necessary to evaluate $\Delta G^\circ$ at a specified extent of area covered. The symbol $\theta$ is used to indicate the fractional area covered by the chemical. Since the micrograms adsorbed per gram of soil is directly proportional to $\theta$, the actual numerical value of $\theta$ need not be known to evaluate the free energy change. It is possible then to select a point at which a given number of micrograms (or micromoles) of chemical are adsorbed per gram of soil and evaluate the free energy change at this fractional coverage at different temperatures.

The free energy change in this adsorption reaction indicates the extent to which the reaction goes. However, it does not follow that because an appreciable amount of chemical is adsorbed that it is also tightly bound to the surface. It is quite possible to have a substantial quantity of the chemical adsorbed without its being bound very tightly.

In order to determine the effective binding of the chemical by the surface, it is necessary to look for other parameters that offer a more reliable indication of binding. Examination of the problem reveals that there are two factors involved. One is the extent of binding, the second is the degree of order that is attained during the binding process. If a high degree of order is achieved during the binding process, then the binding, will of necessity, be strong. This consideration immediately leads to the examination of the change of entropy which is a measure of the degree of order imposed during the reaction. Entropy is determined from the rate of change of the free energy with a change in temperature as shown in equation 8.

$$(8) \qquad \frac{\Delta G^\circ_{\theta}}{T} = -\Delta S^\circ_{\theta}$$

With this information, it is possible to derive a new relationship which is more indicative of the energy with which a compound is adsorbed to a surface. The relationship purpose is shown in number 9.

$$(9) \qquad \Delta H^\circ_{\theta} = \Delta G^\circ_{\theta} + T\Delta S^\circ_{\theta}$$

From the data calculated with the foregoing equation it is possible to tell whether the chemical is tightly bound by the surface of soil constituents. There should be a large change in the amount of chemical adsorbed at different temperatures if the binding is strong. That this is the case is illustrated in Table I.

Table I
**Variation of Adsorption with Temperature**

| Chemical | T° C | % Adsorbed |
|---|---|---|
| CIPC | 5 | 56.6 |
| | 30.5 | 51.5 |
| Amitrole | 20 | 50.3 |
| | 28 | 47.8 |

At first glance, the differences in the above Table may seem small but it must be remembered that these changes are evaluated in terms of absolute temperature (273 + ° C). In this light, the magnitude of change become appreciable for amitrole indicating considerable strength of binding to the soil.

Using the variation of change in adsorption with temperature the "entropy" factor ($\Delta S$) may be calculated. This has been done for monuron on two different soil types as shown below.

Table II
**The Energy of Adsorption by Different Soil Types – Monuron**

| Soil | "Energy" K cal | $\Delta S$ (E.U.) |
|---|---|---|
| Sandy | 1.25 | .5 |
| Muck | 5.6 | 15.5 |

Clearly the muck soil with its higher affinity for the chemical adsorbs the monuron in such a manner that results in a higher degree of order of arrangement of the adsorbed monuron.

Such data as shown in Table I are obtained by determining the amount of chemical adsorbed by a given amount of soil at various temperatures. Since this is a heterogeneous system that is hard to define, a standard procedure must be established and followed strictly in all cases in order to be able to compare data for different chemicals. A convenient method that has been followed in this laboratory is to use 50 ml. of the solution of the chemical and 25 grams of soil in the case of mineral soils. The amount of chemical adsorbed is then determined with various concentrations and at two different temperatures. Because of the wide range in solubilities of the different herbicides, it is suggested that these determinations be done at relatively low concentrations of chemical such that the concentration of the most soluble compound would overlap the range of concentration of the least soluble. In all cases the range of concentration should be such that at some point the miromoles adsorbed per gram of soil would coincide with a similar point determined for the other chemicals. This permits direct comparison then of the heat of adsorption of the different chemicals. It should be pointed out that these comparisons should always be made at the same temperatures.

Adsorption of chemical by soil may be a very important factor in the biological effectiveness of that chemical. For example, it is a matter of common knowledge that a chemical which is strongly bound by soil colloids is less effective at a given rate of application as one goes from a light sandy soil to increasingly heavier soils and finally to muck. This point has been repeatedly demonstrated with the urea herbicides. While the adsorption process is an equilibrium process, if the chemical is strongly bound by a colloid the effective concentration at any given instance in the soil solution is materially reduced. The stronger the binding the less the amount of chemical in the soil solution available for action against the plant.

The strength of this binding varies among the constituents of the soil-sand, silt, clay and organic matter. As a general rule clay and organic matter are the portions of the soil that adsorb most strongly. For example around sawmills and other establishments where there may be a heavy deposit of carbon (charcoal, clinkers) many of the organic soil sterilants are ineffective because of adsorption. Thus the choice of materials for use is governed by adsorption.

Another instance where adsorption by the soil is a factor is in the leaching process. In leaching, as water enters the soils and moves down through its horizon, the chemical is dissolved and carried along with the water stream but always in contact with soil surfaces. The chemical dissolved in this percolation water equilibrates between the colloid surfaces and the water. If the chemical is tightly bound by the soil colloids the amount of chemical leached to a given depth in the soil and the rate at which it is leached is markedly reduced. It has been found that the heat of binding may be used in describing the leaching process. Loss by evaporation or steam distillation is another process in which the heat of binding plays an important role. As the strength of binding increases, less and less of the chemical is volatilized from the soil surface. It is not possible to give exact rules of adsorption based solely on physical properties of chemicals. However, the adsorption of many chemicals may be predicted to a first approximation based on their physical properties.

Adsorption, as pointed out earlier, is a complex phenomena involving everything from simple nonspecific adsorption to chemisorption such as is found in ion exchange. Certain correlations have been found between chemical structure and adsorbability as well as relation between water solubility and adsorption (19,20,22). In general it might be stated that compounds of an aromatic nature or containing groups capable of polarization will tend to be more readily adsorbed. Similarly, compounds having high intra-molecular attraction are readily adsorbed. It has been found, in the case of gases for example, that the most readily liquefiable gases are adsorbed to a greater extent (22). This comes about from the high intra and inter-molecular attraction in these materials. Table III shows how water solubility gives a rough degree of correlation to the extent of binding of compounds. It should be noted however, that extent of binding and strength of binding are not necessarily correlated.

Table III

**Amount of Chemical Adsorbed as a Function of Water Solubility**

| Chemical | $H_2O$ sol. ppm (25° C) | Fract. Avail. Ads. |
|---|---|---|
| ATA | 28% | 0.1 |
| 2,3,6 TBA | 7700 | 0.2 |
| 2,4-D | 605 | 0.55 |
| 2,3,6 TPA | 203 | 0.6 |
| CIPC | 103 | 0.6 |
| Monuron | 230 | 0.6 - .7 |
| Atrazine | 70 | 0.7 |
| Simazine | 5.6 | .85 |
| Casoron | 45 | .48 |
| Diuron | 42 | .80 |
| Dacthal | 5.6 | .90 |

It was noted that the more readily liquefiable gases are adsorbed to a greater extent. In studying this phenomena, the concept of integral heat of adsorption was introduced. This value is the heat of adsorption found as the amount of chemical adsorbed increases. The integral heat of adsorption was found to approach but not necessarily equal the latent heat of evaporation as multimolecular layers built up on the adsorbing surface. Examination of the situation when multimolecular layers are built up reveals that not only is there attraction between the surface and the adsorbed species but at this point there is an attraction between the adsorbed molecules. It is reasonable to assume, therefore, that the integral heat of adsorption should approach the latent heat of evaporation in this case. In light of this information, it would be expected that there should be a parallel between the behavior of gases and the behavior of solutes in a water solution. Examination of several cases revealed that there is a reasonably good correlation between the strength of binding and the latent heat of solubility of many of the herbicides. The following Table IV illustrates this point.

Table IV

**Adsorption as a Function of the Latent Heat of Solution**

| Chemical | ΔH sol (K cal) | Leaching | Adsorption Indicated by Soil type Response |
|---|---|---|---|
| 2,3,6 TBA | 1.6 | Readily | Small |
| 2,3,6 TPA | 6.7 | Resistant | Large |
| Amiben | 2.8 | Readily | Inter. |
| 2,4-D | 6.1 | Inter. | Large |
| 2,4,5-T | 8.9 | Resistant | Large |
| Simazine | >15.0 | V. Resistant | V. Large |
| Fenuron | 3.9 | Inter. | Inter. |
| Monuron | >6.0 | Resistant | Large |
| CIPC | <4.9 | Moderate | Some |
| Casoron | 2.8 | Moderate | Small |
| Dacthal | 12.4 | Resistant | Large |

The seeming correlation between latent heat of solution and adsorption, while good, is not sufficient proof that this is a valid relationship. If an organic compound could be found whose latent heat of solution were negative i.e. one less soluble at high temperature than low and whose adsorption behavior was in accord the relationship could be established. Such a compound was found in EPTC. The solubility of this compound decreases as temperature increases (375 ppm at 25° C and 636 ppm at 3° C) giving a negative heat of solution. Similarly, as shown in the following Table, the amount of chemical adsorbed decreases as the temperature increases. This data, therefore, confirms the coorelation between the latent heat of solution and adsorption.

Table V

**Relation of Heat of Solution to Adsorption and Leaching in Soils**

| | ΔH | % Ads | | % Leach | |
|---|---|---|---|---|---|
| | | 23° C | 3° C | 25° | 3° C |
| CIPC | +4.9 | 60 | 71 | 0.2 | 0.0 |
| EPTC | -3.9 | 61 | 52 | 0.6 | 5.2 |

In considering the adsorption of herbicides by soils, it is necessary to think in terms of the variation in extent and binding of the chemical with varying soil types. Examination of the amount of chemical adsorbed by different soil types has shown that there is a regular progression in the extent of adsorption as well as binding starting with the light sandy soils and progressing on through the muck or high organic soils (1,4,10,21,31,35,52,59).

This is shown by the data given in the following Table.

Table VI

**Adsorption as a Function of Soil Type**

| Chemical | Fraction of Available Chemical Adsorbed: Sandy | Loam | Peat |
|---|---|---|---|
| 2,3,6 TBA | .14 | .45 | .40 |
| Monuron | | .47 | .69 |
| Amitrole | .05 | .20 | .9 |

The differences in amount of chemical adsorbed by soils and clays at different pH's has been reported by Frissell (20). There can be no doubt that the various clays found in different soils will vary markedly in their ability to adsorb chemicals (10). This is shown in the following Table.

Table VII

**Adsorption of CIPC by Various Clays**

| Adsorbent | Temp. °C | ug/g Adsorbed |
|---|---|---|
| Sandy Soil | 24 | 10.3 |
| Kaolin | 30 | 30.1 |
| Bentonite | 30 | 77.0 |
| Illite | 30 | 77.5 |

The foregoing data probably reflects not only the difference in specific adsorptive capacity but differences in surface area as well. It has also been noted that change of ionic environment e.g. salts and pH cause a marked variation in adsorption. This may arise from the effect of other ions such as $Ca^{++}$, $H^{+}$ or $OH^{-}$ on the clay itself or on the organic species being adsorbed.

It is seen then that the adsorption phenomena is of utmost importance in the soil behavior of chemicals (15,16,25,26,55). This particular phenomena plays a role not only in determining the concentration of chemical in the soil solution but it may also modify leaching (55), volatilization (16) and rate of breakdown.

**Vapor Phenomena in Soil Behavior of Herbicides**

Many of the modern organic herbicides have measurable vapor pressures which play a role in the behavior of the chemical in the soil (1,39). The tendency of the chemical to vaporize may be an important factor in the biological activity, as was thought to be the case with EPTC, or it may be an important source of loss as in the case of IPC. The behavior of herbicides in the gaseous state is a complex one involving an equilibrium between the vapor, the solid surface of the soil and the solution of the chemical in the soil water (23,31).

In the gaseous state molecules behave as if they have little attraction for each other and are in a perfect solution of the diluting gas. As a consequence, the molecules tend to rapidly occupy all space available to them. Distribution of vapors of a herbicide in soils at a given temperature is dependent on this tendency of a gas molecule to diffuse in all directions but limited or restricted by the ease of diffusion through a porous solid, the effect of gravitational attraction of the gas molecule, the amount of moisture and solubility of the gas in that moisture and the adsorption of the chemical by the soil surface.

The tendency of a chemical to change into the vapor state is indicated by its vapor pressure. Vapor pressure is described conveniently by the following equation.

$$(10)\quad \ln P = \frac{\Delta H}{P} \cdot \frac{1}{T} + C$$

It will be noted in this equation that there is a constant ($\Delta H$) of evaporation which is a parameter of the material under consideration. The constant ($\Delta H$) is of importance because it determines the rate of change of vapor pressure with temperature. If $\Delta H$ is small, then the rate of change of vapor pressure with temperature will be small. Conversely if large, a large change of vapor pressure with temperature will be noted. The relation of this physical constant to vapor loss of herbicides from soil is shown by the data in the following Table.

Table IX

**Latent Heat and Vapor Loss**

| Compd. | V.P. mmHg | H (Kcal/mol) | % Loss |
|---|---|---|---|
| 2,4-D IPE | $1.5 \times 10^{-2}$ | 24 | 13 |
| EPTC | $2.0 \times 10^{-2}$ | 14.5 | 18.8 |
| Tillam | $4.8 \times 10^{-3}$ | 12.0 | 16.7 |

$\Delta H$ may be defined as the quantity of heat in calories required to convert 1 mole of liquid at a given temperature to 1 mole of gas at the same temperature. This rate at which a chemical volatilizes is then going to be a function of its latent heat of evaporation and the rate at which the heat is supplied to the system from the outside. The fraction of molecules with energy sufficient to vaporize at any given temperature is readily calculated from the following approximation of the Maxwell distribution equation.

$$(11) \quad \frac{N}{No} = e - \frac{\Delta H}{RT}$$

The vapor loss of CIPC in the following table indicates how appreciable the factor of volatilization may be in certain instances.

Table X

**Vapor Loss of CIPC from Soil (24° C)**
**(Sandy Loam Soil)**

| Soil Condition | Air | % Loss in 16 hrs. |
|---|---|---|
| Dry | Still | 2.0 |
| Wet | Still | 10.0 |
| Wet | Wind | 25.7 |

In dealing with herbicides of a volatile nature, the addition of nonvolatile solvents or solid materials will modify the vapor loss (50). This phenomena is expressed in Raoult's law where the vapor pressure (P) of a component – in this case the solvent – is equal to the vapor pressure of the pure solvent times the mole fraction. Raoult's law generally applies to the solvent in very dilute solutions.

$$(12) \quad P = P_0 N$$

The vapor loss of EPTC as influenced by an additive is shown in the following Table.

Table XI

**Vapor Loss of EPTC from Soil**

| | % Loss in 24 hrs. | |
|---|---|---|
| | **Dry Soil** | **Moist Soil** |
| EPTC | 18.3 | 33.4 |
| EPTC + Oil | 5.6 | 23.4 |

When dealing with gases that dissolve in a liquid, particularly in water, Henry's law is usually applied (23). In this case the pressure of the solute in the aqueous solution is equal to a constant times the mole fraction of the solute present. This relationship is shown in equation 13.

$$(13)\quad P_{solute} = KN_{solute}$$

When considering the behavior of a volatile herbicide in soil and its relationship to water content, there is another way of expressing Henry's law. This is shown in equation 14.

$$(14)\quad K = \frac{\text{solute as vapor}}{\text{solute in aqueous phase}}$$

The foregoing equation indicates that with a given amount of herbicide as a vapor in the soil, increasing the amount of moisture in the soil will reduce the amount of chemical in the vapor state. This follows because the numerator of the equation decreases as the concentration of chemical in solution decreases.

Another factor in soil behavior of volatile herbicides is the matter of steam distillation or co-distillation. In this phenomena organic compounds having a low water solubility but a measurable vapor pressure will distill with water. This deduction follows logically from application of Dalton's law of partial pressures and Henry's law which shows that there may be a measurable vapor pressure of a volatile solute above an aqueous phase. Under ideal conditions these volatile materials will co-distill with water and do so in a proportion expressed in equation 15.

$$(15)\quad \frac{W_2}{W_1} = \frac{V.P._2\ \text{Mol. wt. } 2}{W.P._1\ \text{Mol. wt. } 1}$$

A number of herbicides are know to distill with water, among them dinitrophenol, EPTC, and other carbamates. In the soil, it is quite probable that both evaporation and co-distillation occur simultaneously. The rate of loss as influenced by co-distillation is apparent from the previous two tables but is shown more conclusively in the following table where evaporative efficiency was measured. In this instance the loss of chemical as a function of water loss was measured at the same temperature. It is apparent that with rapid water evaporation the system failed to attain equilibrium between the vapors with a consequent reduction of efficiency.

Table XII

**Co-distillation Efficiency EPTC, Isothermal**

| | % $H_2O$ Loss | % EPTC Loss |
|---|---|---|
| 1 | 100 | 8.6 |
| 2 | 85 | 14.1 |
| 3 | 65 | 25.8 |

In considering the loss of a herbicide from the soil due to evaporative and distillation phenomena, the rate of removal of the vapor from the few millimeters above the soil surface becomes important. If it were possible, for example, to allow the herbicide to attain its equilibrium vapor pressure immediately above the soil surface and prevent the escape of these vapors, the loss would stop. However, diffusion into the air and removal by air currents and wind proceeds continuously at the soil surface. In this case the loss of chemical is accelerated by causing the concentration of vapors to approach 0 with a subsequent shift of the equilibrium to more and more material vaporizing. This is demonstrated in table X where the rate of loss of chloro-IPC from soil was studied.

The movement of herbicides in soils is of importance in their activity. The two major methods of movement is as a solution or as a vapor. The subject of diffusion and leaching of a material in the soil solution will be taken up later so that to be considered here is the movement of the material as a vapor. The movement of a vapor in a porous solid such as soil is going to be influenced by the porosity or amount of free space in the solid the size of the pores, the amount of adsorption of the vapors by the solid surface and the homogenity of the of the medium. In a given soil the porosity and pore size will be determined in some measure by the amount of moisture. It has been found, for example, that vapor movement is much reduced in a wet soil. The diffusion or movement of a vapor in soil can thus be described by the following equation which was derived from Fick's law of diffusion.

$$(16)\ \frac{N}{At} = CD\,\frac{dp}{dL}$$

Where N equals a mass of the diffusing molecules, A = a cross sectional area, t = time, $\frac{dp}{dL}$ = a rate of change of pressure along some axis, C is a constant for the soil and D = a diffusion of constant.

Examination of this equation shows us immediately that if the media into which the gas is diffusing is not homogeneous the factor $\frac{dp}{dL}$ may approach a constant in one direction but that the change in another direction would be essentially 0. Thus, if a vapor tight barrier was encountered by the diffusing gas, the concentration of vapor would rapidly build up to where the pressure at the barrier was the same as the pressure at the point from which the gas was diffusing. Under this situation the gas then would tend to diffuse in the line of least resistance and a greater amount of it would diffuse in this direction. In the soil one may find hard pans and clay barriers below the point of application which have reduced permeability to the gas. In this case the downward movement of the gas is restricted so that more and more of the gas will tend to diffuse toward the soil surface and escape there through air movement.

It is sometimes assumed that vapors of herbicides, because of their greater molecular weight than air, rapidly settle to lower elevations. This concept is supported by the barometric formula as given below.

$$(17)\ P = P_0 e - \frac{Mgx}{RT}$$

Where P = pressure at some point x, $P_0$ is the vapor pressure, M is the molecular weight, g the acceleration due to gravity, x the distance or length, R the gas constant and T the temperature in degrees absolute.

This equation indicates that a gas will distribute itself in a uniform gravitational field according to its molecular weight. Thus, the greater concentration of gas of higher molecular weight will be found at lower elevations. However, it is important to note that due to the kinetic motion of the gas molecules, a finite pressure will be found at greater heights. Hence while gases do tend to concentrate in a gravitational field, one does not find as distinct layering that is encountered with heavy immiscible liquids when added to water. Thus, the concept that vapors of gases readily sink down through the soil displacing the soil atmosphere is much too naive.

Adsorption as it relates to diffusion of gases is a matter of reducing concentration or of material available for movement. The adsorption phenomena described in the foregoing section under adsorption applies equally well to vapors as to solutes. Of particular interest in the case of the gases, however, is the fact that many of the alkyl or chain compounds have but weak adsorption forces to interact with the soil surfaces and are therefore readily displaced by water.

#### Leaching of Herbicides

The movement of herbicides in soil in association with water is a phenomena of considerable importance in determining the effectiveness of these materials (14,21,24,25,28,36,39,43, 54,55). For the most part, the downward movement or leaching of a chemical is that given the first consideration. However, lateral movement in the soil with water and even upward movement is of great importance. The upward movement as a result of mass upward transfer of water under the influence of evaporation from the surface may concentrate a chemical at the soil surface, thus effectively removing it from the root zone. This concentration at the surface may result in poor weed control or, depending on the chemical, may result in a situation where the phytotoxicity remains too long. Concentration at the surface as a result of evaporation of water is not infrequently experienced in row or furrow irrigation or where subsoil water is abundant. The movement of water downward in soil is thought to be in the form of film and is produced by the combined effects of capillary forces and gravitational forces. Upward movement of the water as in the case of evaporation from the surface is the net difference between capillary forces and gravitational forces. Of particular pertinence to the problem considered here is the rate of permeation and leaching of a given mass of water.

The chemicals of interest in this discussion are applied to the surface of the soil or mixed rather shallowly in the soil. As water arriving at the surface of the soil penetrates, it encounters the sheet of applied chemical, dissolving and carrying the chemical with it as it percolates through the soil. The displacement of the chemical under rapid percolation of water is predominately with the bulk of the water solution. Counteracting this downward movement is the tendency of isodiametric diffusion of the chemical in solution. Where the water percolation is rapid, the bulk movement of chemical will be in direction of water flow but as water percolation becomes slower and slower, that is the mass of water passing through a given point in the soil, diffusion becomes an ever greater factor in determining the ultimate distribution of the chemical in the soil profile.

As the chemical is carried through the soil profile by movement of water, it is in instantaneous equilibrium between the dissolved phase and the absorbed phase. That is to say, some of the chemical molecules in solution are absorbed by the surface of the soil particles and others released. This equilibrium is being constantly re-established as the chemical moves down through the soil. However, it should be noted that at no time will all of the chemical be removed from the solution by adsorption on the surface of the soil particles.

The process of leaching of a chemical through the soil profile may be considered to be analogous to one dimensional paper chromatography. By this analogy, it would be expected that after a given amount of solvent, had passed a given point in the soil profile, it would have carried at least a portion of the chemical down through the soil profile. In this instance there should be some point in the soil profile where a maximum concentration of the chemical would be found.

Such has been found to be the case with several chemicals as reported by different authors (21,48;51,55). The "wave" movement of a solute through the soil profile with water giving rise to bands of high concentration has been noted with chemicals other than herbicides. The "velocity" of this movement in terms of depth of penetration as a function of amount of applied water was described in terms of the following equation (19).

$$(18)\quad y = x\, e\, -\frac{\Delta H}{RT}.\ {}^{1}/_{x}$$

Where y = depth in inches for maximum concentration, x = inches of water, $\Delta H$ = enthalpy of adsorption, T = temperature degrees absolute, and R = gas constant in calories.

The movement of strontium 90, on the other hand has been described in terms of the number of cycles of water (54).

The most rapid and probably most predominant movement of dissolved solutes in the soil is with the mass water movement. It would seem to follow from this that both the direction and path of the movement of chemicals in the soil will be those followed by the water. Thus, it would be expected that the bulk chemical travel would be in the water flow lines found in the soil.

The amount of herbicide carried into the soil by water passing through the sheet of chemical applied to the surface will depend upon the solubility of the chemical (25) the amount of water available to affect solution and the rapidity of with which it moves through the chemical zone. The solubility of a chemical under conditions of equilibrium with the solid or liquid phase is a function of temperature and latent heat of solubility.

$$(19)\quad \text{LogS} = \frac{\Delta H}{RT} + C$$

S = solubility at equilibrium, H = latent heat of solubility, T = temperature° absolute, R = molar gas constant in calories and C = Log solubility at reference temperature.

The rate or speed at which the chemical dissolves under the conditions of the field is a function of not only the foregoing factors but the state of dispersion as well. Thus, with the same amount of chemical, increasing the extent of surface area as with small particles will increase the rate of solution and thus enhance the rate of penetration into the soil.

