THE PHENOXY HERBICIDES

Second Edition

Council for
Agricultural Science and Technology
Report No. 77
August 1978

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Headquarters Office: Agronomy Building
Iowa State University, Ames, Iowa 50011
Telephones 515-294-2036 and 2903

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The cover picture, courtesy of A. J. Turgeon, University of Illinois, shows the effects of a common lawn management practice, that of applying 2,4-D and fertilizer. The 2,4-D kills the dandelions, and the fertilizer improves the growth of the grass.

TASK FORCE MEMBERS

Boysie E. Day (Chairman of the task force), Department of Plant Pathology, University of California at Berkeley

Norman B. Akesson, Department of Agricultural Engineering, University of California at Davis

L. E. Bode, Department of Agricultural Engineering, University of Illinois

Rodney W. Bovey, SEA-FR, U. S. Department of Agriculture

W. R. Byrnes, Department of Forestry and Conservation, Purdue University

Donald G. Crosby, Department of Environmental Toxicology, University of California at Davis

Robert A. Darrow, SEA-FR, U. S. Department of Agriculture

Donald E. Davis, Department of Botany and Microbiology, Auburn University

R. E. Doersch, Department of Agronomy, University of Wisconsin

Harvey A. Holt, Department of Forestry and Conservation, Purdue University

Charles L. Leinweber, Environmental Quality Program, Texas A & M University

William E. Martin, Department of Agricultural Economics, University of Arizona

Michael Newton, Department of Forest Science, Oregon State University

Gary D. Osweiler, Department of Veterinary Anatomy-Physiology, University of Missouri

Jack S. Palmer, SEA-FR, U. S. Department of Agriculture

Jack Plimmer, SEA-FR, U. S. Department of Agriculture

FOREWORD

This report was prepared as a concise summary of the available information on the phenoxy herbicides for the benefit of persons who are concerned about the properties of these substances, their uses, their impacts on the environment, their hazards to humans, and the socioeconomic effects of their use. The first edition, published in February 1975, was widely accepted. The second edition includes the latest information along with numerous literature citations for the benefit of those who may wish to examine some of the background scientific literature that has been condensed into this report. A task force of 15 scientists was responsible for preparing the first edition. The same scientists, with one addition, prepared the second edition also.

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SUMMARY

The phenoxy herbicides, 2,4-D, 2,4,5-T, MCPA, silvex and related materials, are selective herbicides widely used in crop production and in the management of forests, ranges and industrial, urban and aquatic sites. These chemicals are related to naturally occurring plant growth regulators. They kill plants by causing malfunctions in growth processes. Broad-leaved plants are generally susceptible to the phenoxy herbicides, whereas most grasses, coniferous trees and certain legumes are relatively resistant.

The phenoxy herbicides are used to control broad-leaved weeds in wheat, barley, rice, oats, rye, corn, grain sorghums and certain legumes. Such uses increase yields, improve product quality and reduce production costs. The phenoxy herbicides are used in forests to suppress unwanted hardwood trees and brush, to reduce competition with conifers already established or to prepare sites for the regeneration of conifers. They are used on grazing lands to control unpalatable and noxious plants and to kill brush and small trees that reduce the productivity of pastures and ranges. 2,4-D and other phenoxys are used in canals, ponds, lakes and waterways to kill floating weeds such as water hyacinth, submersed weeds such as pond-weeds, and emergent and shoreline plants such as cattails and willows. Industrial and urban uses include control of brush on utility and transportation rights of way, control of dandelions, plantains and other weeds in turf and suppression of ragweed, poison ivy and other plants of public health importance.

The principal hazard in the use of the phenoxys is to crops and other valuable plants either within the treated area or nearby. Treated crops and forest trees can be injured through accidental overdosing, improper timing of treatments, unusual weather conditions and other causes. Injury to nearby crops and ornamentals can result from drift of droplets or vapors of the spray. Such losses are largely preventable through the use of proper formulations and spray equipment and the exercise of good judgment.

The phenoxy herbicides are predominantly toxic to green plants and are much less toxic to mammals, birds, fish, reptiles, shellfish, insects, worms, fungi and bacteria. When properly used, they do not occur in soils and water at levels harmful to