It may be seen from the foregoing discussion that a compound having a low latent heat of solubility should dissolve rapidly and even under conditions of rapid percolation of water, a substantial amount of chemical would be carried into the soil profile. On the other hand a chemical having a high latent heat of solubility could attain maximum efficiency of penetration only under conditions of slow permeation of the water allowing attainment of equilibrium conditions. The amount of chemical carried in the soil in any case is going to be proportional to the amount of water available to dissolve the chemical and carry it into the soil. Temperature will be a deciding factor in the solution of material. In an instance such as with EPTC a lower temperature will mean a greater amount of chemical will be dissolved in where the converse is true of most other organics.

Consideration of the leaching process suggest that since the solution of at least a small amount of chemical is nearly instantaneous limited quantities of the chemical should be found near the front of the percolating water. This has been difficult to demonstrate because of the relative insensitivity of many of the methods of detection available for this type of study. The advent of radiochemical assay and extremely sensitive chemical methods have permitted the demonstration of the validity of this assumption. The following table clearly supports this point of view in presentation of data in a case of triazines and the chlorinated benzoic acid.

Table XIII

**Leaching of Chemicals in Soil**

| Chemical | Soil Type | In $H_2O$ Added | Depth Max Pen. | Depth Max. Conc. |
|---|---|---|---|---|
| Monuron | Loam (15% $H_2O$) | 1 | 1.75" | 0.25" |
| | Loam (15% $H_2O$) | 3 | 5.75" | 2.0 |
| | Clay (15% $H_2O$) | 1 | 1.65" | 0.25 |
| | Clay (15% $H_2O$) | 3 | 4.5 | 1.75 |
| 2,3,6 TBA | Loam | 3 | 12 | 8 |
| | Peat | 3 | 12 | 2 |
| Simazine | Loam | 12 | 7 | 1 |
| Atrazine | Loam | 12 | 12 | 7 |

It may be noted also that the findings of Upchurch (55) in the study of leaching of monuron in soil further supports the data presented in the above table. Thus, it becomes apparent that a small amount of chemical does follow the water front. The point of highest concentration however, will be function of both soil type and the strength of the bond between the chemical and the soil.

However, it should be noted that the zone of higher concentration becomes more diffuse as the amount of leaching increases. Thus, at the surface of the soil prior to leaching, one might find an extremely high concentration in the surface quarter inch. Following leaching by one inch of water, the zone of highest concentration may be at the two inch depth where the concentration will be approximately one-half that of the zero depth concentration. After leaching with four inches of water, one might find a maximum concentration six inches deep in the soil profile but at about one-eighth the original surface concentration. However throughout the entire soil profile one would find varying amounts of chemical both above and below the zone of maximum concentration. The depth of maximum concentration of chemical in the soil profile would be predicted to be independent of the surface application on the basis of the theory of leaching. That this is true, is illustrated in the following table with benzoic acids. In this instance identical columns of soil were treated with one, two, and four X rates of 2,3,6 TBA. The columns were leached under identical conditions with the same amount of water and the percentage of the amount of chemical in three inch sections of the column determined. The percentage distribution was then calculated from the total amount of chemical in the column.

Table IV

**Depth of Penetration as a Function of Rate of Application of 2,3,6-TBA1/**

| Column Section | Rate | % of Total |
|---|---|---|
| 1 | 1X | ---- |
| 2 | | 20.4 |
| 3 | | 20.4 |
| 4 | | 59.2 |
| 1 | 2X | 15.4 |
| 2 | | 10.5 |
| 3 | | 26.8 |
| 4 | | 47.3 |
| 1 | 4X | 20.1 |
| 2 | | 12.3 |
| 3 | | 31.5 |
| 4 | | 36.1 |

It is apparent from the foregoing table that the penetration is about equal for all rates of application. Likewise, Phillips, (Weeds, 7:284, 1959) in studying the distribution of benzoic acids under field conditions find this to be true also. The absolute amount of chemical at this zone of maximum concentration is, of course, directly dependent upon the surface application.

Under static conditions of soil moisture or where the percolation rate is very slow, diffusion may tend to become a very important factor in determining the distribution of the chemical in the soil profile. Thus, diffusion would be expected to cause a redistribution in the soil profile perhaps flattening the curve of maximum concentration and giving a more uniform distribution throughout the soil profile. Such an interpretation appears to be the case in the work presented by Logan, et. al. (36) with IPC. It was demonstrated that the IPC redistributed upon standing after leaching the columns.

The intensity and frequency of moisture or rainfall would markedly influence the distribution of chemical in the soil profile (55). Thus, the amount of chemical and the depth at which the chemical penetrates depends upon the amount of water percolating through the soil profile to the depth of reference. If the intensity factor is low, the rate of percolation of water will be low also; there will be ample time for redistribution of the concentration of chemical through the diffusion process. The frequency with which water is applied to the soil surface will also be a factor in the sense as the interval between water applications increases there is more opportunity for diffusion and for redistribution through evaporation of water from the soil surface. The very excellent treatise of Upchurch and Pierce (55) of leaching of monuron clearly demonstrates this to be the case. Soil type is an extremely important factor in determining the rate and extent of leaching of a given chemical. Thus, in the equation given by Freed, the distribution in the soil was determined by the strength of binding through adsorption. Thus, with a given amount of moisture to leach the chemical in different soil types, it is obvious that the greater amount of chemical will leach to a greater depth in sandy soils than in clays or mucks. However, closer examination of this situation suggests the possibility that when starting with air dry soil, if sufficient moisture is applied to wet the soils to field capacity to an equal depth, then the chemical will penetrate to about an equal depth in all soil types.

1/ Del Pozo, J., 1959 (14)

Del Pozo (14) in a study of the leaching process confirmed this deduction.

Examination of the foregoing data suggests that by specifying soil type, amount of moisture, rate of percolation and certain physical properties of the chemical, the leaching of that chemical through the soil profile may be predicted at least in a qualitative way. Thus, the velocity of leaching is determined to be the amount of water for leaching and the binding energy of adsorption which was shown previously to be related in a general way to the latent heat of solubility. The absolute amount of chemical carried into the soil under a given set of conditions will be dependent upon this factor and on the absolute solubility of the parent compound.

### The Loss of Herbicides Through Decomposition in the Soil

The final consideration in the behavior of herbicides in soil has to do with loss of these materials through decomposition. This decomposition may arise from photodecomposition in surface applications, chemical reaction or biological attack (2,3,4,5,26). The susceptibility of a compound to photodecomposition is dependent on the compound's makeup which determines its ultra-violet absorbing ability and the effect of this added energy on different bonds in the molecule. Heterocyclic compounds and compounds containing nitrogen appear to be particularly susceptible to this type of attack.

Loss of a biological activity of a chemical in the soil through chemical reaction is determined by the relative susceptibility of that chemical to undergo reactions either in solution or in the adsorbed phase. Many chemicals will undergo oxidation or hydrolysis under these conditions. The case for microbiological decomposition is well documented for a number of herbicides. Such compounds as the aryl carbamates, phenoxyacetic acids, phenylureas and triazines have all been shown to undergo microbiological degradation.

The point to be discussed relative to decomposition of herbicides in soil is that of the physical chemistry of the process. It was reasoned by Burschel and Freed (7) that this loss should follow a first order rate law. It may be adduced that since the soil, the moisture and the microorganisms of the soil are in such abundance that the rate limiting component should be that of the herbicide itself. Exploration of this concept in a case of IPC, CIPC and aminotriazole demonstrated that this was valid for these cases. It was shown that a parameter, namely the enthalpy of activation, could be derived from the data obtained. This parameter can be used in predicting the extent or length of residual life of a compound in the soil where decomposition was a major factor in loss of activity. This has been subsequently substantiated using other materials (6,8).

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# PERSISTENCE OF HERBICIDES IN SOILS

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The persistence of herbicides in soils may be temporary or extremely prolonged; and residual toxicity depends on the herbicide, soil type, and environmental variables. Temporary soil sterilants dissipate rapidly, often within a few days and usually within a few weeks. Semipermanent soil sterilants may persist in soils for 1 year or more in sufficient quantities to control weeds.

Problems in soil persistence are often encountered. When relatively persistent organic herbicides are applied for selective weed control in resistant crops, sufficient residues may remain in the soil to injure susceptible crops planted the following year or crop season. On the other hand, prolonged persistence of soil sterilants on noncropped areas may be desirable.

In this paper the relations of persistence to soil properties and processes and environmental variables will be discussed, and recent results and developments on the persistence of herbicides in soils will be presented.

## Variables Influencing Herbicide Persistence

*Soil properties and processes.* When a herbicide is applied to soil, several processes may influence its persistence. Vaporization, chemical reactions, photochemical alterations, leaching, and adsorption and metabolism by microorganisms and by higher plants are directly involved to some degree in the disappearance of herbicidal activity from soils.

Solution and adsorption indirectly influence persistence through their effects on availability in the soil solution, which determines leaching and absorption by microbes and higher plants.

The amount of soil water, the water solubility of herbicides, and the degree and tenacity of soil adsorption may have considerable influence on the persistence of herbicides. Most organic herbicides are leached more readily in sands and sandy loams than in clay loams, clays, and soils high in organic matter. This relation is a function of the adsorptive capacity of soils and the percolation rate of water through soils, and herbicide inactivation is promoted by dilution and adsorption as herbicide molecules are moved into untreated soil.

Soil properties such as structure, type and amount of clay, and organic matter affect herbicide persistence indirectly through their effects on the soil processes enumerated.

The persistence of herbicides in soils may be influenced indirectly by soil reaction. pH affects adsorption, chemical reactions, herbicide solubilities, and growth of microorganisms.

From the standpoint of number of herbicides affected and the amount of change or loss of activity, absorption and metabolism by microorganisms and leaching appear to be most important.

Most organic herbicides are inactivated more rapidly in soil under conditions optimum for growth of microorganisms than in autoclaved soil or soil altered in some other manner to eliminate soil microorganisms or to retard or prevent their growth.

Once bacteria capable of inactivating 2,4-dichlorophenoxyacetic acid (2,4-D) have multiplied in the soil, the capacity of the soil to inactivate additional applications of 2,4-D is far greater than before the initial application (5). Proliferation of effective microorganisms does not seem to occur with other important groups of herbicides.

Soil persistence of the phenylureas and *s*-triazines is enhanced by treatments which inhibit the growth of soil microbes; but under most favorable conditions for growth, so-called "enrichment" of the soil or proliferation of microorganisms apparently does not occur. Two suggestions may be offered for this type of degradation: (a) certain microorganisms may utilize these herbicides but not preferentially to other energy sources, and the added organic matter (the herbicide) is not sufficient to promote an increase in the general bacterial population and (b) adsorption-desorption equilibria determine the rate of inactivation; the adsorption-desorption equilibria of these herbicides may lie toward the adsorbed state so that the concentration in the soil solution remains low, and slow uptake and metabolism by microorganisms results. Because the rate of inactivation of these herbicides seems to follow a first-order reaction (15), the adsorption-desorption mechanism for influencing microbial inactivation rates seems most feasible. Neither of the two suggestions has been investigated, and reliable conclusions regarding inactivation relations cannot be given.

Research by Audus (4) and Whiteside and Alexander (19) showed that 2,4,5-trichlorophenoxyacetic acid (2,4,5-T), 2-(2,4-dichlorophenoxy)propionic acid (2-(2,4-DP) ), 2-2,4,5-trichlorophenoxy)propionic acid (silvex), and 4-(2,4,5-trichlorophenoxy)butyric acid (4-(2,4,5-TB) ) were not readily inactivated by soil microorganisms. Although Audus (5) recently discussed experiments in which 2,4,5-T was changed more rapidly than 2-methyl-4-chlorophenoxyacetic acid (MCPA), in previous work 2,4,5-T was not readily degraded by microorganisms and was much more persistent than MCPA. Perhaps phenylacetic and benzoic acid herbicides are relatively resistant to microbial degradation; their inactivation in soils may occur largely by other means.

The persistence of certain chlorinated phenoxyacetic acids, carbamates, and phenylureas in soil is related to halogenation of the benzene ring (5,10,11,12,17). The results of Alexander and Aleem (1) showed that resistance of chlorinated phenoxyalkylcarboxylic acid herbicides or their derivatives to microbial degradation was governed by the position of the halogen rather than by the number of halogens on the ring. The linkage and type of aliphatic side chain also influenced susceptibility to microbial breakdown. Conversely, Audus (5), in summarizing work from his laboratory, concluded that there was no obvious relation between rapidity of microbial inactivation and substitution on phenoxyacetic acids; however he maintained that the position of a chlorine substituent made some difference. For example, in a garden loam 2-chlorophenoxyacetic acid (2-CPA) persisted for more than 360 days, whereas 4-chlorophenoxyacetic acid (4-CPA) dissipated in 12.1 days, 2,4-D in 16.0 days, and 2,4,5-T in 47.5 days. Thus phenoxyacetic acid with a chlorine in the *two* position of the ring and without additional substituents was extremely persistent. Compounds with a chlorine in the four position, with or without additional substituents, were much less persistent.

The decomposition of 3-amino-1,2,4-triazole (amitrole) was largely by microbial action (2,9), and the optimum temperature for decomposition was between 20 and 30° C (9). Dissipation of amitrole was also more rapid in soils of medium and high moisture than in dry soils (9). Variability in rates of amitrole decomposition among soils suggested differences in soil microbe populations or activity levels. In contrast to the results of Day et al (9), those of Ercegovich (13) showed that the rate of disappearance of amitrole from Hagerstown silt loam increased with temperature up to 100° C, the highest temperature used. Some process other than microbial absorption and metabolism was obviously the dominant degrading mechanism in Ercegovich's experiments.

In greenhouse experiments the residual toxicity of methoxy-*s*-triazines disappeared more slowly from soils than that of corresponding chloro and methylmercapto derivatives. In these experiments the soils containing the herbicides were confined in metal cans, and leaching did not occur. In the field the persistence of these herbicides may be considerably different. Herbicides are inactivated by soil adsorption and soil dilution as they are moved by water; and because of differences in water solubility and soil adsorption, leaching rates and, accordingly, the dissipation rates would vary.

Under proper environmental and soil conditions, some herbicides are lost rapidly from the soil surface by vaporization. Some herbicides with very low vapor pressures may slowly evaporate or sublime, and over a long period significant amounts may be lost from the soil surface.

Ethyl N,N-di-*n*-propylthiolcarbamate (EPTC) disappears rapidly from soils moist at the time of application (14), and the loss appears to be related to the amount of water present at the time of application or to the amount of water evaporated. EPTC was extremely persistent in dry soils, and retention against vapor loss appeared to the attributable to adsorption to soil particles (14). EPTC vapors were sorbed in greater amounts by dry soils than by wet soils (3). Adsorption appears necessary to prevent loss of EPTC from soil surfaces. Soil incorporation and subsurface application of EPTC are often superior in effectiveness and duration of weed control to conventional surface applications probably because vapor loss is reduced by these practices.

The persistence of EPTC was influenced by the solvent used in application (8). Technical EPTC applied in kerosene disappeared more rapidly from soils than the commercial formulation of ETPC in water and technical EPTC in acetone, benzene, or xylene. In early evaluations of carbamates as herbicides, effects of solvents and subsurface placement on herbicidal activity and soil persistence were usually not considered. Compounds previously bypassed because of variable performance may eventually be more useful as their behavior in soils is better understood (8).

*Environmental variables.* Temperature, rainfall, wind, and sunlight affect the persistence of herbicides directly and indirectly through their effects on soil processes. Temperature affects vaporization, adsorption, chemical reactions, absorption and metabolism by microorganisms and higher plants, solubility, and leaching. In addition to directly causing movement and dilution in the soil, rainfall and irrigation supply water to the soil; and water is essential for the occurrence of many of the processes which promote the dissipation of herbicides from soils. Air movements influence vaporization and, therefore, loss of herbicides from soils.

In recent years considerable interest in the effects of sunlight on herbicides applied to soils has arisen since Hill et al (15) reported that 3-(p-chlorophenyl)-1,1-dimethylurea (monuron) was changed on exposure to sunlight. Weldon and Timmons (18) showed that the biological activities of monuron and 3-(3,4-dichlorophenyl)-1,1-dimethylurea (diuron) were greatly reduced by exposure for 28 hours to radiation from a mercury vapor lamp. Rake (16) reported that granular forms of organo-borate herbicides were photo-inactivated about half as much as the unformulated organic components.

In an experiment conducted in cooperation with the California Agricultural Experiment Station, the activity on monuron and diuron disappeared more rapidly from soil exposed to the sun than from shaded soil (Table I). The activity of monuron and 2-chloro-4,6-bis (ethylamino) -*s*-triazine (simazine) disappeared more rapidly from moist soil than from dry. Although the soil was autoclaved before treatment, contamination was certainly possible; therefore the effect of soil moisture might have been due to microbial activity or to physical processes. Soil temperature was not controlled in this experiment, and soil temperatures varied considerably among treatments during the day. Vaporization and chemical reactions are influenced by temperature. Therefore the portion of the herbicides inactivated by the direct effect of sunlight in this experiment cannot be estimated with any certainty.

Table I. **Effects of sunlight exposure, soil moisture, and position in the soil on the persistence of monuron, diuron, and simazine.**

| Treatment | Percent of herbicide remaining 80 days after application | | |
|---|---|---|---|
| | Monuron | Diuron | Simazine |
| Sunlight | 35 | 27 | 34 |
| Shade | 68**[a] | 49* | 39[ns] |
| Moist Soil | 44 | 36 | 30 |
| Dry Soil | 59** | 40[ns] | 43** |
| Surface | 48 | 36 | 35 |
| Subsurface | 55[ns] | 41[ns] | 38[ns] |

[a]Each statistical symbol describes a difference between two values.
*Significant at the 5 percent level.
**Significant at the 1 percent level.
[ns]No significance.

Recently at Beltsville, Maryland, we found that 3-amino-2,5-dichlorobenzoic acid (amiben) is rapidly changed by sunlight. When a $10^{-3}$ molar aqueous solution of amiben was exposed in quartz cells to sunlight, a 50-percent change occurred in 6 hours. The amount of amiben present after exposure was determined by a colorimetric method involving diazotization and coupling with chromotropic acid. Therefore the results indicate a 50-percent loss of the amino substituent during the exposure. Preliminary tests indicate a concurrent loss of herbicidal activity. Study of irradiated samples by paper chromatography suggests the presence of at least one major and three minor products. This work will be continued to determine the effects of sunlight on amiben applied to soils.

Investigations in which decomposition or inactivation could be attributed unquestionably to the direct effects of light have been conducted only in the laboratory. It is impossible to estimate accurately the magnitude of photochemical alteration in the field. Greater losses attributable to photoinactivation probably occur in the arid west than in humid regions where herbicides are moved by rainfall into the soil (15). The important consideration from the standpoint of weed control is that the activity of some herbicides is reduced by exposure to sunlight. However, if the magnitude of photochemical alterations is to be determined when the herbicides are actually on the soil surface, vaporization as a complication in the measurements must be eliminated.

### Accumulation of Herbicides in Soils

Inactivation rates of several herbicides including diuron and simazine are related to the initial concentrations of the chemicals in soils (6,15, Table 2). Theoretical calculations based on this interpretation show possible accumulation levels in soils. If 80 percent of an annual application of 2.0 pounds per acre is inactivated each year and this application is repeated indefinitely on the same soil, the amount present in the soil prior to each application would eventually approach 0.5 pound per acre. With an annual application rate of 4 pounds per acre and 80-percent loss, the amount in the soil just before the annual application would approach 1.0 pound per acre. If the annual decomposition rate is 50 percent of the total at the beginning of the year, the amount in the soil just before the annual application would eventually approach the amount added each year. Rates of inactivation of herbicides vary tremendously with chemical structures, soils, and climates. Therefore, carry-over of the persistent selective herbicides can be expected under some conditions; but the possibilities of massive accumulation seem rather remote.

Table II. **Percent of monuron and simazine remaining in Yolo clay loam 13 months after soil incorporation.**

| Herbicide | Concentration applied | | |
|---|---|---|---|
| | 5 ppmw | 10 ppmw | 20 ppmw |
| Monuron | 32 | 34 | 32 |
| Simazine | 24 | 25 | 19 |

The concept that the rate of inactivation is related to the rate of application explains why massive doses of organic soil sterilants will not persist in sufficient quantities in the soil to control weeds for several years.

The ideal approach to preventing carry-over of toxic residues from a treated crop to another is to develop herbicides which control weeds adequately yet dissipate before planting time of another crop. The ideal is difficult to attain; but suitable rotations permit the use of herbicides, the persistence of which may be sufficient to injure very susceptible species.

The observation that polysulfide enhances the breakdown of simzaine in soil (7) should be followed by investigations to determine the usefullness of this finding in solving field problems. Application of this substance to land containing active simazine residues may provide a means of eliminating within a short time the toxic residues which would otherwise prevent the establishment of sensitive crops.

## CONCLUSIONS

In modern agriculture several different pesticides are often applied to the same crop. These pesticides vary widely in chemical structure, biological activity, and persistence in plants and soils. Little or no consideration has been given to combined or total pesticide residues in soils or to the possible effects of one pesticide on the persistence of another. In the future, scientists must consider possible interactions among pesticides with respect to to inactivation in plants and soils.

Considerable data on the movement and persistence of herbicides in soils have been collected, and many of these data have been widely used in the development of weed control practices and, as well, some have been fundamentally interpreted. The need is still great however, for establishing fundamental principles of soils relations of herbicides, old as well as new ones, and for developing practical solutions to many field problems of soil persistence and variable performance.

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# MOVEMENT OF HERBICIDES IN SOILS AND PLANTS

A. S. CRAFTS

Two important factors may be largely responsible for the effectiveness of soil-borne chemicals as herbicides. First is the availability of the chemical to plants as determined by its location in the soil, its concentration in the soil solution, and its supply as related to solubility, adsorption and fixation by soil colloids. Second is the uptake and movement of the chemical by plants. Experiments have shown that herbicide molecules may be handled quite differently by the plant, some being rapidly absorbed and translocated, others being accumulated in roots and moved relatively slowly. There is also evidence that different plant species react specifically to chemicals with respect to uptake from soils; selectivity of soil-borne chemicals may well relate to such differences.

When herbicides that have their primary action on or through the roots are applied to the soil surface, it is obvious that they need to be distributed into the zone of absorbing roots by leaching, vapor movement, or physical incorporation. And as they come into intimate contact with moist soil they are subject to a number of forces inherent to the soil that determine their availability to plants.

Cationic compounds in moist soil are immediately affected by the base-exchange complex, a phase of the soil colloidal system present in all soils but of widely varying contents and properties. Fixation in this complex explains the rapid immobilization of ammonia in soils; it probably has a similar action on the pyridilium herbicides diquat and paraquat that have quaternary nitrogen in their molecules. These compounds are known to be rapidly detoxified in soils.

Many herbicidal toxicants are anionic; these do not react with the replaceable-base complex but they may be subject to other forces that restrict their movement such as van der Waal's intermolecular attractions, secondary valences, hydrogen bonding and even precipitation as insoluble compounds of soil bases. Many of the newer organic herbicides are weakly dissociated or nonionic. These compounds are also subject to van der Waals' and secondary valence bonding forces and while water solubility may be an index of their polarity, there is no sure basis for predicting how each compound will behave with respect to movement of water through the soil. Toxicity and leaching tests are necessary to discover the behavior of such compounds in soils, and work of this kind is needed in much more detail than is generally done.

Not only do we need data on toxicity, fixation, and leachability of soil-borne herbicides in soils; all pesticides eventually reach the soil and hence all of these that are field applied should be studied in the soil with respect to initial toxicity, fixation, mobility, and detoxification. Only as a result of such complete knowledge can we use pesticides intelligently and safely; recent difficulties with pesticide residues are mute evidence for such needs.

## Soil Reactions of Some Herbicides

Three distinct properties of herbicides in soils are relevant to their effectiveness, (1) fixation as related to their availability to plants, (2) bonding as related to their mobility and hence locality, and (3) lability with respect to decomposition and detoxification. A number of herbicides will be listed and these properties will be given so far as they are known.

*Arsenic*

The arsenite ion is the toxicant of the common sodium arsenite and arsenic trioxide herbicides. This ion in the moist soil is rapidly fixed in the crystal-lattice structure of kaolinitic clays and rendered unavailable and relatively nonmobile. Whereas 10 ppm of $As_2O_3$ is arsenite ion in culture solution completely inhibited growth of oats, in Aiken clay loam 340 ppm in the soil (air-dry basis) had no inhibitory effect. Arsenic, being elemental, is not subject to detoxification by breakdown. It is somewhat mobile in inverse relation to soil colloid; eventually it is lost by leaching.

*Boron*

Borates in soils are lightly fixed by soil colloids; toxicity may be reduced 50 percent in a heavy clay soil. Borates held in the surface layer may be leached from a 3 foot column of a clay soil by 6 surface inches. Borates may be precipitated as calcium or magnesium salts; they may complex with organic molecules; they vary in $O_2$ content; but the boron cannot be decomposed.

*Chlorate*

Chlorate ions are freely mobile in the soil moving directly in solution in the soil moisture. They are not fixed but they do decompose; decomposition is relatively rapid in warm moist soils.

*Thiocyanate*

Ammonium thiocyanate proved to be highly toxic and freely mobile in soils; however, it broke down rapidly and completely in time. Apparently the thiocyanate ion is neither fixed nor bound in soils but it is subject to bacterial decomposition, and the nitrogen and sulfur released eventually have a stimulating action on plant growth.

*Sulfamate*

Ammonium sulfamate is comparable with sodium chlorate in toxicity in the soil. It is not strongly fixed nor firmly bound. It lies between thiocyanate and chlorate in rate of decomposition.

*Substituted phenols*

Dinitro cresol and its salts are toxic in soils in proportion to the amount of cresylate ion present; cresylate ion is lightly fixed by soil colloids and mobility is inversely proportional to clay content; retention is intermediate between arsenite and borate. Decomposition is microbial and quite rapid in fertile soils; residues should not constitute a problem in soils where these compounds are used either as selective sprays or for pre-emergence treatment.

Dinitro secondary butyl- and amyl-phenylates resemble the cresylate except that they are inherently around three times as toxic; fixation, bonding, and lability are similar.

Pentachlorophenol and its sodium salt are extensively used in sugar cane, pineapples, and other tropical crops. In initial runs pentachlorophenate resembled dinitrocresylate in toxicity; it is not fixed nor retained by clay colloids; it is highly persistent possibly because of its biocidal activity against micro-organisms. Repeated use at phytocidal dosages has not resulted in soil toxicity under field use in Hawaii.

*Chloro-phenoxy compounds*

2,4-D and its analogues are lightly fixed being most toxic in sandy soils. They are also lightly bound and hence somewhat retained in the surface soil. These compounds are highly labile being completely decomposed by the second cropping in all but the lightest soils. In the soil tests there was no simple relation between toxicity and soil characteristics and because the applications were based on the air-dry soil, differences in toxicity probably reflected mainly the concentration of the toxicants in the water required to bring the soils to field capacity. Rate of breakdown also enters the picture; it indicates little liability to accumulation of toxic residues from use of these herbicides as selective sprays or as soil treatments.

*Carbamates*

Although IPC and CIPC are widely used, soil-borne herbicides, little work has been done on their behavior with respect to soil properties. Being low in solubility they are formulated either as emulsifiable esters, as dry powders or as granules. Because they are active in the range of from 1 to 10 ppm in a solution culture and in the range of from 10 to 100 ppm in soils it may be concluded that they are not strongly fixed by soil colloids. Since application to the soil surface followed by light to medium rainfall will bring about their characteristic effects on mistosis in roots in the soil it seems that they must be reasonably mobile. IPC has proved highly labile in warm moist soils; CIPC is much more resistant to breakdown but it seldom presents a residue problem hence it must decompose between normal crop cycles.

*Substituted urea and triazine herbicides*

The substituted urea and triazine herbicides that are in greatest use are low in water solubility. Their toxicity is reduced by organic matter in soils and to a lesser degree by clay colloids. Their toxicity decreases with time and successive cropping but of all the herbicides studied these compounds are the most persistent. Leaching displaces these compounds downward in soil columns the more water-soluble ones leaching the most freely. Decomposition of these compounds results from hydrolysis, from microbiological attack and by absorption by tolerant plants (turkey mullein; monuron; corn; simazine). Detoxification is favored by high soil temperature, available moisture, and by organic matter and clay colloids. The less-soluble compounds are very persistent, compared with most organic molecules. Simazine, propazine, diuron, and neburon are used as soil sterilants and reapplication at yearly intervals usually maintains a weed-free condition.

*Chloroacetamides*

Randox and Randox-T are herbicides based on the alpha chloro-N,N-diallylacetamide molecule. This compound is highly soluble in water and is readily leached. It is not strongly fixed and it performs well in soils high in clay or organic matter. When incorporated in moist soil it does not require rainfall to be effective. Breakdown occurs with the production of glycolic acid and diallylamine; when used as a pre-emergence treatment no difficulty has been experienced from toxicity to subsequent crops.

*Chlorinated aliphatic acids*

TCA is a grass killer used through the soil; it is highly water soluble and is readily leached. There is little evidence for fixation of TCA and breakdown is rapid in warm moist soil, slow in cold soil. Persistence is influenced by rainfall, temperature, soil type, and organic matter content. This herbicide has been widely used to control annual grasses in vegetable and field crops and soils are usually free of residue two months or less after its application.

Dalapon is a translocated, water soluble grass killer. It is not normally used through the soil but being resistant to breakdown it may bring about crop injury through soil residues, particularly in trees and vines. There is no evidence for fixation of dalapon; it is readily leached; it is only slowly decomposed in soils and plants.

*Chlorinated aromatic acids*

TBA is a translocated herbicide that is active both through the plant and through the soil. It is readily absorbed by roots of bean, field bindweed, Russian knapweed, and other plants. There is little evidence on fixation of TBA is soils; it leaches readily; it resists breakdown and may persist in active form for a year or more. This makes it useful against perennial weeds and water may be used to remove it once the weeds are killed.

Banvel D(2-methoxy-3,6-dichlorobenzoic acid) is a new herbicide that is effective both as a foliar spray and as a soil-borne weed killer. Since testing has proved it effective as a spray against a number of perennials it apparently translocates as does TBA. Its dosage rate ranging from 1 to 10 pounds per acre indicates little or no fixation by soil colloids. At the same time recommendations on control of witchweed, Russian knapweed, leafy spurge, perennial sow-thistle, and field bindweed at from 4 to 15 pounds per acre suggest ready leaching to the roots of these perennial weeds. The fact that sugar cane displayed no injury from repeated applications at 8 pounds per acre suggests that breakdown is rapid in warm moist soils.

Fenac (2,3,6-trichlorophenylacetic acid) is a water soluble compound of strong herbicidal action. It is strongly fixed by soils but in an available form. It is proving useful as an aquatic weed killer and it has the property of persisting throughout the season of application in the soil that constitutes the sides and bottoms of ditches and lakes. It resists leaching and is not readily decomposed. It is useful against a number of perennial weeds by soil application.

*Thiol and dithiocarbamates*

Vegedex, 2-chloroallyl diethyldithiocarbamate in a pre-emergence material than is selective against grasses. Its principle use has been in vegetable crops. It is not strongly fixed; it leaches readily; and it breaks down rapidly leaving no toxic residue.

Vapam, sodium N-methyldithiocarbamate is a water soluble compound that decomposes in warm moist soil to form a toxic vapor; it may be looked upon as a soil fumigant. Most effective in light soils Vapam is fixed but soon decomposes. It leaches quite readily; after decomposing the vapor moves through and out of the soil leaving no toxic residue.

Eptam, ethyl N,N-di-n-propylthiolcarbamate is a clear, volatile liquid slightly soluble in water that is used by soil incorporation as a pre-emergence herbicide. It is strongly fixed in heavy soil but is removed by volatilization. The vapor is strongly adsorbed by dry-soils; more so by clay than by sandy soils. Detoxification is by volatilization, fixation, and decomposition.

Tillam, propyl ethyl-*n*-butylthiolcarbamate resembles Eptam but has different selectivities. It has proved useful in sugar beets and in field planted tomatoes. From its chemical properties one night expect that the vapor would be strongly adsorbed and that detoxification would involve volatilization, fixation, and decomposition.

*Endothal, Aquathal*

Used for many years as a contact herbicide, endothal has recently been found to perform well as a selective pre-emergence herbicide in sugar beets. Little is known of the reactions of this compound with soils; it resists leaching, is readily absorbed by plant roots, and is decomposed leaving no toxic residue.

*Alanap (NPA)*

Alanap is a trade name for a group of compounds having N-1-naphthylphthalamic acid as the toxicant. Used through the soil these compounds are toxic to a variety of weeds; members of the cucurbit family are tolerant as are a number of other field and vegetable crops. Being low in water solubility the Alanaps are applied as water suspensions or as pellets. They resist leaching and they break down so as to leave no toxic residue after harvest of the treated crop.

*Additional compounds*

Additional soil-borne herbicides that have been screened and tested include:

| | | | |
|---|---|---|---|
| Alipur | Carsonate | Falone | Prometryne |
| Ansar | Caseron | Hyvar | Propazine |
| Aretit | Celatox | Ipatone | Sesin |
| Atratone | Chlorazine | Ipazine | Sesone |
| Atrazine | Dacthal | Karsil | Simetone |
| Avadex | Dicryl | Methin | Simetryne |
| Bandane | Dinoben | Mylone | TCB |
| Banvel T | Diphenamid | Natrin | Trietazine |
| Bi PC | Dipropalin | OMU | Trifluralin |
| Biuret | Disodium methyl arsonate | PBA | Urab |
| Cacodylic acid | | Proban | Urox |
| Calcium methyl | Erbon | Prometone | Zytron |

Of this great number of compounds, little is known of their behavior in soils. In addition to these there are probably as many or more on test under code numbers. Many of these will eventually prove useful and hence be named and placed on the market. All such chemicals should be studied in soils so that their effects on plants, their breakdown, and their residual properties may become known.

With respect to the three properties; fixation, bonding, and lability that have been mentioned as being important, in general a chemical that is effective at dosages of a pound or so per acre is probably not highly fixed; a compound that is highly water soluble and that is effective against deep-rooted perennial weeds when applied to soil must leach readily; a compound that is highly toxic upon application but which leaves to toxic residue for subsequent crops must decompose rapidly. These indications, often expressed in technical data sheets containing no data of fixation, leachability, or decomposition, can be used as rough measures of the basic behavior of soil-borne herbicides.

## Translocation of soil-borne herbicides in plants

Chemicals that are applied as herbicides to plants via soil show a wide range of mobility in plants. Studies using radioactive tracers prove that most herbicides applied to roots through culture solution are rapidly and rather strongly sorbed by the roots; migration to the xylem and translocation to the tops is a different matter. Whereas monuron and simazine were rapidly transported to the tops of plants, phosphate, amitrole, and dalapon required several hours to translocate and maleic hydrazide, 1AA and 2,4-D moved upward only after 2 to 4 days. Urea did not leave the roots within the 8-day period of the experiments.

Table 1 presents data on the sorption of 24 labeled tracers by roots of bean plants and their transport of hypocotyls, epicotyls, and leaves. From these data it is evident that some compounds are rapidly absorbed and moved, some are moved relatively slowly, and some may be unable to pass through the roots and reach the foliage. Recent tests using dichlorophenol in conjunction with 2,4-D indicate that this inhibitor uncouples oxidative phosphorylation in the root cortex and reduces the potential of the cells to retain solutes by active accumulation. As a result accumulation of 2,4-D is significantly reduced at the same time that transport to tops is appreciably increased. This would seem to strengthen the concept that retention of 2,4-D by roots is not a passive sorption but an active accumulation.

Table 1

**Translocation patterns of 24 labeled tracers in bean plants, averaged results/1**

| | | Root Application | | | |
|---|---|---|---|---|---|
| | | Sorption by root | | Transport to tops | |
| No. | Compound | Amount | Hypo | Epi | Leaves |
| 1 | Alanap | ++ | + | + | + |
| 2 | Amiben | ++ | O | O | O |
| 3 | Aminotrizaole | ++ | + | + | ++ |
| 4 | Ammonium thiocyanate | ++ | + | + | ++ |
| 5 | Atrazine | ++ | + | + | ++ |
| 6 | Barban | +++ | + | + | + |
| 7 | Dacthal | ++ | + | + | tr |
| 8 | Dalapon | + | ++ | + | tr |
| 9 | 2,4-D | ++ | +++ | tr | O |
| 10 | 2,4-DB | +++ | + | + | + |
| 11 | Duraset | ++ | + | + | + |
| 12 | Eptam | ++ | ++ | ++ | ++ |
| 13 | 2060 | +++ | ++ | ++ | + |
| 14 | Maleic hydrazide | ++ | + | + | tr |
| 15 | Monuron | ++ | ++ | ++ | +++ |
| 16 | 1607 | ++ | ++ | ++ | + |
| 17 | 3-CP | ++ | tr | tr | O |
| 18 | 2061 | +++ | +++ | +++ | ++ |
| 19 | Simazine | ++ | + | + | ++ |
| 20 | Sodium acetate | +++ | tr | tr | O |
| 21 | Sodium benzoate | +++ | tr | tr | O |
| 22 | 2,4,5-T | ++ | tr | tr | O |
| 23 | 2,4,5-TB ester | ++ | tr | tr | O |
| 24 | TCP | ++ | tr | tr | O |

1/ The symbols used are as follows: tr = a trace,
+ = light gray,
++ = dark gray,
+++ = black.

# HERBICIDES AND SOIL MICROORGANISMS

W. B. BOLLEN

Two questions involved with the use of agricultural chemicals are: will they injure fertility of the soil? will soil microorganisms destroy agricultural chemicals? The widespread use of pesticides, amounting to millions of pounds on millions or acres per year, is cause for concern as to the effects of these highly potent chemicals on soil microorganisms of significance to soil fertility. Indispensable functions of these microbes include the following:

1. *Decomposition of organic matter* to liberate plant nutrients and form humus.
2. *Ammonification,* the liberation of ammonia from proteins and other organic nitrogen compounds.
3. *Nitrification,* the oxidation of ammonia to nitrate, which under some conditions is the nitrogen source most suitable for plant nutrition.
4. *Nitrogen fixation,* by which gaseous nitrogen in the soil solution is combined in products that directly or indirectly become available plant food.
5. *Sulfur oxidation,* which converts elemental sulfur, sulfides, and organic sulfur compounds into assimilable sulfate form.
6. Direct interaction on and immediately around plant roots in the *rhizosphere.* In this zone microbes exert symbiotic, stimulating, antagonistic, and pathogenic effects.

Study of interactions between pesticides and soil microorganisms is beset with several difficulties that must be considered in interpreting results.

1. If a pure chemical compound is not used, the effects may be altered by isomers, carriers, solvents, diluents, synergists, stabilizers, or other adjuvants.
2. Extremely low rates of application used in field practice are difficult to reproduce uniformly with small amounts of soil in the laboratory. In many instances it is required to mix less than a milligram of chemical with 100 grams of soil. If, as is often the case, the compound is insoluble in water, the difficulty is compounded; other solvents are likely to produce their own positive or negative effects. In addition to these low rates corresponding to field practice, rates 10 to 100 times higher are often employed in the laboratory to ensure more uniform distribution, force extreme results, and cover variations likely to occur with nominal applications in the field. Although a treatment of 50 lb. per acre corresponds to 25 ppm if distribution to a depth of 6-2/3 in. is uniform, most methods of application result in zones giving lateral and vertical mosiacs of concentrations varying from 0 to possibly more than 100 ppm.
3. Laboratory studies on soils under controlled conditions give results that may not necessarily follow in the field, where changes in environmental factors, drainage, and plant roots introduce variables. Tests on field samples are necessary for practical conclusions but become cumbersome and time consuming because of the large number of samples required to compensate for variations in pesticide distribution.
4. Physical and chemical as well as microbial influences are involved in transformations of chemicals applied to the soil. Our present knowledge is insufficient to distinguish these, and to adequately assess the role of each in different soils. The sorptive and ion exchange properties of clays and organic matter are especially important. A comprehensive study would involve identification of these components and determination of their specific effects on given compounds in sterilized soils.

From the standpoint of microorganisms present in different soils the variation is quantative rather than qualitative. With few exceptions the same morphological and physiological types of microorganisms occur in all soils. Their numbers and activities vary with environmental factors, including moisture, temperature and other radiant energy, aeration, pH, food, and biological interations. Kinds and amounts of organic matter as well as extremes of the other factors have marked influence. Under appropriate conditions it is likely that any chemical applied to any soil will be attacked by some representatives of the native microflora. Rate of the transformation will be determined by soil type and the existing combination of factors of environment.

Of all the pesticidal chemicals, organic herbicides appear most susceptible to microbial attack. In many instances this is fortunate, because to avoid injury to subsequent seedlings of a desired crop it is necessary that the herbicide be detoxified. Substituted ureas, especially, are attacked with relative rapidity, and to a large extent by some species of *Pseudomonas*. Others can utilize dinitro compounds but not ureas, and still others, both types of compounds. Calcium cyanamid, often used on asparagus after discing in spring, serves first as a weed killer and subsequently as a nitrogenous fertilizer through transformations effected, at least in part, by microorganisms. Persistence of fatty acid-type herbicides can be valuable for specific crops, but toxicity to succeeding crops may make rapid detoxification desirable. This detoxification is largely or entirely biological, because the active compounds remain for long periods in sterile soil.

*Corynebacterium simplex*, a common soil microbe, can utilize DNOC as a sole source of carbon and nitrogen. Other species as well as some *Arthrobacter, Achromobacter, Bacterium, Pseudomonas*, and representatives of the actinomycetes decompose 2,4-D and other chloraacetic acids. Dalapon, monuron, DNOC, and other related herbicides can be used as energy sources by many soil microorganisms. Chlorine substituents favor attack by *Corynebacterium* and other gram-positive organisms. Carbamyl, cyano, or nitro groups favor attack by gram-negative bacteria, especially *Pseudomonas*.

Of the molds, some species of *Acrostalagmus, Aspergillus, Trichoderma*, and others have been shown to attack 2,4-D and similar compounds.

Herbicides vary in their effects on soil microbes. The same herbicide often effects different kinds of microbes differently, while different chemicals vary widely in their effects. Moreover, a given herbicide often exhibits a spectrum of influence ranging from none through stimulatory, inhibitory, and germicidal as concentration increases. Maleic hydrazid, a true growth inhibitor, in concentrations used as a herbistat, appears inactive against bacteria. Monuron is extremely toxic to algae. *Azotobacter* and *Pseudomonas* are resistant to high concentrations of 2,4-D, while *Bacillus cereus* is less resistant. MCPA depresses growth of *Aspergillus niger* and other molds.

Environment may strongly influence the effect of an herbicide. 2 ppm of 2,4-D inhibits nitrification in solution cultures but 100 ppm in soil does not severely check the process. In certain soils dalapon was found to depress nitrification for one month, monuron for three months. After this time the organisms not only recover their activity, but also become adapted so that second applications are less depressive. Sodium propionate applied to soil at 100 ppm greatly depresses molds but considerably increases total bacteria. *Azotobacter chroococcum* is stimulated by 2,4-D at 100 ppm but is inhibited by 200 ppm; *A. agile*, on the other hand, is stimulated at even the 1000 ppm level. Fenac is toxic to *Nitrobacter*, which oxidize nitrite to nitrate, but has little effect on *Nitrosomonas*, the ammonium oxidizing bacterium.

In studying the effect of 5 and 100 ppm of 2,3,6-TBA, EPTC, diuron, and simazine on respiration in nine widely different Oregon soils, it was found that in most cases, the herbicides decreased $CO_2$ evolution for at least 28 days, after which the inhibition decreased considerably at the end of 56 days. Treatments of 100 ppm were little more depressive than were 5 ppm. Although the different soils responded differently, pointing to a significant influence of soil type, there was no correlation with percentage of organic matter, clay content, or cation exchange capacity.

Residual copper in lake bottom samples, accumulated from copper sulfate used for aquatic weed control, has been observed to decrease total bacteria, even in the presence of large amounts of organic matter. Ammonium thiocyanate, sometimes used as a weed killer, at 750 ppm is rapidly nitrified and certain bacteria can use it as a sole source of nitrogen. *Thio-*

*bacillus thiocyanoxidans* can use thiocyanage as a source of energy, carbon, and nitrogen. Sodium cyanide is comparatively toxic to bacteria but increases development of molds.

By adaptation or mutation certain bacteria can be "trained" to decompose some herbicides. Repeated spraying of turf with 2,4-D or MCPA develops a microflora that rapidly decomposes these compounds. Adapted organism have also resulted from growth on artificial culture media containing the herbicide in gradually increasing amount, and the herbicide need not be the sole carbon source.

While certain pesticides in combination exhibit synergism, such as the potentiation of sevin by sesoxane, antagonism between some herbicides has been shown to reduce the toxicity of one of the pairs towards certain soil bacteria. Thus fenac at 300 ppm strongly inhibits *Nitrogacter,* but in combination with dalapon at 100 ppm the toxicity is reduced.

In at least one instance microbial attack appears essential for activation of an herbicide. 2,4-DS (sesone), which is non-injurious to plants on direct contact, is hydrolyzed by *Bacillus ceseus mycoides* to 2 (2,5-dichlorophenoxy) ethanol, which is then oxidized to 2,4-D.

Any of the various chemicals used as pesticides are capable of inhibiting or destroying at least certain soil microorganisms under certain conditions. Investigation so far, however, indicates that when used at recommended field rates these toxicants will not seriously effect microbial activities that are important in soil fertility. Inhibitions when produced are only temporary. Despite this fortunate circumstance, newly introduced compounds should be investigated insofar as feasible under field and laboratory conditions. The great number of different pesticides now available render impractical the testing of all for possible harmful effects on desirable soil microbes. When the physical and chemical properties of soil can be correlated with behavior of pesticides of known composition and molecular structure, possible deleterious influences on fertility may perhaps be predicted. Hueppe's principle should also be borne in mind: "Every substance which in definite concentration will kill protoplasm, will inhibit development in smaller amounts, and in still greater dilution act as a stimulant." This and the production of adaptive enzymes, may account for many of the known interactions between herbicides and soil microorganisms.

# RESULTS OF STATE-WIDE COORDINATED WEED CONTROL TRIALS

By DAVID E. BAYER
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The problems of state-wide coordinated weed control projects originating from the state level can be summarized under three major headings:

1. Developing and instigating the project.
2. Compiling and getting the material to those interested at the proper time with detailed instructions.
3. Collecting and compiling the data.

We can eliminate the first two problems by careful planning and selection of the project to be undertaken. The major problem we have had in the past two years with state-wide cooperative projects has been number three, collection and compiling the data.

It has been difficult to compile and integrate the information into one report to obtain maximum value from the work expended. We tried to overcome this by including detailed rating sheets so all the cooperators would rate on the same scale using the same figures. This gave us the uniform figures we wanted but it did not mean anything to us because no two cooperators would rate a plot the same.

We were able to obtain a gross rating in this manner but could not rely on any detailed evaluations. We attempted to overcome this by making at least one rating cooperatively with the county cooperator. The major difficulty occurred when it was impossible for us to make it into each county in time for the first evaluation. Therefore, we were unable to initiate each project from the same starting point. It was then necessary to go back over the earlier evaluations and re-calculate the ratings to put all the data on the same or equivalent readings for weed control and crop injury. A problem arose here since many of the evaluators did not maintain the same rating for a given degree of herbicidal affect throughout the season.

After the first year our experience indicated that even though the rating forms had been sent to the various cooperators with detailed instructions many of the entries were not completed. It turned out that many of them completed only the portions for which they had the data handy making it impossible to compile the data into one report. We attempted to overcome this and other problems of the program by discussing the necessity to take uniform notes at a training conference for Farm Advisors working in weed control. This helped some but did not overcome all of the difficulties. We still ran into the problem of uniform evaluation as even though we made one rating with each worker it was difficult for him to maintain his evaluations since he had no standard to fall back on for calibration. We are attempting to overcome this by devising a rating sheet using physical measurements in conjunction with the use of photographs at each period of evaluation to show the condition of the plant as far as stunting and injury are concerned. Color photographs are an advantage over black and white.

While we do not have all of the obstacles worked out of this program, we feel it is very worthwhile and have actually been able to accelerate our field testing program many times fold. An example of this was the project on wild oat control in small grain. While we realize we do not have the final answer, we do have a recommendation that can be used until a more satisfactory herbicide comes along. We were able with the use of this state-wide program to take a material from greenhouse studies to a state-wide recommendation in three years. This program enabled us to include in our recommendations various restrictions as the various locations gave us a wide variety of environmental factors, soil factors, fertility levels, stages of growth, etc., necessary for a sound overall state-wide recommendation.

We are continuing to emphasize the necessity of uniform evaluations particularly with those Farm Advisors primarily responsible for weed control. We feel that physical measurements will take out much of the variation and the use of photographs will aid the coordinator materially in evaluating the effect on both weeds and crop. We do not have all of the variables worked out of this program yet but feel it is the greatest stride we have made in our applied research program for the state.

## ARE WE PLANTING WEEDS?

*Summary of a talk presented at the education section, Western Weed Conference, Las Vegas, Nevada, March 20, 1962, by Louis A. Jensen, Extension Agronomist, Utah State University, Logan, Utah*

Many of our crop fields are clean and free of weeds. This usually results in high yields of good quality. However, some of our crop land is so infested with weeds that the crops are hardly worth harvesting. Weeds spread and get into our fields in many different ways, such as by wind, water, animals, machinery, and by planting weed infested crop seed.

In order to determine the kind of seed being planted in Utah, a drill box survey was conducted in 1958. This was a cooperative program with the Extension Service and State Department of Agriculture participating. Samples of seed grain were collected out of the drill boxes at planting time by county agents and district agricultural inspectors. When the sample was collected, a questionnaire was filled out. It included a lot of information such as farmer's name, kind of grain and variety, planting rate, source of the seed and price. Was it certified, was it tagged, was it cleaned and how? Was it treated and what with, also acreage planted, etc. A total of 1232 samples were collected at random over the state. All of the samples were tested at the state seed laboratory for germination and purity. The questionnaires were summarized. Then the information was placed on punch cards and tabulated by IBM. A great deal of interesting information was obtained about the kind and quality of seed being planted. This report will include only that pertaining to weeds.

Regarding source of seed, 41% of the farmers were planting their own seed, 14% had obtained it from a neighbor, 44% had been purchased from a seed dealer and 1% from a peddler. Eighty-seven percent of the seed had been cleaned, most of this at a commercial cleaning plant. Thirty-seven percent of the growers planted tested and tagged seed, but this seed planted only 24% of the acreage. Twenty-three percent of the growers used certified seed but this only planted 13% of the acreage. The amount of certified seed varies considerably in different counties.

Certified seed was found to be superior in every respect. A very low percentage of certified seed contained weed seeds. One-third of all the seed was "good seed" of high quality but 14% of the seed would have been illegal to sell in Utah due to weeds.

Wild oats was the most prevalent weed seed in grain seed, with 36% of the samples infested. Over half of the samples contained weeds. The relation of source of seed to weeds showed the farmer's own seed to contain the most weeds. Tested and tagged seed, of course, had fewer weeds than untested. Ninety-one percent of the uncleaned seed contained weed seeds and 44% of the cleaned seed still contained weeds. The percentage containing weed seeds varied considerably from county to county.

The worst grain sample we found contained seed of five different noxious weeds, with a total of 167,600 noxious weed seeds per 100 lbs of grain seed. This farmer was planting five noxious weed seeds on each square foot of his field. Certainly it is a poor practice to plant weeds and then have to spend time and money in controlling them.

Growers should buy only seed that is tested and tagged. Check the germination, purity, and insist on weed free seed.

The following has been done to use the information in an educational program. This illustrated talk was given at 10 district weed and seed schools with a total attendance of 410 people, to the State Seed Council, the State Weed Committee and the State Weed Conference. It was the subject of one T.V. show, four radio programs and numerous newspaper articles. County Agents have used the information in many meetings. This slide series was duplicated for County Agents to purchase or borrow. A printed publication is being prepared giving detailed information on the results of the survey.

## EXTENSION AND COUNTY WEED CONTROL DISTRICTS

By EUGENE HEIKES
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We, as Extension Weed Specialists, Agronomists and County Agents, are fortunate to have special interest groups, specifically county weed districts, to work with and help promote our phase of Extension. It is important that we work with these county organizations, keep them informed and help them become effective. County weed districts, if managed properly, can be very useful organizations and a valuable asset to extension, both at county and state levels. But a good county weed district does not just happen.

Probably education and publicity are the weakest links in most county weed district programs. This emphasizes the importance of a close working relationship between extension and county districts. County weed districts are formed to establish certain legal requirements, but the legal aspect is probably the least important and should be the least emphasized. The stepped-up educational program is the greatest good that will come from a weed district and failure to carry on a good educational program is the one thing which often makes districts fail or be ineffective. In many cases the same goal could probably be reached through a voluntary organization or committee of farmers if the same thorough educational program was carried out. Some state weed laws specify that the Extension Service shall be responsible for education and publicity. Whether this is necessary or good I am not sure, but Extension must work with districts and do a good job of education and publicity.

When a weed district is first being considered the organizational work begins with the county agent. He is largely responsible for the educational work necessary in setting up a program. This is usually done by committees and general farm meetings, newsletters, newspaper articles, etc. He usually works through a committee of farm leaders, but he has the responsibility of getting the job done. Before steps are taken to form a district in a county, I have always encouraged county agents to examine the situation carefully and make sure there is real interest and a desire by a big majority of the farmers. Unless there is real interest the organization will probably not be successful. From the very beginning, success or failure depends largely on what kind of an educational job is done.

While petitions are being circulated and the district is being organized, there should be a continuous educational and publicity campaign, with meetings, newsletters, etc. This will help the committee members who are passing petitions. This will stimulate interest and get farmers to thinking about weeds and the idea of a district. The agent should hold frequent meetings with his committee, advise them and try to avoid difficulties before they develop. If there are certain farmers who seem to oppose the organization, some personal visits by committee members can often clear up misunderstandings and avoid adverse publicity.

After the district is formed, the county agent should certainly not divorce himself of the organization or of weed control education. The formation of a district is not going to reduce the work load or job of education for the county agent; it will undoubtedly mean more work for the agent, but now he will have a special interest group to work with.

In the beginning, there will need to be good planning done to get the district started and operating. Of course, final decisions are made by the weed board or advisory committee but the county agent can have an influence in these decisions. Above all he should keep the district active and make the weed board feel it has an important job and definite responsibilities. I have always encouraged frequent, well-planned board meetings – at least once a month. The board should be kept informed on problems, what is trying to be accomplished and constantly plan the program, not let it drift. I have also encouraged the weed boards to plan a 12-month program rather than just a policing or spraying program during the summer. A properly planned organization can kill more weeds in the winter with a good educational program than they can in the summer. Again, this is where many weed districts fail, by failing to stress education.

The Weed Supervisor or Pest Inspector is a key man in a weed district organization. These men must be public relations specialists. He must be a man who can meet people, persuade and not antagonize, but still must be firm and command respect. He must be a good organizer, for he cannot hope to accomplish the job alone. The Supervisor and County Agent should work closely together, but he should understand educational procedure also and be one who can sell his program. He must be a technician to the extent that he knows the proper action to take to correct specific problems. He must be able to work with other agencies. He should bring the problems to the Weed Board or County Committee, and keep them informed so they can make proper decisions. This kind of man is not easy to find but he can be the key to success or failure of a district.

This emphasizes the importance of hiring Weed Supervisors on a 12-month basis, getting the best man possible and paying a salary that will attract and keep good men. Often weed districts operate on a limited budget; they hire a weed supervisor on a part-time basis – either through the summer months or by the hour, and pay a minimum salary, about the same as a farm laborer. This results in constant turnover and certainly little stability to the organization. This kind of man is not going to learn the job, learn the technical aspects, learn the county, or be respected by the people. The job of County Weed Supervisor is an important one and without the right man a weed district will not likely be successful.

How can the Extension Weed Specialist fit into the organization? Of course, he should work closely with and advise county agents – from the beginning. It involves more than providing technical information. He should have a good understanding of the State Law and how county weed districts operate. The specialist can work with weed districts much the same as he does with county agents.

Most states have annual weed conferences and state associations. This is a place where the specialist can work with supervisors, board members and get better acquainted. These associations are probably more beneficial to weed district people than the general public or county agents. I have encouraged that annual association programs be planned for the benefit of weed district people first and the general public second. These associations can do much to standardize weed districts and pull them together. State Associations should also make an effort to pull in other organizations, get them on the program and stimulate their interest. This can be one of the most important things gained from having a state conference. State conferences can be a valuable educational tool for weed specialists and is an organization we can justify spending time on.

County weed districts should be the center of weed control activity in a county. They should be the coordinating group to make the best use of other agencies, to inform dealers, work with the ASCS and other community groups. Weed district organizations can do much more than just carry on policing or spraying programs, but for a weed district to be most effective Extension must help.

# PRINCIPLES OF SELECTIVE WEED CONTROL

By W. A. HARVEY
Extension Weed Control Specialist
University of California – Davis, California

We use herbicides to control weeds in crop and ornamental plants on an ever increasing acreage. As this use increases it becomes increasingly important that we understand the reasons for selectivity. Most of the selective herbicides are selective only if we use them properly and such use requires an understanding of the method or methods by which selectivity is achieved. Many factors contribute to herbicidal selectivity. These processes, however, are not mutually exclusive. The choice of a herbicide for a certain crop-weed combination is often determined by several factors.

**LEAF PROPERTIES.** Certain leaf properties such as narrow, upright leaves or waxy leaf surfaces contribute to selectivity of certain herbicides. Sprays may bounce or run off these surfaces but wet broad-leaved plants with wide, horizontal leaves covered with little wax.

**LOCATION OF GROWING POINTS.** The growing points of grasses and cereals are located at the base of the plant and protected by the surrounding leaves. In some cases they are actually below the soil surface. Sprays may injure the leaves without damage to the growing points which can send out new shoots. Broad-leaved plants, in contrast, have exposed growing points at the tips of the shoots and in the leaf axils. These may be readily contacted by the herbicide.

**GROWTH HABITS.** Annual weeds in a field of perennial crops can be controlled because the perennial crop, e.g. alfalfa, has a deep root system which will recover from moderate injury to above ground parts. Annual weeds with shallow roots may be killed.

**ABSORPTION.** Movement of herbicides into plants through the leaves can vary with thickness of cuticle, number and location of stomata and the wetting characteristics of the spray solution. Absorption may be high in plants with thin cuticle and numerous, large stomata. The addition of wetting agents to a spray solution may enhance absorption and may decrease selectivity.

**TRANSLOCATION.** Movement of herbicides within plants from the point of absorption to sites of action may differ in rate and amount. Susceptible plants may move greater quantities of the herbicide than resistant plants.

**BIOPHYSICAL-BIOCHEMICAL.** There are a number of biophysical and biochemical differences between plants which can serve as bases for selectivity. Herbicides may be bound to certain plant constituents so they are not translocated, membranes may be resistant to chemical action, enzyme reactions may be blocked and the herbicide may be activated or decomposed by action within the plant.

**POSITION OF HERBICIDE IN SOIL.** Certain herbicides may function selectively because of their position in the soil. Herbicides of low solubility may remain in the surface soil affecting germinating weed seed but not deeper rooted plants and conversely highly soluble chemicals may leach rapidly to deeper levels affecting the deeper rooted plants more than shallow rooted species.

**SELECTIVE PLACEMENT.** It is possible to apply herbicides in such a way that the weeds are contacted but not the crop plant. This may be done by shielding either the spray or the crop plant, by directed spray in tall crop and ornamental plants or by the use of granules which bounce off crop plants onto the soil where they become effective against germinating weed seed.

(Material summarized from University of California Circular 505, Principles of Selective Weed Control)

## LOOKING AHEAD IN EXTENSION WEED CONTROL WORK

By J. M. SAUNDERS
Agronomist, Federal Extension Service
Washington, D. C.

As has been so ably pointed out by participants in this and other similar meetings, weeds are an important national agricultural problem. The extent and intensity of the progress in weed control will depend to a great degree, on the effectiveness of the work done by groups and interests represented here.

As servants of agriculture, a major responsibility of ours and our collaborators is to insure that the continuing battle to keep weeds under control is reasonably well won. We in the Cooperative Extension Service recognize that we must and should shoulder a very significant share of this responsibility. However, our responsibility cannot be met effectively by going it alone. Our educational contribution is largely dependent on the progress made by research scientists, whether in the experiment station of the Land Grant College and the U.S. Department of Agriculture or the research laboratories of industry. In between the research laboratories and the manufacturer of weed control materials and equipment on the one hand, and the farmers and ranchers who are destined to use these materials and equipment on the other, are a vast number of dealers and handlers who can and should play an important part in speeding progress.

All of us have a responsibility to see that these intermediate suppliers are properly informed as to the latest proven techniques and materials adapted to specific weed control problems if they are to play their part in this common effort effectively.

### A Major Challenge

The control of weeds represent a major challenge to optimum efficiency in farming operations Take cotton for example. The average cost of all tillage in cotton production is estimated at 14 per cent of the value of the crop. It is also estimated that at least one half of the tillage required in producing cotton is due to the presence of weeds. This means that our farmers are losing seven percent of the value of their crop each year due to the increased tillage required to control weeds. To this amount must be added an additional 10 percent due to reduced yields, lowered quality and weed control costs. It is estimated that the total losses in cotton production due to weeds exceeds $440 million dollars each year. This example is applicable to many of the field crops.

In addition to lowering quality, yields, and increasing tillage costs, weeds cause losses in many other ways such as poisoning livestock, inducing off flavor of milk and reducing flow of irrigation waters.

Many other such examples could be cited of which you are already familiar. I would however, like to show some slides that give emphasis to the need for increasing agricultural efficiency of which weed control is an important practice.

**Slide** – *Farm Prices and Costs*

The cost-price squeeze has become progressively worse since 1952. In 1952 farm prices and farm costs were pretty well in balance – both were about 290 percent of the base period 1910-14. By 1960 prices had fallen to about 240 percent of the base period – and farm costs had risen to an index of about 300. This has resulted in a serious cost price squeeze on the farmer.

**Slide** – *Income per person*

During the same period the income of non-farm families moved steadily upward. In 1960 the per-capita income of farm people was no more than half that of non-farm people. The average return for farm workers was about 85 cents per hour. As a result of this wide difference in earning power there was a mass movement of farm workers to non-farm employment.

1/ ARS Special Report "Losses in Agriculture"

**Slide** – *U.S. population and farm output*

In spite of the cost price squeeze, agricultural production has raced ahead of demand.

**Slide** – *Rising technology*

This spectacular rise in output has followed a rapid improvement in farm technology. Between 1924 and 1960 total farm imputs of mechanical power and machinery rose from 44 percent to 142 percent of the 1947-49 level. The use of fertilizer and lime rose from an index of 28 to an index of 192, and the imputs of purchased feed, seed and livestock from 42 to 149. We have reviewed some of the need for increased efficiency through weed control. What have extension workers done to assist farmers?

**Slide** – *Farmers assisted*

A summary of annual reports of State Extension Services show that in 1953, we in Cooperative Extension were assisting 560,000 farmers and others in control of weeds in the United States. In 1959 we assisted one million 500 thousand. The trend was consistently upward.

**Slide** – *Regional chart showing farmers assisted, by regions*

This slide is self-explanatory – as you will note, Extension has shown a consistent uptrend in each region.

In the western region the 1959 farm census showed a total of 337,464 farms. Extension reports show that in the same year 138,347 farmers were assisted with weed control. This represented 41% of the total farms in the region.

Tomorrow afternoon at the general session I will discuss the National Weed Survey. This study has been summarized and is now available for distribution. It brings into focus the weed-crop situation, by regions and nationally and is of mutual interest to Research, Industry and Extension. It is a joint effort of all agencies and industries concerned with the control of weeds and will serve as a benchmark from which to plan future programs both in research and extension and from which to measure future progress.

In looking ahead we must broaden our educational programs as they pertain to weed control to avoid problems that may arise from the use of herbicides in the future. Farmers know that *thorough* seedbed preparation followed by efficient and timely cultivation has an extremely important place in weed control. They know too that there are no substitutes for good varieties, properly fertilized and managed. However, farmers must be taught the values of rotational use of herbicides in crop rotations, just as they have been taught the values of rotating crops, the use of good varieties and sound fertilization practices. The present herbicides used for controlling weeds in corn are not effective in controlling Johnsongrass in corn because the herbicides that will kill Johnsongrass will also injure corn. However, effective chemicals which can be used to control Johnsongrass in alfalfa grown in the rotation with corn are available. There are many other annual and perennial weeds that can be easily controlled by the use of various herbicides when used effectively on tolerant crops in the rotation. Given time, it is reasonable to believe that research will be able to develop tailor made herbicides to meet all or most of our needs.

In a paper presented at the Beltwide Cotton Production Mechanization Conference, January 1961, Dr. Warren Shaw, plant physiologist, Crops Research Division, Agricultural Research Service, USDA, stated that:

"No one would attempt to predict what new discoveries might develop in weed control from intensive fundamental research involving chemistry, plant physiology, genetics, crops and soil science, and agricultural engineering. We can be certain, however, that unless fundamental and applied studies are brought into better balance and expanded, applied studies in the development of weed control practices in crop production will suffer. The use of herbicides in some instances is beginning to exceed the fundamental and applied research information available to insure their safe use. If a better balance between research in weed control and the use of chemicals is not obtained and maintained in the immediate future, the risk of damage to crops will increase.

"If a seed is to germinate, a number of environmental conditions must be met prior to germination. If these conditions do not occur, the seed does not germinate. When basic research is inadequate, the shut-off period in scientific development is not as immediate and definite as with the germination of a seed but it is almost as certain in the long run. Yet all of us are keenly aware of the difficulties involved in developing and obtaining support for such programs.

"I am convinced that our weed control progress will be characterized by the discovery, development and utilization of more efficient forms of energy in the future. The adaptability of chemical energy for controlling weeds offers almost unlimited possibilities for improving the efficiency of weed control. Thus it seems that our future rate of progress will be largely determined by (a) the discovery of more selective, more specific, better translocated, more efficient, better formulated, safer, and more economical herbicides; (b) a basic fundamental understanding of the effects of chemicals on plant growth and soils; (c) our ingenuity in supplementing and combining chemical and cultural practices; (d) a fundamental understanding of the limitations of our current weed control practices; and (e) the development of new and more effective weed control techniques and the discovery of more effective and more efficient sources of energy for selective weed control."

Chemicals alone cannot win the battle against weeds. Producers can contribute to weed control by planting weed free seed, and following recommended crop rotations when necessary to expedite weed control.

The development of improved chemical, cultural, biological, mechanical and combination weed control practices, applied timely and properly represents one of the most effective approaches to increased efficiency, and lower cost, mechanized crop production.

# THE STATUS AND PROSPECTS IN AQUATIC WEED CONTROL[1/]

By F. L. TIMMONS
presented by R. H. HODGSON [2/]

The importance of aquatic and marginal weeds and their control is closely related to the importance and value of water. Water is now or is rapidly becoming the most precious and limiting resource in most parts of our country. Deficiencies in quantity or quality of available water limit agriculture, industrial and urban development, navigation, or recreation in many areas. Therefore, it is not surprising that aquatic and marginal weeds that waste water, reduce water quality, interfere with economic uses of water, and prevent its free and timely flow through waterways should cause general public concern.

Weeds cause losses or create public nuisances in aquatic areas in many ways. They may reduce the flow in canals and streams, and interfere with navigation, delivery of irrigation water or drainage of excess water and may cause flooding, breakage of canal banks, or damage to bridges and other structures and may result in salt-water intrusion in low-lying coastal areas during drought periods. Algae and other aquatic weeds may affect the health and comfort of people and livestock by causing undesirable odors or tastes in potable water, harboring insect pests and vectors of human diseases, and interfering with proper sewage disposal and stream sanitation. Many forms of aquatic vegetation are nuisances in fishing and bathing areas and in wildlife habitats. Emersed aquatic weeds such as cattails (*Typha* spp.), tules (*Scirpus* spp.), and common reed (*Scirpus* spp.), and common reed (*Phragmites communis* Trin.) transpire large quantities of water from reservoirs, canals, and marshes, and thus cause serious losses in areas of water shortage.

I do not wish, however, to imply that all aquatic plants are harmful. Many forms of aquatic vegetation, properly managed, are beneficial and necessary, especially in fish and wildlife habitats.

## Extent and Importance of Aquatic Weed Problems

Reliable statistics on the total area of different aquatic environments in the United States that have important weed problems are not available. Also, no overall figures are available on the total monetary losses caused by aquatic and marginal weeds or on the cost of controlling them. However, a few examples of such losses and costs and of the extent of certain aquatic weed problems may give some indication of their economic importance.

A survey of the extent of aquatic- and bank-weed infestations, losses caused by weeds, costs and benefits of weed control on irrigation and drainage systems in 17 Western States provided some interesting and apparently reliable data for 1957 (8). Approximately 65 percent of the canals, laterals, and drains and 74 percent of the ditchbanks were infested with weeds. Totals for the 17 Western States showed that 90,768 miles of channels were infested with aquatic weeds and 395,020 acres were infested with bank weeds. Total estimated losses of water caused by weeds in 1957 were 1,966,068 acre-feet. This water was valued at $3,626,742 at the farmer's headgate and had an estimated net productive value of $39,321,360. The cost of other damages by the weeds was $2,112,422. The total cost of weed control on irrigation systems in the 17 Western States in 1957 was $8,113,297. This cost added to the losses from weeds brought the total annual cost of weeds on western irrigation and drainage systems to nearly $50 million. Incidentally, the estimated losses prevented by the expenditure of $8,113,297 for aquatic and bank weed control in 1957 were $15,860,026, a net saving of $7,746,729. This was a sizeable annual return on the Nation's investment in research, extension, and other efforts directed toward the development and use of improved methods of controlling weeds in the irrigation and drainage systems of the West.

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1/ Paper also presented at Northeastern Weed Control Conference, January 3, 1962, and published in Proceedings of that Conference.

2/ Agronomist, U.S. Department of Agriculture, Agricultural Research Service, Crops Research Division, University of Wyoming, Laramie, Wyoming, and Plant Physiologist, USDA, ARS, Crops Research Division, Denver, Colorado.

No equally comprehensive and reliable data are available on the extent of aquatic and marginal weed problems, the losses caused by them, and the extent and costs of control in other parts of the United States. However, fragmentary information indicates that aquatic weed problems are just as critical in other parts of the country as in the West. It was estimated in 1947 (5) that there were 500,000 acres of Louisiana waterways and wetlands infested with waterhyacinth and alligatorweed. Figures supplied by the U.S. Army Corps of Engineers (3) show that over $5 million was spent controlling waterhyacinth in Louisiana, Florida, and Alabama between 1905 and 1955. The infestation in Louisana has been reduced about 50 percent according to recent estimates.

The Central and Southern Florida Flood Control District has a network of 500 miles of drainage canals for which the annual costs of aquatic weed control exceeds $50,000. In addition, about $30,000 is spent annually for aquatic weed control in the smaller irrigation and drainage ditches serving 15,570 square miles of agricultural land in southeastern Florida.

One way to estimate the potential aquatic weed problem in the United States is to determine the extent of different aquatic areas in which weed problems could occur. Pertinent data on that question from the 1949 or 1954 Agricultural Census and the 1961 Statistical Abstract of the United States are summarized as follows:

| Region of the United States | Kind of aquatic situation | | | |
|---|---|---|---|---|
| | Ponds and reservoirs 1/ | Drainage ditches 2/ | Irrigation canals 2/ | Inland water surface 3/ |
| | Number | Miles | Miles | Sq. mi. |
| Northeastern | 107,790 | 2,336 | None | 7,621 |
| Northcentral | 624,624 | 100,636 | 6,312 | 11,045 |
| Southern | 878,792 | 39,956 | 15,601 | 20,927 |
| Western | 153,184 | 12,525 | 117,954 | 26,616 |
| Total | 1,765,020 | 155,423 | 139,867 | 66,209 |

1/ From 1954 Agricultural Census.

2/ From 1949 Agricultural Census.

3/ From 1961 Statistical Abstract of the United States. Data include permanent inland freshwater surface such as lakes, reservoirs, and ponds having 40 acres or more area and streams, sloughs, estuaries, and canals 1/8 mile or more in width. The Great Lakes were not included.

In an attempt to obtain information on the extent of weed problems in these aquatic areas and on the extent of control programs, methods used, and costs of control a questionnaire-type survey was initiated in September 1961. Questionnaires on the problem in farm ponds, drainage ditches, and irrigation canals were sent to all 50 State Agricultural Experiment Stations and questionnaires on inland natural lakes and waterways and artificial impoundments stocked with fish were sent to Fish and Game Commissions or Conservation Departments in all 50 states.

Replies received from 38 State Experiment Stations and 31 Fish and Game Commissions indicate that very little definite information is available on aquatic areas in central and eastern regions of a type that was obtained for irrigation and drainage systems in the West. However, the 26 complete reports do provide valuable information. Most of the information on percentages of aquatic areas occupied by problem weeds were based on estimates by aquatic weed specialists and can be considered the most reliable information now available. Only a very few of the specialists attempted to estimate the monetary losses caused by aquatic and marginal weeds.

Complete reports from 13 Northcentral, Southern, and Western State Agricultural Experiment Stations indicate that filamentous algae, rooted submersed, rooted emersed, and marginal weeds all constitute serious problems in farm ponds and drainage ditches in each of the three regions. The weed problem is especially serious in farm ponds in the northcentral and southern regions where each type of weed is a problem in 15 to 84 percent of the ponds. The average percent infestation of each of these weeds in drainage ditches and irrigation canals ranges from 11 to 70 percent in the three regions. Floating weeds are a problem in 10 to 19 percent of the farm ponds and 5 to 7 percent of the drainage ditches in Southern and Northcentral States. No complete reports were received from the 13 Northeastern States on aquatic weed problems in farm ponds and drainage ditches.

Complete reports from 12 Northeastern, Northcentral, and Southern State Fish and Game Commissions indicate that the different types of aquatic weeds constitute problems much more more frequently in marshes and artificial impoundments than in natural lakes and streams. This is especially true of rooted submersed weeds. The percentages of infestations for each of the different types of weeds average 10.4, 8.7, 3.4, and 3.3, respectively, in marshes, artificial impoundments, natural lakes, and natural streams for all three regions. Algae and rooted submersed weeds were reported as problems much more frequently in natural lakes and streams in the northcentral region than in other regions.

The single complete report from the western region was not considered representative of that region. You, no doubt, will be interested in the report from Alaska which states there are no weed problems in any aquatic situations there. Apparently Alaska, with its primeval lakes and streams, abundant fish and game, and few people, is comparable with your own Northeast about 200 years ago.

More than 130 aquatic weeds are common enough in the United States to justify being included in a list of common and scientific names now being considered by the Weed Society of America Terminology Committee for official action. That suggested list was prepared by ten aquatic weed specialists in different parts of the country. The genera or species that most frequently cause problems include pondweed (*Potamogeton* spp.), watermilfoil (*Myriophyllum* spp.), elodea (*Elodea canadensis* Michx.), coontail (*Ceratophyllum demersum* L.), naiad (*Najas* spp.), stonewort (*Chara* spp.), cattail, smartweed (*Polygonum* spp.), waterhyacinth (*Eichhornia crassipes* (Mart.) Solms.), alligatorweed (*Alternanthera philoxeroides* (Mart.) Griseb.), spatterdock (*Nuphar advena* (Ait.) Ait. f.), common reed, buttonbush (*Cephalanthus occidentalis* L.), willow (*Salix* spp.) and the groups of duckweed and filamentous algae.

## History of Aquatic Weed Control and Research

Progress in research and improvement of methods of controlling aquatic weeds has lagged considerably behind that for control of land weeds and is just beginning to catch up. At this point let us review briefly the recent history of aquatic weed control and research to give us a better understanding and appreciation of their present status and future prospects. Hand-cleaning and mechanical methods of control probably were used on aquatic weeds about as early as on land weeds. The U.S. Army Corps of Engineers has made extensive use of various mechanical methods of controlling waterhyacinth since 1900. Many types of chains, drags, and disks were being used for removing aquatic weeds from irrigation ditches by 1940 (1). We are still relying on mechanical methods for aquatic weed control to a much greater extent than we are for control of land weeds.

Copper sulfate was first used for control of algae as early as 1904 (7) and it is still the most widely used method. Sodium arsenite was used rather extensively for control of waterhyacinth in Louisiana from 1902 to 1937 (9). Sodium arsenite was used for control of submersed weeds in lakes as early as 1926 in Wisconsin (6). It is still the most extensively used herbicide for control of submersed weeds in lakes and ponds in many parts of the country despite its toxicity to warm blooded animals.

During the early 1940's chlorinated benzenes were used to some extent for control of submersed weeds in eastern ponds and lakes and in western irrigation canals. Research by Agricultural Research Service and Bureau of Reclamation scientists beginning in 1947 developed an effective method of using xylol-type benzenes, commonly called aromatic solvents, for control of submersed weeds in irrigation canals (2). More than 500,000 gallons of xylol is now used annually for this purpose.

The renaissance in general weed control, which was sparked by the discovery of the herbicidal properties of 2,4-D in 1944 and really got underway about 1947, did not have much effect on aquatic weed control or research until nearly ten years later.

The general lack of interest in aquatic weed control research prior to 1955 is indicated by the fact that less than 2 percent of the papers presented at Northeastern, Northcentral, and Southern Weed Control Conferences each year were on aquatic weeds. Research subcommittees on aquatic weeds were not established until 4 to 8 years after general weed research committees were created. It was only in the Western Weed Control Conference that an early interest was shown in aquatic weed control research. Beginning in 1950, 5 to 10 percent of the papers and research reports in that conference were on aquatic weeds and the Research Section included an aquatic weed subcommittee from its establishment in 1952.

The reawakening in aquatic weed control really began about 1957. In that year the Agricultural Research Service increased its research effort on aquatic weeds from about 3 man-years to 9 full-time scientists. A contract was arranged with Auburn University to conduct primary evaluation of 750 chemical compounds as aquatic herbicides on representative submersed aquatic weeds and to check 100 of the most promising of these for toxicity to representative species of fish. Previously, very few of the many thousands of chemicals tested for herbicidal activity on land weeds had been tested for effectiveness on aquatic weeds by the chemical industry.

In July 1958, Congress authorized the annual expenditure of $1,350,000 by the U.S. Army Corps of Engineers and eight Atlantic and Gulf Coast States for the control of alligatorweed and other obnoxious aquatic plant growths in the combined interest of navigation, flood control, drainage, agriculture, fish and wildlife conservation, public health, and related purposes including continued research for development of the most effective and economic control measures. The cooperative research program, "Expanded Project – Aquatic Plant Control," which was developed as part of this total program, involves six Federal and State action and research agencies.

### Present Status of Aquatic Weed Control and Research

That brief history brings us to the present when public interest in aquatic weed control and research seems to be at flow tide and to be surging higher. One indication is the fact that 25 papers on aquatic weeds were presented at the Weed Society of America program in December 1961 as compared with 11 papers in 1960, 13 in 1958, and 7 in 1956. Another indication is the fact that 16 State Agricultural Experiment Stations submitted proposals in September 1961 for participation in a regional research project on aquatic weed control financed by Federal funds. Four of these proposals by the Alabama, California, New York, and North Carolina State Experiment Stations were approved and funded. Previously, only Alabama, Michigan, and Oregon State Experiment Stations had been active in research on aquatic weed control.

The total acreage of aquatic areas treated for control of different types of aquatic weeds in 1961 as reported by 10 to 16 State Fish and Game Commissions in Northeastern, Northcentral, and Southern States were 10,552 (14) of filamentour algae, 33,808 (10) of other forms of algae, 15, 373 (16) of rooted submersed weeds, 10,576 (16) of rooted emersed weeds, and 39,611 (10) of floating weeds. With the possible exception of floating weeds these treated areas represent only small fractions of the areas in which these weeds were reported to be serious problems.

Reports on the extent of treatment of farm ponds and drainage ditches for aquatic weed control in northeastern, northcentral, and southern regions were not sufficient in number for a reliable general indication. However, there appeared to be considerable chemical treatment for weed control in farm ponds in New Jersey, Ohio, South Carolina, Missouri, and Texas. Apparently, the use of weed-control practices in aquatic areas is not nearly as extensive in Central, Southern, and Eastern States as it is in irrigation and drainage can canals of the West.

A summary of reports in the questionnaire survey indicates the order of preference for chemical and mechanical methods of controlling the different types of aquatic weeds as follows with the number of specific mentions shown in parentheses after each method:

**Algae** – copper sulfate (32), sodium arsenite (8), carp (2), dichlone (1).

**Rooted submersed (ponds and lakes)** – sodium arsenite (27), 2,4-D (24), silvex (12), endothal (9), mechanical methods (2). **(Canals and ditches** – mechanical methods (7), xylol (4), urea (3), acrolein (2).

**Rooted emersed** – 2,4-D (38), dalapon (22), amitrole (16), mechanical methods (15), silvex (7), 2,4,5-T (5).

**Floating** – 2,4-D (19), 2,4,5-T (4), silvex (4).

**Marginal** – 2,4-D (34), dalapon (26), amitrole (13), 2,4,5-T (12), silvex (11). mechanical methods (10), oil (8), burning (6).

The Hawaiian Agricultural Experiment Station reported that a herbivorous fish, *(Tilapia mossambica*, has given excellent control of submersed aquatic weeds in canals, ditches, ponds, and reservoirs with permanent water supply. This fish is used for food in Hawaii and the Philippines but is not highly regarded as a food or game fish in Southern United States where preliminary tests have shown it to be not well adapted.

Lack of time prevents my saying more about control methods. I recommend for your reading a recent publication by T.F. Hall (4) which contains an excellent discussion of the nature of aquatic weed problems and of control and management methods with an extensive review of literature.

### Future Prospects for Aquatic Weed Control and Research

All signs point toward continued and probably much increased interest and activity in aquatic weed control. We have a larger backlog of unsolved problems than in most other phases of weed control. As water supplies become more limiting and critical those aquatic weed problems will increase and become more acute. The 38 replies to my questionnaire to State Agricultural Experiment Stations reported a need for increasing research on aquatic weeds from 10.5 to 88.5 man-years, eight times as many. The Federal agencies that have shown an early interest in aquatic weed problems probably will continue and perhaps increase their present efforts.

The replies to the survey questionnaire were almost unanimous in pointing out the need for a more effective, less expensive, longer lasting, more easily applied aquatic herbicide that is safe for fish, humans, livestock, and wild game. I do not predict that many miracle herbicides that meet all those specifications will be found but the prospects seem promising for much better herbicides than we now have in commercial use. A total of 131 chemicals of the 854 compounds evaluated by Auburn University in the initial contract with the Agricultural Research Service gave 90 percent or better control of representative aquatic weeds at 5 ppm. Sixteen of these chemicals proved safe for fish. Many of these promising chemicals are now undergoing secondary evaluation, and a few look extremely promising in field tests. Probably additional promising aquatic herbicides will be discovered in two primary evaluation programs still underway at Auburn University. Several chemical companies have recently established screening programs for aquatic herbicides. That development should greatly increase our supply of promising aquatic herbicides for further testing and development.

Biological agents probably will play an important role in future eontrol of aquatic weeds. The Entomology Research Division of the Agricultural Research Service is now investigating in South America the feasibility of introducing promising insect pests of alligatorweed into the United States. A large freshwater snail, *Marisa cornuarietis* L., has shown considerable promise for control of certain submersed and floating weeds in Puerto Rico and Florida in investigations conducted by the Agricultural Research Service, the International Cooperation Administration, and the Department of Health, Education and Welfare. Investigations of promising herbivorous fishes for control of filamentous algae are underway at Auburn University. Observations by Bureau of Reclamation personnel in Washington indicate that a low-growing species of water plantain (*Alisma gramineum* K. C. Gmel.) is an effective competitor with rank growing pondweeds in large irrigation canals.

Future research on aquatic weeds undoubtedly will place more emphasis on the anatomy, morphology, physiology, and life cycles of aquatic weeds in relation to their control. The fate of herbicides in water and aquatic soils and the factors that affect adsorption, retention, and decomposition in soils will also be thoroughly investigated. Participants in the new co-operative Regional Research Project on Aquatic Weeds involving the Alabama, California, New York, and North Carolina Agricultural Experiment Stations will investigate fundamental aspects of the problem and should contribute greatly to the understanding and improvement of aquatic weed control.

Control efforts probably will continue to be directed toward final eradication of certain problem species. However, I agree with Dr. T.F. Hall (4) that "For most aquatic species control will be more realistic and economical than attemps at eradication." For the most economical and long-lasting results we will need to take full advantage of the natural forces of plant competition and biotic balance aided by judicious use of herbicides and management.

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# THE BUSINESS OF CONTROLLING WOODY PLANTS

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When one stops to think that in the United States the selective control of woody plants by chemical or mechanical means can be beneficial on nearly 489,000,000 acres (1) of commercial forest land, on nearly 240,000,000 acres of rangeland (15) and on undetermined millions of acres of railroad, highway, utility and ditchbank right-of-way the enormous scope and importance of the business of woody plant control is obvious.

In preparing this paper the author attempted, through the media of letters and personal contacts, to determine the money spent on woody plant control and the number of acres of woody plants treated annually in this country. Three broad areas where herbicides are used to control woody plants were considered: weed tree control in forests, brush control on rangelands, and brush control on railroad, highway, utility, and ditchbank rights-of-way. Nearly all persons contacted co-operated fully, but in only a few instances were accurate figures available on specific woody plant control activities.

However, certain reliable figures were obtained that do help define the scope of the problem and these have been incorporated into the body of this paper. In addition, a considerable amount of information was gathered on the chemicals and application methods used by the foresters, ranchers, and right-of-way managers. Particular emphasis is given to the progress in controlling weed trees in forests, because of the great interest across the country in the special application techniques being evolved in this field.

## I. Weed tree control in forests.

The primary purpose of a herbicide program in forestry is to weed the forest of undesirable trees competing for the light, moisture and nutrient requirements of the more desirable species.

There are four broad areas in this country where herbicide techniques have been perfected and are being widely used to control undesirable trees in favor of more desirable species or those better suited to the site. These areas are the Southeast, the Pacific Northwest, the Lake states and the Northeast.

The most pressing need for herbicides exists in the southeastern part of this country where brush hardwoods are encroaching on 103,000,000 acres of pine land at the rate of over 600,000 acres per year, or nearly 1800 acres per day (13). Several hundred thousand acres of timber and pulpwood land are weeded chemically yearly in the eleven state area extending from eastern Texas and Oklahoma to the Atlantic Coast. Two commercial companies in this area, between them, treat chemically over 50,000 acres per year as part of their pine regeneration programs.

In the Pacific Northwest which includes the states of Washington, Oregon, western Montana and western Idaho, unless planting or direct seeding by air establishes Douglas fir (*Pseudatsuga taxifolia*) and related species within one to three years after clearcutting, the area is taken over by a complex of brush species, many of which are impossible to control with known chemical or mechanical methods (12). Ceanothus (*Ceanothus* spp.), Manzanita (*Manzanita* spp.), vine maple (*Acer circinatum*), big leaf maple (*Acer macrophylla*), Alder (*Alnus rubra*) and willow (*Salix* spp.) are potential invaders of 35,000,000 acres of high site land in this area.

In the Lake states of Minnesota, Wisconsin and Michigan where red pine (*Pinus resinosa*), white pine (*Pinus strobus*) and jack pine (*Pinus banksiana*) are species of commercial importance; hazel *Hamamilis virginia*), alder (*Alnus* spp.) aspen (*Populustremuloides*), oak (*Quercus* spp.) and willow (*Salix* spp.) are constant competition throughout the life of many conifer plantations.

The northeastern section of the country, which for the purpose of this discussion we will say includes the states of Pennsylvania, New Jersey, Ohio, Delaware, Maryland, Kentucky, West Virginia and New York as well as the New England states, presents a unique problem in the use of herbicides. Some of the most valuable hardwood forests in the country grow in the river bottoms of this section. Vast areas of white, red, shortleaf (*Pinus echinata*) and loblolly pine (*Oinus taeda*) as well as spruce (*Picea* spp.) and balsam fir (*Abies balsamea*) are also found here. The selection of the proper herbicide technique for use in a forest management program is more difficult in this area than it is in any of the three areas previously mentioned.

The presence of both hardwood and conifer forests in the area, and the intermixing of the two on many sites make blanket prescriptions for weed tree control almost impossible. Each area must be carefully studied and a prescription written that will favor the most valuable species for the site.

In all four sections of the country, the objective of foresters is to grow the tree species best suited to the site. One should never be misled into thinking that the objective in using herbicides is to kill trees rather than to grow them. All undesirable weed trees in a forest cannot be killed any more than a farmer can kill every weed in his corn, wheat or soybean field. Yet, this does not stop the farmer from using 30,000,000 pounds of 2,4-D every year to double and triple his yields.

Regardless of whether chemicals or some mechanical method of release or site preparation are being used, weed trees will return and will always be a problem. But, as in farming, yields can be increased by obtaining a degree of control with these mechanical and chemicals methods. As many forest managers have expressed it, we are buying a few critical years' freedom from weed tree competition to release our tree crop.

With the specific goal of growing trees clearly in mind, several tools and techniques are available to the forester that show promise for controlling weed trees.

There is some confusion today on the subjects of weeding for site preparation and weeding for release in regeneration work. Generally speaking, our best chemical tool, 2,4,5-trichlorophenoxyacetic acid, is not the best answer for site preparation on areas supporting dense stands of hard to kill species such as red maple (*Acer rubrum*), ash (*Fraxinus* spp.), water oak (*Quercus nigra*), laurel (*Kalmia latifolia* ) and rhododendron (*Rhododendron maximum*). Even if these species could be killed with 2,4,5-T at a per-acre rate that the value of the tree crop grown on the land could justify, the dead stems would still be so thick that planting would be difficult and costly. If direct seeding is to be used, herbicides do nothing toward preparing a seedbed. Herbicides can be used successfully for site preparation when the underbrush is made up predominantly of susceptible species such as alder, hazel, gum (*Nyssa sylvatica*), oak, hickory (*Carya* spp.) , manzanita (*Arctostaphylos* spp.), cherry (*Prunus serotina*) or birch (*Betula* spp.) and should be sparse enough for easy planting.

A more economical approach to regenerating dense thickets may be to clear them mechanically with bulldozers equipped with "KG" blades. Clearing by this method is costly but if the land, due to location or high site index, is valuable and must be returned to production the cost may be justified. Clearing in strips or clearing without windrowing and burning are means of reducing the cost of mechanical clearing. A park-like condition is not needed for trees to grow.

The possibility of using controlled burns to remove small dense understory brush and prepare a seedbed should always be considered in site preparation work. Where sufficient logging slash or needle duff from overstory pine is present in the ground litter to carry a hot fire, controlled burning followed by planting may be the cheapest solution to reforesting the land.

Occasionally, where there is not enough litter but where susceptible species are prevalent it is possible to use herbicides to set up an area for controlled burning. The chemical is applied at the beginning of the growing season as soon as foliage has reached full size and the burning is done at the end of the growing season or the following year when foliage and stems are dead and dry. Planting or seeding should be done immediately after the burn to take advantage of the release obtained.

More work needs to be done on this chemical-fire combination treetment to determine the ideal time to use the controlled burn. Following chemical treatment too closely with fire will not allow sufficient time for trans-location of chemical to plant roots. The result will be vigorous resprouting from the root collar which can cause severe competition to newly planted trees or seedlings.

It is interesting to note that the main reason for the brush hardwood problem on millions of acres of valuable pine land in this country today is largely due to the intensive fire control now in practice. If controlled burning can be substituted for the wild fires of the past, brush can be controlled temporarily and planting sites can be prepared fairly economically.

Once a desirable species has been established on a site, fire and mechanical clearing can no longer be used. Selective techniques that favor one species over another are required. These are release situations and are ideally suited to herbicide programs. As a general rule, the greatest return from money spent on a single herbicide treatment will be realized on areas where desirable species are already established and release is needed.

A number of application methods are available to the forester interested in release work. Table I summarizes the acreage treated in 1960 by these methods by a representative sampling of 13,550,000 acres of company owned forests in 12 southwestern states (5).

TABLE I ACREAGE TREATED BY VARIOUS METHODS OF HARDWOOD CONTROL IN 12 SOUTHEASTERN STATES

| Method of hardwood control | Acres treated | |
|---|---|---|
| A. Chemical methods | | |
| 1. Tree injector | 101,000 | |
| 2. Axe plus chemical | 36,500 | |
| 3. Little Beaver plus chemical | 31,000 | |
| 4. Aerial spray, helicopter | 30,100 | |
| 5. Aerial spray, fixed-wing plane | 4,400 | |
| 6. Mistblower, vehicle mounted | 18,600 | |
| 7. Mistblower, portable | 200 | |
| 8. Basal spray | 10,800 | |
| 9. Foliage spray, tractor mounted | 8,400 | |
| Sub total, chemical methods | | 241,100 |
| B. Mechanical methods | | |
| 1. Little Beaver alone | 45,200 | |
| 2. Axe alone | 40,200 | |
| 3. Disking | 19,700 | |
| 4. Bulldozer | 10,900 | |
| 5. Brush chopper | 10,000 | |
| 6. Chain - rake - harrow | 3,500 | |
| 7. Furrowed | 2,500 | |
| Sub total, mechanical methods | | 132,000 |
| C. Controlled or prescribed burning | | 79,600 |
| Grand Total | | 452,700 |

If one considers this sampling to be representative of the 33.5 million acres owned by southern timber companies, this would indicate that in 1960 approximately 600,000 acres can be presumed to have received chemical weed tree control, about 330,000 acres were probably treated mechanically and about 200,000 acres control burned. This same survey indicated that 8 million dollars was spent on weed tree control by southern timber industries and that they spent over 1 million dollars for herbicidal chemicals.

Since some of the herbicide application techniques reported in Table I may not be entirely familiar to western foresters, a brief description of the more important is given here.

### A. Foliage spraying by air

The use of aircraft to apply herbicides for conifer release in this country is a firmly established practice. The technique is most economical on areas in excess of 500 acres. Most of the work is done by helicopter aircraft, using 1½ to 2 pounds per acre of a low volatile ester of 2,4,5-T in 2 quarts of oil and 4 gallons of water (7, 11). Examples of low volatile esters in use today are the butoxy ethanol, iso octyl and propylene glycol butyl ether esters. Timing of aerial sprays should coincide with full foliage development on the weed tree species and they should be applied after the new growth on conifers has hardened off. Soil moisture should be sufficient for good growth and relative humidity should be high. For uniform coverage, swaths should overlap on 30 to 40 foot centers and should be flagged. Boundaries of sprayed areas should be marked clearly. Costs for aerial application of 2 lb of 2,4,5-T as low volatile ester range from $6.50 to $10.00 per acre depending on the type aircraft used, the size of the acreage sprayed in one block, and the region in which the spraying is done.

An exception to applying chemicals by air to the foliage of brush is the newly developed technique of dormant budbreak spraying with helicopters in the Pacific Northwest. This technique if most effective on vine maple (*Acer circinatum*), but bigleaf maple (*Acer macrophylla*) and alder (*Alnus rubra*) can be partially killed. Two pounds of low volatile 2,4,5-T is applied in 9½ gallons of diesel oil just as the buds are swelling in the spring. One treatment is generally sufficient to release Douglas fir that is growing just under the brush canpoy. Newly planted fir may require an additional spray 3 to 5 years later.

### B. Foliage spraying by mist blowers

The need for equipment that will apply the low volumes of spray used in aerial application to understory hardwood brush has led to the development of tractor mounted and portable mist blowers. One of the greatest problems in aerial application is getting good penetration to the understory weed trees when a dense overstory is present to intercept the spray. Repeat sprays by air that remove the overstory and then the understory in a two canopy weed tree situation have been successful.

However, the capacity of the mist blowers to apply the same 5 gallon per acre volume as the aircraft to understory canopies up to 30 feet in height has virtually eliminated the need for aerial application on smaller areas of accessible terrain (6, 21, 22). Mounted on D-4 or John Deere 440 tractors, these blowers can negotiate dense brush and surprisingly rough terrain. Portable backpack blowers are ideal for spot treatment or for treating areas just a few acres in size.

Two pounds of low volatile ester of 2,4,5-T in 2 quarts of oil and 4 gallons of water are used through the blowers. Costs are generally equal to those encountered in aerial application. In respect to timing, chemical, carrier and volume, the recommendations for mist blowing are identical to those for aerial application.

The use of aircraft or mist blowers to apply foliage sprays is confined largely to conifer release work. Selective weed tree control in hardwood forests cannot be done with overall foliage applications, because most valuable hardwoods are killed or severely damaged by even the lowest rates of 2,4,5-T. At present, there are no herbicides available as foliage sprays. However, cut surface treatments which include frilling, girdling and tree injecting offer individual tree treatments which are economical to use in weeding hardwood as well as conifer stands.

### C. Frilling and girdling

For years, frilling and girdling trees by use of the axe and girdling machines has been a standard practice in the forests of this country. 2,4,5-T ester at 20 or 40 pounds per 100 gallons of diesel oil solution or the same rate of amine in water have been applied to these cut surfaces. Sodium arsenite has also been used extensively, but because of its toxicity it has it has gradually been replaced by 2,4,5-T or more recently by the cheaper combination of 2,4-D and 2,4,5-T (22). Kills of 90% or better can be expected on most weed tree species found in this country from frilling or girdling and treating with 2,4,5-T or a 50:50 mixture of 2,4,-D and 2,4,5-T. Where amines are used, best results will be obtained in the growing season.

Where more than a few hundred stems per acre must be treated a more rapid and cheaper method that is gaining in popularity in other sections of the country is the use of the tree injector.

### D. Tree injecting

Most tree injectors are hollow cylinder tools about four feet long, with a cutting bit in one end. Hand operated or automatic triggering mechanisms for releasing the chemical into the cut made by the bit are used. The injector is thrown at the base of a tree at an angle of approximately 60° to the ground. Injections are spaced around the base of the tree at 1.5 to 2 inch intervals. Trees from one to ten inches in diameter are best suited for this treatment.

A solution of 20 pounds of 2,4,5-T as low volatile ester per 100 gallons of oil (5 gallons of a 4 lb/gal acid equivalent material in 95 gallons oil), or more recently the 50:50 combination of 2,4-D and 2,4,5-T at this rate have given 95% kills of oak, hickory, cherry, maple and related species (19, 22).

The amine formulation may be substituted for the ester in this work during the growing season. However, if amines are used in the dormant season kills will drop from 95 to 100% with esters and to 85 to 90% with amines. This is not a significant amount where release of conifers is the objective.

Some of the older work by Leonard (16) reported at this conference and the more recent work by Starr (23) and Peevy (19) in the South indicates that amine concentrates may be used satisfactorily in injector cuts. As little as ½ to 1 cc of a 4 lb/gal formula of 2,4,5-T or the 50:50 mixture of 2,4-D and 2,4,5-T have given 95% complete kill on hickory (*Carya* spp.), post oak (*Quercus stellata*), blackjack oak (*Quercus morilandica*), southern red oak (*Quercus rubra*), live oak (*Quercus wislizeni*), and sweet gum (*Liquidambar styraciflua*).

Over 10,000 of these tree injectors have been sold to foresters in this country. One commercial company in the South has treated over 30,000 acres with tree injectors at a cost of approximately $10.00 per acre. This was on land where up to 2000 stems per acre were treated (6).

In addition to being ideally suited to the weeding of hardwood stands where individual stem treatment must be used, tree injecting is also the most effective treatment available for species that are hard to kill by foliage sprays, such as maple, ash and beech (*Fagus grandifolia*). This technique may be used at any time of the year.

### E. Basal sprays

Basal spraying of small weed tree stems less than 1 inch in diameter is a technique employed by some forest companies. The technique is slightly different than that commonly used on utility rights-of-way. Rather than wetting the bottom 12 to 18 inches of the stem, only the root collar zone is wet to run-off in forest operations. Backpack sprayers equipped with three-foot extension wands are used. Pressures are kept very low, so material barely flows through the nozzle. Twelve to 16 pounds of 2,4,5-T or 2,4-D and 2,4,5-T per 100 gallons of diesel oil may be used. This treatment is effective at any time of the year, but requires careful supervision to insure that enough material is applied to obtain a good kill.

**F. Combination treatments**

No single herbicide application technique will solve all the weed tree problems in forests. Most forest companies have found that their most effective programs involve combinations of these techniques.

For example, a very effective program in the Southeast today consists of summer treatments with tractor mounted mist blower to kill back understory brush up to 30 feet in height. This is followed by planting in the fall and winter. The final step is to remove the overstory canopy which usually consists of 300 to 500 stems per acre, with tree injectors after the seedlings have become well established (6, 11). This program eliminates any herbicide injury to newly planted seedlings and takes advantage of the light shade from a high overstory canopy during the first critical years of a seedling's establishment. Most important, the overstory hardwoods delay further encroachment of brush in the understory until conifers are well established.

**II. Brush control on rangelands.**

A statement by Klingman (15) at the recent Southern Weed Conference defines the magnitude of the brush problem on the range and pasture lands of this country:

"Brush infests 320 million acres of range and pasture land in the United States. This is more than the total acreage used for annual cultivated crops or almost as many acres as there are in the 11 southeastern states. Species with extensive infestations include juniper with 76 million acres, mesquite with 70 million acres, and sagebrush with 96 million acres. In Texas alone there are 20 million acres of live oak, 60 million acres of prickly pear, 18 million acres of post oak, 16 million acres of creosote bush and 13 million acres of grajillo and huisache. Almost equally large figures apply to other brush species in other states."

In 1960 the Federal Government through the Agricultural Conservation Program spent $6,299,653.00 on partial financial support of brush control treatments on 1,990,074 acres of range land (3). Table II gives some idea of the number of acres treated in a few of the states having major range brush problems.

TABLE II

Acres of brush treated in several states and portion of state total assistance under the Agriculture Conservation Program spent on brush control.

| STATE | ACRES TREATED | PORTION OF STATE TOTAL ASSISTANCE |
|---|---|---|
| Texas | 1,334,010 | 22.29% |
| Oklahoma | 127,445 | 6.26 |
| Nebraska | 84,811 | 3.13 |
| Arizona | 83,605 | 7.0 |
| Colorado | 50,835 | 3.64 |
| California | 26,692 | 2.24 |

Texas alone received 68% of the payments for brush control made by the Federal Government in 1960. This figure is readily understandable when one realizes that more than 65% of the State's 95 million acres of rangeland has a definite brush problem (9). An unestimated sum far in excess of the six million dollars spent by the government in 1960 is spent annually by individual ranchers in this country to rid their range of undesirable woody species. Fortunately, good chemical and/or mechanical control measures are available for most of the problem rangeland brush species. Since these programs are well outlined in the proceedings and research reports of the Western Weed Control Conference and the Southern Weed Conference, it is not necessary to mention them here.

However, before moving on to the business of controlling woody plants on rights-of-way it should be pointed out that there is great similarity between the programs used for weed tree control in forests and those used for brush control on rangelands. Chemicals, timing and methods of application are in many cases interchangeable. Also, both are problems of release, in one case grass and in the other, trees. Complete woody plant kills may be desirable, but they are not essential to grow grass any more than they were to grow trees.

With these similarities it would seem that a close exchange of information between research workers interested in rangeland brush control and those interested in forest weed tree control would be mutually beneficial. An example of this in recent years has been the development of portable and tractor-mounted mistblowers already described for forest weeding. There is no reason why the same blowers would not be very useful for applying chemicals to rangeland brush problems.

The extensive work done by Darrow (8) using pellet applications of the substituted ureas, the benzoic acids and others on rangeland species may have application in forest weeding. Most rangeland will not stand the cost of a blanket treatment of enough pelleted material to give good kill, but the situation could be considerably different in forestry. Here the release needed to grow 800 conifer stems per acre may require far less chemical than that needed to release an acre of grass. Then too, the monetary returns on an acre of forest land may justify a greater expenditure for chemical than on rangeland. More work needs to be done to determine the selectivity of the pelleted materials on conifers and also to establish treatment costs for best release or site preparation.

## III. Brush control on railroads, highways, utilities and ditchbank rights-of-way.

The number of acres of brush on all rights-of-way in this country was impossible to determine from the data received. In many cases, the figure for miles of right-of-way was given, but the actual acreage on which brush was a problem was not known.

The state of Minnesota reported that 57,288 acres of highway; 4,198 acres of railroad and 7,374 acres of utility right-of-way were sprayed in 1961. This included both brush and herbaceous species, however.

Of the 366,000 miles of railroad track in this country, it was reported that approximately 270,000 miles are treated chemically each year (20). The cost of such treatment is estimated at over $20,000,000 annually with another $10,000,000 spent for other methods such as burning-disking and mowing. Again, most of this acreage is not infested with brush.

Only one reference (10) gave an estimate of the number of acres of right-of-way under utility lines. The figure of 50,000,000 acres was given as a "guesstimate". Another reference indicated 388,000 miles of transmission line 35 KV and up (18) , of which 4,000,000 acres might require brush control. No figure for distribution line was mentioned.

No total figures were available for highway rights-of-way. However, the states of Illinois, Massachusetts, Pennsylvania, Florida, New York and North Carolina together reported a total of 535,112 miles of road on part of which they practiced chemical brush control.

The acreage of brush along irrigation and drainage ditches is evidently quite large, particularly in the drainage areas of the Mississippi, Missouri and Ohio Rivers and in the arid regions of the Southwest. Again, figures on total miles of ditchbank were available but the amount covered by brush was not.

Although the author was unsuccessful in obtaining complete figures on the brush acres on rights-of-way in this country one should not assume that there are no such figures. They would be of considerable interest, but to obtain and summarize them will require a considerable amount of time and effort.

2,4-D and 2,4,5-T still continue to be the work-horse chemicals for right-of-way brush control. The standard stem foliage, modified basal, and stump sprays are still used widely, but new application techniques and formulations are constantly being developed. A few of the more recent are discussed here.

### A. Aerial application with invert emulsions

In 1960 more than 20,000 acres of utility right-of-way brush were sprayed by helicopter, over half of this acreage being done with the new low drift invert emulsion formulations (14). For those not familiar with the invert emulsion, it is a thick white water-in-oil emulsion with a consistency like mayonnaise. When applied through special centrifugal sprayer mounted on a helicopter flying at ground speeds not in excess of 25 mph an umbrella-like pattern of large droplets is produced and drift is reduced markedly.

Confining spray to the right-of-way in aerial applications is essential because of the valuable forest and crop land through which these rights-of-way pass. The invert emulsions are somewhat more expensive to fly, but the increased cost is small in comparison to one large damage claim from drift of conventional oil-in-water emulsions.

The most common rate and volume of the invert emulsion flown on right-of-way brush today is 6 pounds of a 50:50 2,4-D/2,4,5-T mixture in 12 gallons total volume per acre. With this application plant kills of root suckering species such as locust (*Robinia pseudoacacis*), sassafras (*Sassafras albidum*), and sumac (*Rhus* spp.) are often 90% or higher. This is quite surprising when one stops to think how difficult it is to kill these species completely with 10 to 12 lbs of 2,4-D/2,4,5-T mixture in 250 to 300 gallons of water per acre with ground application.

Generally speaking, with most brush species such as ash, maple, oak, elm, and hickory a partial or complete kill of the aerial portion of the plant is all that can be expected with the 6 lb rate in 12 gallons volume of invert emulsion per acre. Where higher rates and volumes have been applied kills have been increased. Whether or not there is an economical rate and volume at which helicopter application of invert emulsions will give kills equal to ground applications of conventional material remains to be seen.

At present the helicopter and invert emulsion are control tools. Repeat sprays are needed to keep the brush suppressed, or the initial helicopter spray must be followed by a basal spray from the ground if brush is to be eradicated.

### B. Dormant broadcast spraying

Several advantages of this application method account for its increased use on rights-of-way. First, by spraying in the winter or dormant months, better kills of red maple and pine have been obtained; two species difficult to control by summer stem-foliage sprays. Second, there are no susceptible crops in many areas of the country during the dormant season. Third, there is no unsightly brown-out along roadsides. Finally, longer use of spray equipment is possible.

Dormant broadcast spraying is done from the time of leaf-fall until bud-break in the spring. Sprays are broadcast so as to wet the root collar and lower stems more heavily than tops of the plants. Six pounds of either 2,4,5-T low volatile ester or the 50:50 ratio of 2,4-D/2,4,5-T in 100 gallons of diesel oil is used most frequently. 150 gallons of this solution should cover an acre of fairly dense brush 3 to 6 feet high.

### C. Oil-soluble amines

The oil-soluble amines of 2,4-D and 2,4,5-T are particularly appropriate in areas where volatility is a serious problem and where one wishes to use an oil or oil-water carrier.

Tests to date indicate that on most brush species the oil-soluble amines are equal in effectiveness to the same rate of the low volatile ester and show less volatility (4).

## SUMMARY

The control of woody plants in forests, on rangelands and on rights-of-way in this country has evolved into a very large business, indeed.

In the 18 years since the introduction of the phenoxy acetic acids many other chemicals have been screened for woody plant control, but none have taken the place of these versatile compounds.

Although much has been done in improving formulations and application techniques for the phenoxy materials there are still many unsolved problems. Perhaps the most challenging and one common to all three of the broad areas of woody plant control described in this paper is that of basal sprouting. Good fundamental studies that would point the way to more effective techniques by explaining why so many of the brush species in this country are easy to top kill, but hard to root kill with the chemicals available today are urgently needed.

It is encouraging to note the recent increase in federal funds assigned to Texas A & M College and Oklahoma State University for fundamental studies on woody plant problems. Perhaps the next great break-through in the woody plant field will be the discovery of a new compound that will replace 2,4-D and/or 2,4,5-T but a strong effort in fundamental research on the behavior of these two compounds in woody plants might be equally rewarding.

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## INDUSTRIAL WEED CONTROL, BIG BUSINESS WITH MANY HEADACHES

By R. H. SCHIEFERSTEIN
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As the title of my presentation indicates there are many headaches associated with industrial weedkilling. However, it *is* big business and I hasten to assure you that it is always possible to take a few aspirins before running down to the bank to deposit the money one can make.

To start out, let's briefly review the development of industrial weedkilling with chemicals. A little over 50 years ago when industrial weedkilling with chemicals got started there were only two materials available for use. These were arsenic compounds and high boiling fraction oils. On the surface this may seem the essence of simplicity with no problems, however, treatments with herbicidal oil lacked permanence and arsenic compounds had their associated poison hazards. Both of these materials are still in use today for specific purposes and indeed, sodium arsenite remains one of the most effective and permanent materials for use under minimum surfacing or blacktop. In time, however, the herbicidal properties of sodium chlorate were discovered and its usage to a large extent replaced previous materials. Here the problem of the fire hazard created by sodium chlorate in the presence of dry organic matter caused many headaches. Various fire retardants were tried and used in conjunction with sodium chlorate but ultimately it was found that water soluble borates mixed in proper proportions with sodium chlorate virtually eliminated any fire hazard. At this point many of the troubles had been eliminated, however there was the continuing problem that the chlorate-borate materials were highly soluble and not tightly bound in the soil. Thus, they tended to leach out of the upper soil zone providing growing space for germinating shallow-rooted annuals. This problem sold many bottles of aspirin until in the early fifties the duPont company came along with the substituted urea compounds. These materials gave us a sufficiently long residual in the soil and in combination with the more readily leached chlorate-borate materials it became possible to clean up weeds and prevent their return in practically any industrial situation. Following initial treatment the substituted ureas could then be used alone to maintain bare ground indefinitely or until species with tolerance invaded the area. In the later fifties Geigy introduced their triazine compounds. These had a somewhat different range of species specificity than the substituted ureas. Simazine in particular was found to be somewhat safer than the substituted ureas. in the proximity of many trees and shrubs. Thus, the triazines have found their way into extensive usage for industrial weed control both alone and in combination with other compounds. During the forties and fifties several foliage active materials such as the plant growth hormones, amino triazol, dalapon and others had been introduced and all of these found their way into industrial weedkilling to at least some extent for special situation.

This pretty much brings us up to date. We now have all the tools we need to meet any situation we may encounter; usually at a low enough cost figure to be attractive. Though that statement may sound as though I am saying we have arrived, and have no more difficulties, there are still a few aspirin promoting problems to be faced. For instance, while we can now eradicate any given species the process can be extremely costly in some cases when hard-to-kill species are involved. For example, costs of $100 to $150 an acre are not uncommon for some species and costs of as high as $350 per acre are not unheard of. Believe me, when you can sell much weed control at $350 per acre you are a real salesman.

There has just appeared upon the scene a new series of compounds that I believe hold good promise of improving the economics of control of some of our hard-to-kill species. These are the substituted uracils, including Hyvar, which have just been introduced by duPont.

One of the biggest headache producers that faces us today is recommendations, both verbal and written on labels and bulletins. I am sure you can appreciate the difficulty, no the impossibility, or writing a label for a product that will cover every situation that may be encountered. A great deal of this complexity is due to the large number of compounds that have been found to be useful. Then, when one considers how results with each of these may be affected by species present, various soil conditions, amounts and distribution and rainfall, stage of growth of weeds, sunlight intensity, temperature conditions, humidity and the proximity of susceptible desirable plants and crops the problem becomes enormous. In an attempt to compensate for as many as possible of these variables, label recommendations are usually written with a built-in-safety factor. With the current inadequate number of well trained field men to make recommendations from inspection this appears to be a necessary evil even though a good percentage of the time higher rates than are actually required are being used. This of course, effects the problem of economics inadvantageously.

Not all of the problems involved in industrial weedkilling are of a technical biological nature. Once the presumably correct recommendations have been made there arises the problem of proper application. Where areas to be treated are very small it is uneconomic to either own a sprayer or contract the work done. For such situations several granular formulations that are spread dry by hand have been developed. Where areas are large, accurate efficient application equipment is required. New ideas are forthcoming on improvement of equipment almost continuously. Obviously, the best recommendations in the world and the best spray equipment in the world are of little value without capable well trained men operating the sprayers. The problem of selecting, training, and keeping satisfactory spray personnel where the work is by nature somewhat seasonal is a continuing headache.

Over the past few years there has been an increasing number of bids let on the basis of guaranteed weed control. These bids will read essentially as follows: "To provide weed control on "xxxx" acres of land at "such and such" a location and to maintain the area in a weed free condition for "such and such" a period of time." What an industrial weed control firm can quote on such a bid depends to a large extent on how much of what chemical or chemicals are used. In circumstances such as this firms with well trained technical personnel making recommendations have a decided advantage. Of course, when a competitive firm misses getting one job there is a temptation to bid competitively on the next one that comes along. It is possible to lose, and people have lost, a good deal of money in this manner. Having to come back and re-treat an area is particularly costly because weeds tend to become more difficult to control as the season progresses. One method that has been effectively employed to keep costs at a minimum, where weed control is on a guaranteed basis, is as follows: The area is sprayed with an overall blanket treatment using a minimal dosage that will control most of the weeds. Then, clumps of hard-to-kill species are spot treated individually in addition to the initial spray, usually utilizing a dry granular sterilant or another chemical specific for the control of that species.

I have discussed some of the major problems and some of their answers, which are involved in industrial weed control. By this time I am sure you are convinced that the most useful chemical involved in this specific field is acetyl salisylic acid or, aspirin. However, people involved in the industrial weedkilling field have a good record in the past of being able to cure their headaches in the best of all possible manners. That is, eliminating their cause. I am personally optimistic about the future and feel our biggest headaches will be encountered in the "mornings after" at meetings such as these.

# MAJOR WEED PROBLEMS ON THE WESTERN RANGES AND WHAT IS BEING DONE

By H. P. ALLEY

I was asked to present a paper on the "Major Weed Problems on The Western Ranges and What is Being Done." Realizing that my knowledge of these problems covering the entire western region was limited, I thought this would give me an opportunity to gain a better perspective of the situation. It would no doubt be very enlightening for everyone engaged in weed control research or extension to take on such an assignment.

In considering information for this paper, I also realized that quite an extensive program was presented at the Sixteenth Western Weed Control Conference held at Spokane in 1958, which dealt mainly with weed control on rangeland. Rather than repeat much that was presented at that meeting, I thought it better to look at our range weed problem in a little different light. To do this I am going to base my evaluation of the range weed problem on a questionnaire forwarded to cooperators in the western region, a survey conducted by the Western Directors, and information obtained from Mr. Kenneth Platt's survey as presented in the Journal of Range Management.

I am sure that at least a majority of the same people, engaged in weed control work, were contacted and supplied the information for the Western Directors and for my questionnaire. I am sure that most will agree, after viewing the information presented, on prepared slides and tables, that the first and most important factor to consider in a control program is to fully understand the problem. Is it possible that one's attitude toward specific problems can be changed over a mere period of two years? Pressure for information being placed on only a handful of research personnel for immediate answers on new problems arising each year may be responsible for this. We don't have the specific answers so this is a major range weed problem in our area. Whereas, in contrast, the true economic potential of other plant species are shoved to the back of the file without a good and complete follow-up program.

It was very interesting to note that the list of the ten most important weeds on the rangelands of the western range states, as compiled by our Western Directors and the information obtained through my questionnaire, do not agree as to the weeds of the greatest economic importance, Tables I and II. No acreages are listed by the Western Directors survey – the species were arranged in the order of their indicated seriousness.

Many species of poisonous plants, herbaceous weeds and brush are common on most of the 536 million acres of rangeland in the eleven Western states.

Considerable interest has been created in the control of undesirable plants and many ranch operators are anxious to know what methods can be used and if such programs would be an economic venture. I think this is rightly so when one considers the increasing land values, shortage of additional rangeland, economic requirements for more efficient production and invasion of our western rangelands with unpatable or otherwise low productive plants.

The development of chemicals capable of controlling many undesirable plants have added impetus to the range improvement program. Suffice to say, we can expect a more complete evaluation of the chemicals we now have, and in addition, will have newer and better formulations in years to come.

It would be remiss to not include here that – even though we have an outstanding tool in the form of herbicides, a range weed problem encompasses much more. Rangeland in poor condition is due to many factors – drought, overgrazing and poor management. No matter what control program is applied, the same problems are always faced in the end. The use of the area without bringing about re-invasion of the former or more undesirable plants.

I would like to discuss the range weed problem by separating the information gained into three groups: (1) poisonous plants, (2) undesirable herbaceous weeds and, (3) undesirable woody plants.

## Poisonous Plants

Twelve reports were returned, of the thirty forwarded to research and extension cooperators, in the eleven western states.

The importance of poisonous range weeds is evident. Of the some thirty different species of undesirable plants reported, seven of these were poisonous plants infesting 91,813,000 acres. Oregon and Washington were the only states not reporting poisonous plants as one of their major problems. The Western Directors list five poisonous plants in the ten weeds of greatest economic importance, with locoweed (*Astragulus spp.*) and halogeton (*Halogeton glomeratus*) leading the list. Death camas (*Zygadenus spp.*), larkspur (*Delphinium spp.*) and sneezeweed (*Helenium spp.*) are the other three poisonous plants on the list.

Realizing that the reported acres infested is in many cases an educated guess, I would nevertheless like to compare the acreage reported by my colleagues and that reported in the Journal of Range Management, Tables I and II. Halogeton comprised the largest acreage in both surveys. The Journal of Range Management reports 20,116,000 acres as compared to 31,500,000 by the cooperators. This 31,500,000 acres included only the states of Idaho, Nevada and Wyoming. Extensive surveys have been conducted to determine the infestation of this plant. The publicity this plant has received in recent years has resulted in rather complete surveys.

The infestation of larkspur and locoweed reported in both surveys are reasonably close in acreage listed. Death camas, although listed as the fourth most important weed by the Western Directors was of minor importance in reports returned by cooperators. Other poisonous plants mentioned were water hemlock (*Cicuta spp.*) and lupine (*Lupinus spp.*).

Active research programs to determine methods of control and management have been under way in most of the western states where infestations of poisonous plants occur. Many bulletins and circulars are available outlining control programs. All literature cites the problem facing them. Chemicals can be used on all species with some measure of control. Proper management of infested areas and livestock work hand in hand with all control measures. Scattered infestations over the western rangeland require a serious consideration to this problem.

Programs which are organized to recognize the problem, map the infestations, and understand the growth habits are essential.

Recorded animal losses from poisonous plants is difficult to determine with any degree of accuracy. Estimates based on reports from a large number of incidents indicate that around five percent from larkspur infested rangelands only, with losses in some years running over 15 percent. Specific cases are known in which 30 to 50 head of cattle from larkspur and 500 to 600 head of sheep from halogeton have been lost. These losses occurred on ranges where poisonous plants were abundant, losses were, therefore, attributed to the poisonous plants. Evidence was in many cases circumstantial and there was not always conclusive proof.

The elimination of larkspurs from an infested range is difficult. Where only scattered patches occur, hand grubbing is the most reliable method.

Recent results on tall larkspur (*Delphinium barbeyi*) show that it is easier to kill than plains larkspur (*Delphinium geyeri*). Applications of two pounds of 2,4,5-T plus a wetting agent applied at early bud stage of growth has reduced the population of tall larkspur by 85 to 90 percent. Re-treatments over a two to three year period is necessary to eliminate the old established stand and catch new seedlings infesting the area.

Plains larkspur has been more difficult to control. Under good moisture conditions, when the plants were not under a moisture stress, 2 pounds of 2,4-D ester plus a wetting agent, has resulted in 75 to 80 percent control.

Many of the recommendations on the optimum time for herbicide application have called for treatment during the bud to bloom stage of growth. A close observation of plains larkspur at this stage of growth reveals that practically all of the basal leaves are dried up and the plant is not receptive to the chemical.

Early sprayed areas can usually be grazed with safety in the same season that they are sprayed since the older plants are killed back and regrowth does not occur during the grazing season.

A combination of 2,4-D sprays with management practices to encourage desirable range species will combine the effects of competition and spray for the greatest reduction in larkspur stand.

The most important insurance against halogeton invasion is the maintenance of rangeland in a healthy condition. Halogeton invades barren areas or depleted rangeland. It is not a strong competitor and will not establish itself in stands of good native vegetation.

Reseeding with adapted grasses in areas of 9 inches or more of precipitation has successfully reduced halogeton. Usually where halogeton is found, rainfall is too low to adapt this practice.

Water-spreading devices have been utilized in an attempt to increase forage cover on the semi-desert rangeland. In many cases, halogeton established on the barren areas and dykes has limited the value of this range-improvement technique.

Chemicals offer a possible means of containment. The 2,4-D ester is the best selective herbicide available. This compound, applied at a rate of 2 lbs. of 2,4-D per acre in a volume of 100 to 200 gallons of water and diesel oil per acre, has given good results. Other chemicals along with soil sterilants have been recommended. The practicality of this type compounds is doubtful other than in very few isolated cases.

Locoweed and death camas can be effectively controlled with 2,4-D. Again the problem confronting a chemical program is usually the sparse stands of the poisonous plants over millions of acres. Spray programs, both aerial and ground, have been used in areas of very dense infestation with good results.

#### Undesirable Herbaceous Plants

Only twelve species of undesirable herbaceous weeds on the western rangelands were reported by colleagues. Of these, only three can be found on the Western Directors ten most important rangeland weed list and three on the ten listed as secondary in importance.

This, I think, indicates that we in research and extension do not fully understand the situation in our own states or surveys conducted through correspondence are of little value. I would presume that the information supplied to the Western Directors is of more value and of greater accuracy than the information I obtained. The confusion surely points up the fact that we have a serious problem confronting us in our field of endeavor. Until accurate and comprehensive surveys are conducted and the problem more fully understood, little can be accomplished.

Is it possible that many of us have accepted the range manager's attitude toward many species? By this I mean the utilization of downy bromegrass (*Bromus tectorum*) to take advantage of its spring productive peak. Only interested in the containment or limiting medusahead rye (*Elymus-caput-medusa*) to its present infestation. Being content with the acreage of sagebrush (*Artemisia tridentata*) which has some important values. A considerable amount of research dealing with range weed species has been conducted. However, I would hesitate to say that a proportional amount is being directed toward this area. Especially when we look through Card File No. 20 of federally supported programs in the United States and the Food and Agriculture program of research. I could only find about eight federally supported projects in six western states. I am sure the files were not complete and several states have state projects in the range weed control area.

I will have to agree with Dr. Klingman of the United States Department of Agriculture, Agriculture Research Service, in that downy bromegrass (*Bromus tectorum*) is one of the most serious weed problems on rangelands. This was omitted from the Western Directors list and was listed as a major problem on only two reports returned by cooperators. It would be nice to assume that this problem has been solved. Downy bromegrass probably infests more acres of rangeland than any other range weed. While it is also a useful forage species, it has largely displaced more valuable forage species and is a prime deterrent to the introduction of valuable range grasses into rangelands through seeding.

Downy bromegrass invasion with subsequent low productivity on the western range states is a major concern. The problem of improving range with low-value cover involves about two choices: (1) many years of protection from grazing – an expensive choice, or (2) reseeding with higher value grasses – a less costly choice which has meant taking a chance of serious wind erosion of some soils.

Establishment of grasses requires a reduction of competition from plants already growing on the range, plowing or mechanically destroying existing cover is often risky.

To find a safer way to reduce existing cover – chemical seedbed preparation is showing great promise. The idea is to use chemicals to kill present cover and then seed directly into the dead cover with the dead plants providing soil protection until the new plants are established.

Following the chemical treatment in the early spring, enough of the undesirable annual and perennial plants are removed to allow establishment of desirable species seeded in late fall. The only tillage performed is with a grassland drill with small shoe openers – excellent stands have been obtained.

California and Idaho report 1,750,000 acres of rangeland infested with Medusa-head (*Elymus-caput-medusa*). Oregon and Washington also indicated it was a problem, but no acreage was listed.

Medusa-head, an annual, unpalatable weedy grass, has been tagged as a serious threat to range livestock industry, especially in the Pacific northwest where the grazing capacity in some areas has been reduced as much as 75 percent.

Small spot infestations must be controlled even at high costs, to insure against spread of the weed to uninfested areas.

On large, long established stands, chemical control is not economically feasible. When such conditions persist, the more productive locations should be chosen for improvement by various methods of control which could include: burning and cultivation, combined with proper fertilization and seeding.

Various species of cactus have become increasingly important constituents of the range vegetation. All the western states have serious infestations of *Opuntia sp.* in pastures and rangelands. Over 5 million acres of rangelands in eastern Colorado and eastern Wyoming have infestations of economic importance. New Mexico reports 4½ million acres.

Grubbing, grading, railing and herbicides have all been used for reducing infestations. The methods of control have generally been too erratic and too ineffective to be applicable because intense effort has not been made to understand the complex problems of chemical control by selective herbicides.

Biological control by phytophagous insects have been utilized and been very successful in some instances. Plant pathogenic organisms have been sparingly studied.

Many other species of herbaceous plants were indicated as creating a problem such as Yellow star thistle (*Centaurea solstitialis*), Canada thistle (*Cirsium arvense*), dalmation toadflax (*Linaria dalmantica*) goatweed (*Segilops truincialis*), gumweed (*Grindelia squarrosa*), Yellow toadflax (*Linaria vulgaris*) mulleins (*Verbascum spp.*) and tarweed (*Amsinckia intermedia*).

### Undesirable Woody Plants

Less emphasis was placed on the brush species by the Western Directors than was by the cooperators survey. Approximately 170,000,000 acres was indicated to be infested with woody species in the western states. Six woody species are found on the twenty rangelands weeds of greatest economic importance by the directors.

We, in the eleven Western States, are aware, I am sure, of the recommended portion of the increase in Federal-grant funds for the fiscal year 1962 to step up research programs on weed investigations through the Regional Research Fund or by individual stations.

Two general areas in which weeds were listed as major problems were (a) aquatics, and (b) undesirable woody plants that infest the rangelands of the Great Plains. It was shocking to many engaged in weed control to find that not one project covering the woody species was awarded to states in this conference. Are we so efficient that we have no woody plant problem? Were the projects submitted of poor quality? Or are we poorly represented on the committee of nine?

It was stated in the committee of nine's review that the control used at present on woody species are generally too erratic and not sufficiently effective to be satisfactory. I would have agreed if sagebrush had been deleted from this list. I mention this because I am more familiar with this program of control than with control of other species. Possibly many of you would be in disagreement with those species you are familiar with and have developed programs for.

No doubt there have been failures in the chemical sagebrush control program. But in practically all cases it has been the result of people not versed in the growing conditions, types of herbicides to use, species susceptible, etc., that have caused the five percent failure. This is the case in many other situations. Literature has been available, research and extension personnel are available to assist the laymen. The information and knowledge available has not been effectively utilized.

We will all agree that a better understanding of the conditions that bring about occasional failures or occasionally excellent control from treatments of woody plants would point the way to planning techniques and practices necessary for achieving predictable results. There is a critical need for information on the effects of edaphic, climatic, and physiological factors on the responses of all plants to control methods, particularly as related to the characteristics of individual species.

In closing, I would like to summarize some of the limiting factors in developing a range weed control program and what is being done. The comments are those submitted to me by personnel in the western region.

**Limiting factors:**

1. Education of farmers and ranchers.
2. Low-carrying capacity levels make brush control programs of doubtful economic value, since forage increases may not compensate for costs of treatment.
3. Methods of control on some species and in some areas are not sufficiently developed to appeal to all ranch owners or range administrators.
4. Efficient and effective herbicides to incorporate into agronomic practices.
5. Low value land sets a low ceiling on expenditures that can economically be made for control.
6. Moisture supplies may severely limit growth before the susceptible stage is reached.
7. Difficult terrain – difficult or impossible to reseed with desirable grass.
8. Knowledge of techniques limited.
9. Large, scattered infestations on low value land.
10. Often infestations are on leased land.
11. Lacking knowledge on year to year variation in control measures.
12. Inadequate research to guide the way.

**What is being done:**

1. The program of mesquite control is gaining momentum. Private operators in cooperation with S.C.S. and A.C.P. programs and Bureau of Land Management and Forest Service on federal lands are carrying out active programs. Controlling juniper by cabling is done annually on several thousand acres with A.C.P. assistance. Cholla cactus is being worked mechanically.
2. Commercial companies are discovering important new herbicide groups each year. Eventually we should have effective chemicals for many of the worst problems.
3. Research underway is aimed at improving effectiveness of presently available herbicides by gaining a better understanding of factors effective absorption and translocation, nature of herbicide action, life history, morphology and growth characteristics of important species, fundamental information about formulations and their importance.
4. Fate of herbicides in plants and soils.
5. Continued research to find insects that will control halogeton and other range weeds.
6. Activity in cultural control – reseeding, fertilization and managed grazing.
7. Combination of mechanical, burning and chemicals.
8. Detailed physiological-ecological studies.
9. Learning to live with halogeton – supplementing diet using dicalcium phosphate in alfalfa meal pellets.
10. Educational programs.

Table I. **Weeds of Greatest Economic Importance on Rangelands of Western United States – Western Directors.** 1/

| | | Survey 2/ | Journal of Range Management 3/ |
|---|---|---|---|
| 1. | Locoweed (*Astragulus* spp.) | 15,000,000 | 12,000,000 |
| 2. | Halogeton (*Halogeton glomeratus*) | 31,500,000 | 20,116,000 |
| 3. | Canada thistle (*Cirsium arvense*) | 5,000 | 3,172,000 |
| 4. | Death Camas (*Zygadenus* spp.) | 5,000,000 | 11,060,000 |
| 5. | Larkspur (*Delphinium* spp.) | 10,175,000 | 5,298,000 |
| 6. | Medusa-head (*Elymus caput-medusa*) | 1,750,000 | 1,560,000 |
| 7. | Rabbitbrush (*Chysothamnus* and *Tetradymia* spp.) | 10,100,000 | 9,850,000 |
| 8. | Sneezeweed (*Helenium* spp.) | 4/ | –0– |
| 9. | Yellow star thistle (*Centaurea solstitialis*) | 4/ | –0– |
| 10. | Mesquite (*Prosopis* spp.) | 18,283,000 | 46,000,000 |
| | TOTAL | 91,813,000 | 109,056,200 |

1/ Poll made by Western Directors.

2/ Acreage indicated by Survey 1961-62.

3/ Acreage listed in Journal of Range Management. Vol. 12, No. 4. July, 1959.

4/ Reported, but no acreage given.

**Table II. Weeds of Secondary Importance on Rangelands of Western United States – Western Directors.** 1/

| | Survey 2/ | Journal of Range Management 3/ |
|---|---|---|
| 1. Creosote bush (*Larrea divaricata*) | 7,500,000 | 29,000,000 |
| 2. Dalmation toadflax (*Linaria dalmatica*) | 5,000 | 500 |
| 3. Spotted knapweed (*Centaurea maculosa*) | 50,000 | 50,000 |
| 4. Mediterranean sage (*Salvia aethiopis*) | –0– | 200,000 |
| 5. Scotch broom (*Cytisus scoparius*) | –0– | 200,000 |
| 6. Poison hemlock (*Cicuta maculata*) | 20,000 | –0– |
| 7. Puncture vine (*Tribulus terrestris*) | –0– | 1,000,000 |
| 8. Snakeweed or broomweed (*Gutierrezia* spp.) | 4/ | 2,125,000 |
| 9. Tall larkspur (*Delphinium* spp.) | 4/ | –0– |
| 10. Tansy ragwort (*Senecio jabobaea*) | 4/ | 200,000 |
| TOTAL | 7,575,000 | 32,775,500 |

1/ Poll of Western Directors.

2/ Acreage indicated by Survey 1961-62.

3/ Acreage listed in Journal of Range Management. Vol. 12, No. 4. July, 1959.

4/ Reported, but no acreage given.

Table III. **Poisonous Range Plants as Reported by Cooperators in W.W.C.C., 1962.** 1/

| | Ariz. | Calif. | Colo. | Idaho | Mont. | Nevada | N. Mex. | Ore. | Utah | Wash. | Wyo. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Locoweed (*Astragulus* spp.) | ---- | ---- | ---- | 2/ | 2/ | 5,000,000 | 2/ | ---- | 2/ | ---- | 10,000,000 |
| Larkspur (*Delphinium* spp.) | ---- | 100,000 | 75,000 | 2/ | 2/ | 55,000,000 | 2/ | ---- | 2/ | ---- | 5,000,000 |
| Water hemlock (*Cicuta* and *Occidentalis douglasii*) | ---- | ---- | ---- | ~~2/~~-- | 2/ | 10,000 | ---- | ---- | 2/ | ---- | 2,000 |
| Halogeton (*Halogeton glomeratus*) | ---- | ---- | ---- | 650,000 | ---- | 30,000,000 | ---- | ---- | 2/ | ---- | 850,000 |
| Death camas (*Zygadenus* -pp.) | ---- | ---- | ---- | 2/ | 2/ | ---- | ---- | ---- | ---- | ---- | 5,000,000 |
| Lupine (*Lupinus* spp.) | ---- | ---- | ---- | 2/ | ---- | ---- | ---- | ---- | ---- | ---- | 10,000,000 |
| Burroweed (*Haplopappus tenuisectus*) | 5,500,000 | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- |
| TOTAL | 5,500,000 | 100,000 | 75,000 | 650,000 | ---- | 40,010,000 | ---- | ---- | ---- | ---- | 30,852,000 |

1/ Report from Cooperators in W.W.C.C., 1962.

2/ Reported, but no acreage given.

Table IV. **Undesirable Herbaceous Weeds as Reported by Cooperators W.W.C.C., 1962.** 1/

| | Ariz. | Calif. | Colo. | Idaho | Mont. | Nevada | N. Mex. | Ore. | Utah | Wash. | Wyo. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Medusa-head (*Elymus-caput-medusa*) | ---- | 1,000,000 | ---- | 750,000 | ---- | ---- | ---- | 2/ | ---- | 2/ | ---- |
| Italian thistle (*Carduus* and *Phcn, cephalus Pycnocephalus tenuiflorus*) | ---- | 100,000 | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- |
| Tarweed (*Hemizonia* spp.) | ---- | 1,000,000 | ---- | ---- | ---- | ---- | ---- | ---- | 2/ | ---- | 50,000 |
| Canada thistle (*Cirsium arvense*) | ---- | ---- | ---- | ---- | 2/ | ---- | ---- | ---- | ---- | ---- | 5,000 |
| Dalmation toadflax (*Linria dalmatica*) | ---- | ---- | ---- | 2/ | ---- | ---- | ---- | ---- | ---- | 2/ | 5,000 |
| Downy bromegrass (*Bromus tectorum*) | ---- | ---- | ---- | ---- | ---- | ---- | ---- | 2/ | ---- | 2/ | 25,000,000 |
| Diffuse knapweed (*Centaurea muclosa*) | ---- | ---- | ---- | 2/ | ---- | 50,000 | ---- | ---- | ---- | 2/ | ---- |
| TOTAL | ---- | 2,100,000 | ---- | 750,000 | ---- | 50,000 | ---- | ---- | ---- | ---- | 25,060,000 |

1/ Report from Cooperators in W.W.C.C., 1962.

2/ Reported, but no acreage given.

Table V. **Undesirable Woody Plants as Reported by Cooperators in W.W.C.C., 1962.**[1/]

| | Ariz. | Calif. | Colo. | Idaho | Mont. | Nev. | N. Mex. | Ore. | Utah | Wash. | Wyo. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Mesquite (*Prosopis* spp.) | 7,283,000 | ---- | ---- | ---- | ---- | ---- | 11,000,000 | ---- | ---- | ---- | ---- |
| Cactus (*Opuntia* ssp.) | 1,000,000 | ---- | ---- | ---- | 2/ | ---- | 4,500,000 | ---- | ---- | ---- | 5,500,000 |
| Turbinella oak (*Quercus turbinella*) | 5,824,000 | ---- | 500,000 | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- |
| Interion live-oak (*Quercus wislizenii*) | ---- | 6,000,000 | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- |
| Poison oak (*Rhus diversiloba*) | ---- | 7,000,000 | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- |
| Creosote bush (*Larrea divaricata*) | 2,000,000 | ---- | ---- | ---- | ---- | ---- | 5,500,000 | ---- | ---- | ---- | ---- |
| Sagebrush (*Artemisia* spp.) | ---- | 7,000,000 | 5,000,000 | 2/ | 2/ | ---- | 3,000,000 | 2/ | 2/ | 2/ | 37,248,000 |
| Manzanita (*Arctostophylos* spp.) | ---- | 7,000,000 | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- |
| Chamise (*Adenosteme fasciculatum*) | ---- | 7,000,000 | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- |
| Rabbitbrush (*Chrysothamnus* spp.) | ---- | ---- | 100,000 | ---- | ---- | ---- | ---- | ---- | ---- | ---- | 10,000,000 |
| Juniper (*Juniperus* spp.) | ---- | ---- | ---- | ---- | ---- | ---- | 15,000,000 | 2/ | ---- | ---- | ---- |
| Greasewood (*Sarcobatus vermiculatus*) | ---- | ---- | ---- | ---- | ---- | ---- | ---- | 2/ | ---- | ---- | 5,000,000 |
| TOTAL | 16,107,000 | 34,000,000 | 5,600,000 | ---- | ---- | ---- | 39,000,000 | ---- | ---- | ---- | 57,748,000 |

1/ Report from Cooperators in W.W.C.C., 1962.

2/ Reported, but no acreage given.

# NEW HORIZONS IN TURF WEED CONTROL

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Administrative and educational decisions relative to the development of a new process or product are based on such questions as:

1. Is it based on sound principle?
2. Is it better than existing competition?
3. Does it have large enough volume to warrant development costs?

Regardless of our awareness of these questions, the answers to all three must be yes before this new product or process is accepted. This paper will describe the horizons of the turf weed control sphere in the light of these questions.

The orderly development of successful chemical weed control practices in wheat, cotton, corn, rice, barley, citrus, and seed crops has occurred because each of these individual crops is grown on large acreages of similar soils and under similar macroclimates. Only a dozen or more weeds are serious competitors with each. Consequently, a modest screening program to find materials selective between the crop and groups of common weeds, development of the most promising economic materials, and education programs to alert the commercial producers of these products can easily develop new markets.

Turf is produced in every community of the United States and is generally grouped into seven broad climatic zones. Within each of these zones there are many microclimatic variations and wide differences in soils. In fact, extremes of microclimatic and soil variations can be found on individual turf installations. Ten species of grasses and many varieties of each are cultured under these conditions. The extremely variable climates, soils, and grass varieties managed by a large myriad of personalities varying from the home owner to the university trained turfgrass agronomist, create an infinite number of turfgrass-weed complexes, involving large numbers of weeds.

The introduction and wide successful use of phenoxy acid products on turf has effectively solved many common broadleaf weed problems. In many cases, we are seeing phenoxy acid resistant weed species replace the sensitive plants and ultimately become just as serious.

Development of new compounds for selective control of specific broadleaf or grassy weeds must always be based on principles just as sound as for field crops. The difficulty lies in the higher variation in factors which influence the selectivity between the weeds and the desirable turf.

With the exception of a very few weed species, there is very little competition at the present time for a good selective weed chemical.

The only remaining question then relates to volume of potential market in relation to development costs. Accurate estimates of turf acreages at the national level are not available and the distribution of specific weeds is likewise not known. A recent survey in densely populated New Jersey showed 200,000 acres of turf which costs $95,000,000 annually for maintenance. Per capita expenditure for turf maintenance would be $15 with 32,000 acres of turf per million people.

A similar survey in California shows 211,000 acres of turf costing $308,000,000 annually for maintenance. Per capita expenditure for maintenance would be $19 with only 13,000 acres of turf per million people.

Projecting these figures nationally would result in a total acreage of 2 to 5 million acres at a cost of 2.8 to 3.5 billion dollars annually for maintenance. Obviously we are not dealing with a minor agricultural industry. The weed control proportion of the annual maintenance costs is not known. However, the potential would be quite sizeable if truly adequate materials were available.

How then should this industry be expanded? First of all, let us examine more closely the nature of the management skill used in turfgrass culture. Home owners are essentially amateurs and products placed in their hands must have a wide safety margin and must be convenient to use. Such formulations are expensive in terms of active ingredient units.

Industrial turf, golf courses, highways, and other large turf areas are managed by highly skilled technically trained personnel. Materials used by these people needn't have such wide safety tolerances and can be formulated in more conventional commercial concentrations. There is a rapidly expanding turf retail service industry which has professionally trained men who serve the home and other small turf areas. This expanding market can safely use many of the chemicals which were never released to the home market trade. Clearly then we have two broad categories of turf weed control product markets. The home owner market will continue to need safe, convenient formulations for which they will pay a premium. The professional turf market will demand a wider array of more specific type compounds. Such materials need not be formulated for as much safety or convenience. Unit costs will be a factor in marketing but not nearly as much as in many commercial agricultural uses since the acreage maintenance costs are relatively high. Since the retail service field is commercial, the competitive factor will exist. This market must be informed on how to use the product and what conditions influence its effectiveness. Hence, development costs will be high, but the prices for such commodities can be higher since we are dealing with a valuable agricultural commodity.

In summary, the horizons for turf weed control reveal a wide array of compounds, each of which is to be used for a specific use under exacting conditions. The successful use of these materials will only follow a carefully organized research and educational program geared for the professional turf personnel.

The horizons for turf weed control by amateurs is not very clear because of formulation costs and their failure to identify the actual cause of the problems.

The future for an expanded turf weed control industry is as bright as the industry wants to make it.

# THE EFFECT OF HERBICIDES ON HIGH ENERGY PHOSPHATE LEVELS

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It was observed a few years ago by Salisbury (11) that cocklebur plants treated with 2,4-dinitrophenol (DNP) showed more injury if they were placed in the dark following treatment, than if they were allowed to remain in the light. Since it had been shown (7) that DNP will inhibit ATP formation in respiration (oxidative phosphorylation) at concentrations which failed to inhibit ATP formation in photosynthesis (photosynthetic phosphorylation) (1, 4), it was suggested that herbicidal response came about because of decreased ATP levels and that dinitrophenol could cause such decreases in the dark, but not in the light. Thus, work reported in this paper was initiated as a test of this explanation. ATP levels were measured as a function of herbicide treatment and light or dark conditions.

There are reports (3,6) that 2,4-D promotes metabolism prior to death of the plant, resulting in some cases in increased ATP within the plant. On the other hand, there are reports (9, 13) that 2,4-D acts as an uncoupler in oxidative phosphorylation much the same as DNP. Thus 2,4-D was used in the experiments in this paper. Other compounds were used if there was reason to believe that they might influence either respiration or photosynthesis. Monuron is regarded as a Hill reaction inhibitor (2, 12), and dalapon inhibits pantothenate formation *in vitro* (5), suggestion that it may also influence coenzyme A funtion and respiration. NAA and IAA were used for comparison with the 2,4-D effect, and cobaltous ion was used because it is currently being used in other studies concerned primarily with flowering. Acetone was used to determine the effect of physical injury.

## Methods and Materials

Bean plants (*Phaseolus vulgaris*) and cocklebur plants (*Xanthium pennsylvanicum*) were grown in a greenhouse under daylight conditions, extended to 18 or 20 hours with supplementary incandescent light.

High energy phosphate was estimated by a charcoal adsorption hydrolysis method which is to be described in detail elsewhere (10). Leaf blades were homogenized in 10% trichloroacetic acid in an ice bath. The homogenate was centrifuged, and the supernatant was filtered and diluted previous to addition of charcoal. After allowing time for the nucleotides to become adsorbed on the charcoal, the suspension was centrifuged, the supernatant discarded, and the charcoal was washed. One normal hydrochloric acid was added and the high energy phosphate was hydrolyzed off while the nucleotides were still adsorbed to the charcoal. This was carried out by increasing the temperature in a pressure cooker. Phosphate was subsequently determined after the charcoal had been filtered off. Commercial preparations of AMP, ADP, and ATP indicated that two moles of phosphate were released from each mole of ATP, one mole from each mole of ADP and none from AMP.

DNP, 2,4-D, 2,4-dichlorophenol, dalapon, NAA, IAA, and acetone solutions were applied to one of the first true leaves on a bean plant by dipping. The opposite leaf (dipped in water containing wetting agent) was used as a control. Ten plants per treatment were used. Monuron and IPC were applied to the soil, and water was added to the pots to carry the chemical into the root zone. In such cases untreated plants were used as controls. In the case of cocklebur plants, half expanded leaves were either treated with the chemical or used as controls.

Plants receiving a dark period were placed in the dark immediately after dipping and remained for a maximum of 12 hours. Plants left in the light were left on the greenhouse benches and received a normal light and dark regime.

## Results

Tables I and II summarize the results of a number of experiments. It can be seen that DNP treatment invariably resulted in lowered hydrolyzable phosphate levels, and that levels were consistently lower in plants receiving darkness than in plants left in the light. Hydrolyzable phosphate levels decreased with increasing DNP concentrations and with longer time intervals after treatment. Decreases in hydrolyzable phosphate appeared before injury was apparent and very shortly after treatment. As in the previous experiments of Salisbury (11), damage was virtually absent in plants left in the light and quite apparent in plants placed in the dark.

In contrast to results with DNP, treatment with 2,4-D resulted almost invariably in an increase in hydrolyzable phosphate levels, although extremely high concentrations of 2,4-D did result in levels close to those of the controls or even in lowered levels. In time studies there was often a rapid rise in the amount of hydrolyzable phosphate in 2,4-D treated leaves, followed by a decline to about the same level as the control. Damage to plants increased as time after application increased, but the increase in hydrolyzable phosphate was apparent before damage was easy to detect.

It is evident from the table that the other compounds acted in a manner quite similar to 2,4-D; that is, all of these substances applied at herbicidal concentrations resulted in early increases in the levels of hydrolyzable phosphate. Of the compounds tried, only DNP caused a decrease in hydrolyzable phosphate levels.

**Discussion**

The results with dinitrophenol have fully supported Salisbury's initial hypothesis (11). This compound always causes a decrease, and the decrease is greater in the dark than in the light. Since the decrease occurs even before damage is apparent, this decrease might well be an actual cause of damage in this instance.

The results with 2,4-D failed to support the proposed mechanism of oxidative uncoupler (9, 13), but are in agreement with reports that metabolism is stimulated by 2,4-D (3, 14, 6). Indeed, the other auxins, IAA and NAA, also cause increases in hydrolyzable phosphate levels as shown in tables 1 and 2, and by Marre and Forti (8).

The proposed mechanism of action of dalapon as an inhibitor of pantothenate synthesis (5) would suggest that a respiration should be inhibited through decreased coenzyme A production, and that ATP levels should decrease. Our work fails to support this idea, since hydrolyzable phosphate levels were observed to increase. It is conceivable that phosphorylation by the pentose phosphate pathway or glycolysis or photosynthetic phosphorylation might maintain high ATP levels, although the Kreb's Cycle, which is dependent upon the coenzyme A, was inhibited. It is more likely, however, that our dalapon concentrations inside the cell were lower than the *in vitro* concentrations of Hilton et al., and that coenzyme A formation is not being inhibited in our system.

Since the compounds tried in our experiments represent a rather broad spectrum of herbicides, it might be suggested that plant injury (ultimately death) is typically accompanied by increasing ATP. This might be due either to an increase in ATP formation (in response to increasing ADP?) or a decrease in ATP utilization without a significant simultaneous decrease in ATP synthesis.

Table I.: **Effect of various concentrations of herbicides on hydrolyzable phosphate and apparent injury in plants receiving light of dark.**

| | | | Light | Ligh | Dark | |
|---|---|---|---|---|---|---|
| Chemical | Concentration | Time* | Hydrolyzable Phosphate** | Visual Injury | Hydrolyzable Phosphate** | Visual Injury |
| DNP | .1 x $10^{-4}$ M | 3 hrs. | 90 | None | 85 | None |
| | 6.2 x $10^{-4}$ M | 3 | 95 | None | 85 | None |
| | 1.2 x $10^{-3}$ M | 3 | 75 | Slight | 70 | 50% necrotic |
| | 2.3 x $10^{-3}$ M | 3 | 70 | 50% necrotic | 60 | 90% necrotic |
| 2,4-D | 2.4 x $10^{-5}$ M | 16 hrs. | 100 | None | 100 | None |
| | 2.4 x $10^{-4}$ M | 16 | 100 | Slight curling | 100 | Slight curling |
| | 2.4 x $10^{-3}$ M | 16 | 120 | Moderate curling | 118 | Moderate curling |
| | 2.4 x $10^{-2}$ M | 16 | 102 | Slight necrosis | 100 | Slight necrosis |
| Dichloro-phenol | 2 x $10^{-3}$ M | 12 hrs. | 100 | None | 100 | None |
| | 5 x $10^{-3}$ M | 12 | 104 | None | 100 | None |
| | 1 x $10^{-2}$ M | 12 | 121 | None | 121 | None |
| | 2 x $10^{-2}$ M | 12 | 116 | Moderate | 121 | Moderate |
| Dalapon | 1.0 x $10^{-3}$ M | 16 hrs. | 100 | None | | |
| | 5.0 x $10^{-3}$ M | 16 | 126 | None | | |
| | 1.0 x $10^{-2}$ M | 16 | 142 | None | | |
| | 2.5 x $10^{-2}$ M | 16 | 150 | None | | |
| | 5.0 x $10^{-2}$ M | 16 | 147 | 10% necrosis | | |
| | 7.5 x $10^{-2}$ M | 16 | 138 | 15% necrosis | | |
| | 1.0 x $10^{-1}$ M | 16 | 81 | 25% necrosis | | |
| | 1.5 x $10^{-1}$ M | 16 | 57 | 90% necrosis | | |
| Acetone | (% of pure Acetone) | | | | | |
| | 75% | 1 hr. | 99 | None | | |
| | 85% | 1 | 125 | None | | |
| | 90% | 1 | 115 | None | | |
| | 95% | 1 | 101 | 10% necrosis | | |
| | 100% | 1 | 92 | 90% necrosis | | |
| NAA | 1 x $10^{-3}$ M | 48 hrs. | 103 | None | | |
| | 5 x $10^{-3}$ M | 48 | 117 | None | | |
| | 1 x $10^{-2}$ M | 48 | 115 | Slight curling | | |
| | 2 x $10^{-2}$ M | 48 | 117 | Slight curling | | |
| | 5 x $10^{-2}$ M | 48 | 133 | Moderate curling | | |

* Time of extraction following application of chemical.

** Hydrolyzable phosphate expressed as percent present in the control.

Table II-: **Hydrolyzable phosphate levels and apparent injury in plants receiving light or dark, at various intervals after treatment.**

| Chemical | Concentration | Time* | Light | | Dark | |
|---|---|---|---|---|---|---|
| | | | Hydrolyzable Phosphate** | Visual Injury | Hydrolyzable Phosphate** | Visual Injury |
| DNP | $1.2 \times 10^{-3}$ M | .5 hr. | 100 | None | 90 | None |
| | | 1.0 | 95 | None | 85 | None |
| | | 3.0 | 90 | None | 70 | Slight |
| | | 8.0 | 90 | Very slight | 70 | Severe |
| 2,4-D | $2.4 \times 10^{-2}$ M | 2 hrs. | 111 | Slight curling | | |
| | | 4 | 120 | Slight curling | | |
| | | 6 | 120 | Moderate curling | | |
| | | 8 | 104 | Severe curling | | |
| | | 12 | 102 | Curling & epinasty | | |
| | | 30 | 100 | Necrosis | | |
| IAA | $5 \times 10^{-2}$ | 1 day | 108 | Slight curling | | |
| | | 2 | 114 | Slight curling | | |
| | | 3 | 112 | Slight curling | | |
| | | 5 | 108 | Slight curling | | |
| | | 7 | 107 | Slight curling | | |
| Dalapon | $5 \times 10^{-2}$ | 8 hrs. | 120 | None | | |
| | | 12 | 139 | None | | |
| | | 24 | 158 | None | | |
| | | 48 | 161 | None | | |
| | | 72 | 147 | None | | |
| Monuron | $4.3 \times 10^{-2}$ M | 1 day | 108 | None | | |
| | | 2 | 118 | None | | |
| | | 3 | 100 | Moderate | | |
| | | 4 | 70 | Severe | | |
| IPC | $2.3 \times 10^{-2}$ M | 2 days | 101 | None | | |
| | | 4 | 104 | Very slight | | |
| | | 6 | 111 | Slight | | |
| | | 7 | 108 | Moderate | | |

* Time of extraction following application of chemical.

** Hydrolyzable phosphate expressed as percent present in the control.

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## TEAMWORK AS AN EXTENSION WORKER VIEWS IT

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This year marks 100 years since the beginning of the Department of Agriculture and the signing into law of land-grant colleges. The topic of teamwork between research, extension, industry and other agencies, seems very appropriate. By means of a teamwork approach, the Department of Agriculture and the land-grant colleges have developed the most efficient and productive agriculture in the world. But teamwork will be even more important in years to come if we are going to continue to meet the demands of our increasing population. A little history of the development of our land-grant college system may help to emphasize the importance of teamwork. The need for teamwork was largely the reason for establishing the three phases of the land-grant college system, as we know it today.

The creation of land-grant colleges in 1862 has been considered by many, the most progressive step ever made in education. Soon after land-grant colleges were formed, it became apparent there was little concrete agricultural information on which to go. There were no text books and the information on agriculture which could be found was primarily based on European conditions. As a result, there was an obvious need for a second program, one to obtain information. This was provided in 1887 by the Hatch Act which provided for the organization of state experiment stations in conjunction with the land-grant college program. Therefore, the first two ingredients of the agricultural college system as we know it today — resident teaching and the experiment stations were established.

It soon became apparent that research information should be used if the program was to be effective. In order that farmers on the land could be informed on experimental results and thus improve their life, incomes and standard of living, a third branch was added to the land-grant college system, that of agricultural extension. The cooperative extension service was not established until 1914 when Congress signed the Smith-Lever Bill. The extension program was added to the agricultural college and the experiment station and made a third division of the land-grant college system.

Since there were no established organizational procedures, lines of administration differed between states. There was considerable debate in the early part of the century on a means to best coordinate research, teaching and extension. In many institutions it was decided, that coordination within the subject matter area should be the responsibility of the department head. However, the formal administrative arrangements at and above the departmental level have varied considerably between states.

The history and development of the land-grant college system has emphasized the need for a teamwork approach. Each branch was developed separately for a specific purpose; each with its own regulations; and each responsible to different divisions of the U.S.D.A. organization. Coordination of the three lines of activity (teaching, research, extension) sometimes becomes rather complex.

As agricultural problems become more complex, the coordination of agricultural programs, often must extend across departmental boundaries and even include other agencies and industry. This expanded coordinated approach has proven time and time again the most effective means of solving difficult, complex problems. The recent space program is probably one of the best examples of utilizing research knowledge from many different sources, such as mathematics, astronomy, physiology, physics, chemistry, engineering and many other sciences. This has been necessary to solve a complex problem. As our society becomes more complex, this broad approach and utilization of knowledge from many sources is becoming more common and necessary, both in industry and in agriculture.

Although weeds have always been an agricultural problem, weed control as we know it today, is a relatively new science, one which has suddenly become quite complex and involves many different phases of research and science. Probably there is no other phase of agriculture which involves as many different departments, agencies and industries as does weed control. This complexity has also added to the problem of farmers keeping informed and up to date on new developments.

### Problem Areas

I have frequently made the statement that the greatest problem in improving the weed situation is lack of understanding and interest on the part of the average farmer. We know all weeds can be controlled with methods research has developed; but I have wondered how much, or what percentage, of this knowledge we have is being put to use.

I am reminded of a meeting we held several years ago. After about two days during which we presented recommendations and research findings, we asked the farmers to comment on the meeting and suggest what they thought should be done to improve the weed situation. There was good discussion; some thought there was need for more regulations and tighter restrictions in the state weed law, others thought industry should develop better herbicides and sell them for a lower price; others thought the colleges, universities and industry should expand their research, get new knowledge and learn new methods. Then we asked the farmers how much of the research information available they were making use of; or how many different chemicals they had used other than 2,4-D; or if they would like to have laws passed that would limit their freedom. It soon became obvious that the greatest short-coming was education. They were making use of only a small part of the knowledge already available.

I believe this is a common problem in most states. The problem of getting farmers to accept new ideas has always been the major job of extension workers. Ours is a selling job, much the same as that of salesmen. The major difference is the product. Our product is information and ideas, yours is material things. Many of our working techniques are the same.

We in extension are probably more often confronted with the economic aspects of weed control and other phases of agriculture, than is research. It is difficult to sell an idea to a farmer until he is convinced the practice is good business and will make him money. As I mentioned previously, all weeds can be controlled; but it is hard to get a farmer to adopt a proposed practice until he is convinced the practice is economical. Many of our more serious weed problems are on rather low valued land. It is difficult to sell the idea that money spent on this kind of land is good business. When you tell a farmer it will cost him $50 an acre to eradicate the weeds on land valued at maybe $20 an acre, it takes real salesmanship to sell the idea.

### Program Suggestions

I am reminded of a talk by a college professor that taught the business of selling. Throughout his talk this professor emphasized the importance of selling on the basis of a problem, rather than selling a product. I think we in extension and research should give a lot of thought to this approach. In other words, are we singling out the important problems, then going from there with research and extension, or are we taking the products, the information and the facilities we have available and presenting this to the people. There may be very little correlation between this and the real problem.

Here the teamwork approach is most important; extension workers are probably in closer contact with farm people than most research workers. The extension specialists, working with county agents, should develop his program, based on what he sees the problem to be. The success of failure of his program will depend largely on how well he recognizes the problems and whether he knows what the real problems are. Likewise, he should plan a program and look for the type of information based on problems. This is where a close working relationship with research, industry and other agencies can be of real benefit. The extension specialist should advise on types of research needed, both by experiment stations and industry. He should also work with other agencies that can help solve the problems. Like the salesman, he should present his program based on problems, rather than products.

There are many ways to sell a program and convince farmers that there is a problem, but one of the most effective ways is to talk in terms of dollars and cents and show them specific economic gains. Most farmers know that weeds reduce crop yields and if not controlled, weed infestations can cause serious economic losses. But weed losses are rather intangible. I have wished there was more information and research that showed specifically how much weeds cost. Most of the information we have is very general and much is based on estimates. Also, the economic aspect should be included in research projects whenever possible and dollars and cents gains or losses shown in the reports. This approach would make our job in extension, of selling the idea to the farmers, much easier.

The demonstration method has been proven to be one of the most effective ways to promote new ideas; this certainly is true for weed control. But there is a wide difference between a demonstration and research. This, again, points out the importance of teamwork between industry, research, and extension. Chemicals are first developed, screened and tested by industry. Chemicals which show real promise are then further tested by research workers, either on experiment stations or by industry. Then extension workers should demonstrate the methods in the field. One of the most common reasons field demonstrations are not successful is the failure to publicize them properly. Weed control demonstration plots are of little value unless people see them.

**Branch Stations and Extension**

Administration staffs should encourage cooperation between extension and branch experiment stations. Even extension agents in the counties where branch stations are located are sometimes not completely familiar with research programs or what the station is doing. The same is true for extension specialists. Specialists get busy on other things and fail to keep up on experiment station programs.

Extension is responsible for dissemination information; if agents and extension specialists are not familiar with branch station programs and experimental results, they certainly cannot do the job of getting this information out to the farm people. Of course, data is made available to extension in research reports, but there is much detail and important information that extension people miss unless they see research projects in progress and observe them in the field from time to time. Extension people should not get so busy they cannot find time to visit with branch station people and look over research projects.

County agents are usually not in favor of farmers going directly to branch station workers for information, but unless they keep informed on experiment station results, we can hardly expect farmers to do differently. Of course, it is a two-way street and branch station superintendents and workers should make an effort to keep extension people informed on what they are doing. Also, it is a two-way street in that extension workers should keep researchers informed of research needs as determined by the people in their counties with whom they have a close contact.

I am reminded of the program at the Eastern Montana Branch Station. This station is in a good irrigated area of the state; it is a small station but they carry on quite an extensive research program. The superintendent is not only a good research man but is also very extension-and-public-service minded. One of the first things he did after setting up the station was to establish an advisory committee. This committee is made up of leading farmers, business men and county agents, in the area served by the station. The committee has kept atcive; it meets several times a year; it sponsors field days and tours in the summer, meetings in the winter and advises on needed research. The use of this committee is very much an extension-type approach. Whether the advice and assistance furnished by this committee is needed or not, they are a valuable public relations group; and because of this committee, I am sure farmers in the area served are much more familiar with the branch station and will support it.

Each winter after data has been compiled and progress reports completed, the station staff and extension agents in the area meet for a day or day and a half and go over progress reports and data in detail. Progress reports are given to agents in the area and to state extension staff members. In addition to data and regular progress reports, each research worker prepares a summary and recommendations based on his findings. These are discussed by extension and experiment station people during the winter meeting and recommendations for the area are decided upon. This has been an excellent way of standardizing recommendations and informing county agents and extension specialists. These "up-dating" meetings in the winter plus field days in the summer have kept agents well informed and has made for a close working relationship between the station personnel and county agents in the area.

### Cooperation with Industry

Field men of chemical companies and special commodity groups such as sugar beet companies, canning companies, etc. should be included when state weed control recommendations are discussed. This will help to standardize recommendations so dealers, industry representatives and county agents will be making the same recommendations.

In recent years I have noticed a definite increase of interest in weed control; part of this can be contributed to teamwork and cooperation All groups have definite responsibilities but an overall program should be planned that will make the best use of the facilities each group has to offer. Most states have state weed organizations and hold annual conferences. One of the major objectives of such an organization should be to coordinate and make use of other agencies such as the ASCS, the Bureau of Reclamation, Indian agencies, the SCS, Bureau of Land Management, highways, railroads, and of course, County Weed District organizations.

### Summary

Throughout development of the land-grant college system, cooperation between the three branches has been emphasized. With agriculture and agricultural problems becoming more complex coordination of programs is even more important now than before. It is also important that we work with industry and other agencies. With a continuation of well-planned research based on major agricultural problems and effective disemination of information, American agriculture will continue to be the most efficient and productive in the world.

## THE NATIONAL WEED SURVEY – ITS SIGNIFICANCE TO RESEARCH, EXTENSION AND INDUSTRY

By J. M. SAUNDERS
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In the Agricultural Research Service publication "Losses in Agriculture" the following paragraph gives emphasis to the need for the study on the national weed crop situation:

"In his agricultural endeavors man has adjusted himself to live with certain species of plants growing where they are not desired. These plants are called weeds. Too often, and at prohibitive costs, weeds have been taken for granted. Unwanted, non-useful, often prolific and persistent, they reduce the efficiency of agricultural operations, increase labor, add production costs and reduce yields."

Today the farn er cannot afford to take weeds for granted. Farm costs have risen and farm prices have fallen. In 1952 farm costs and prices were pretty well in balance – both about 290 percent of the base period 1910-14. By 1960 prices had fallen to about 240 per cent of the base period – and farm costs had risen to an index of about 300, resulting in a cost-price squeeze.

Weeds are said to be the greatest contributors to production costs on American farms. Because of this, a concerted effort directed at their control is under way. The Cooperative Extension Service assisted by research and industry has taken the first step by assembling information to guide future progress. The study was designed to furnish information for:

* Planning research on specific weed problems in particular crops or sites in different areas.
* Planning long-range basic research and development programs on new herbicides.
* Planning long-range basic research that will open new frontiers for practical weed control development.
* Predicting problems which may be encountered in recommending herbicides for use by farmers and
* Developing educational programs.

In obtaining certain basic information, a survey was conducted. Extension specialists responsible for weed control activities in their respective States were asked to supply information concerning chemical weed control problems and practices.

The information collected by use of a questionnaire included, important weeds in each crop, acres treated, treatment costs per acre, effectiveness of available chemicals and expected trends of chemical weed control by crops; and the need for better chemicals. The lack of precise information made necessary the use of estimates in most cases. In arriving at estimates the reporting specialists frequently consulted with other research, industry personnel concerned and with weed control organizations. Weighted averages were computed by regions and nationally on the estimated acreage treated and the costs per acre.

A summary of the extent of weed control for all crops shows:

| | |
|---|---|
| Acres treated per emergence | 3,859,000 |
| Acres treated post emergence | 46,887,000 |
| Total acres treated | 50,746,000 |
| Cost pre-emergence treatment | $ 21,500,000 |
| Cost post-emercence treatment | 119,020,000 |
| Total cost | $140,520,000 |

The significance of the study to research, industry and extension will depend on the nature and scope of the problem. However, the following points seem significant:

It will help research to:

a. Rate problems according to importance

b. Plan research on specific weed problems in

  (1) particular crops

  (2) sites in different areas

c. Plan the research and development on new herbicides

d. Plan long-range basic research for practical weed control developments

e. Predict problems which may be encountered in recommending herbicides for use by farmers

It will serve industry:

a. As a guide for planning research on specific weed problems

  (1) by crops

  (2) by areas

b. Will indicate effectiveness of present herbicides

c. As a guide to distribution of herbicides

d. Indicate opportunities for expansion

e. Alert salesmen to local situation

It is significant to the Cooperative Extension Service for:

a. Establishing benchmarks for measuring progress and farmer needs

b. Predicting problems which may be encountered in recommending herbicides for use by farmers

c. Rating the regional weed problems

d. Developing educational programs

In conclusion let me express the hope that the cooperation between research, industry and the Cooperative Extension Service that has resulted in such rapid advancements in the past will continue in the future.

## REPORT OF THE RESOLUTIONS COMMITTEE

DAVID E. BAYER, *Chairman*

The Committee moves the adoption of the following resolutions and further moves that the Conference Secretary be instructed to send copies of each to the appropriate agencies and/or individuals concerned.

### RESOLUTION NO. 1

WHEREAS, our officers during the past biennium, President, W. R. Furtick; Vice President, Eugene Heikes; Secretary-Treasurer, E. J. Bowles; have spent much time and effort in connection with the conference,

NOW, therefore be it resolved that we express to them our appreciation and thanks for their services.

### RESOLUTION NO. 2

WHEREAS, the Western Weed Control Conference assembled in Las Vegas on March 22, 1962, appreciates the opportunity to meet in Las Vegas, and

WHEREAS, the local arrangements committee under the chairmanship of Dudley Zollar has done an outstanding job,

NOW, therefore be it resolved that we express to them our appreciation and thanks for their service.

### RESOLUTION NO. 3

WHEREAS, the Western Weed Control Conference assembled in Las Vegas on March 22, 1962, recognizes there are several thousand acres of Federal land infested with noxious weeds that are co-mingled with private lands not now infested or are under a control program, and

WHEREAS, there are now satisfactory, effective, and economical control measures available,

NOW, therefore be it resolved that the Western Weed Control Conference support the control of noxious weeds on Federal land as set forth in Senate Bill 457, 1961.

### RESOLUTION NO. 4

WHEREAS, the Western Weed Control Conference assembled in Las Vegas on March 22, 1962, recognized Commodity Credit Corporation is storing grain in population centers, and

WHEREAS, they are distributing said grain throughout various population centers under the Defense Act and for livestock feed grain, and

WHEREAS, such grain may contain weed seeds known to be noxious in states of destination,

NOW, therefore be it resolved that the Western Weed Control Conference request the United States Department of Agriculture intercede to prevent the movement of such weed seed infested grain.

### RESOLUTION NO. 5

WHEREAS, the Western Weed Control Conference assembled in Las Vegas on March 22, 1962, recognizes Federal grain standards now permit a maximum dockage allowance, and

WHEREAS, there are no Federal legislation to prevent noxious weed seeds in grain, and

WHEREAS, it is a practice to clean grain and re-incorporate dockage that may contain noxious weed seed,

NOW, therefore be it resolved that the Western Weed Control Conference make a strong recommendation that the grain standards be amended to prohibit the interstate movement of grain containing noxious weed seed.

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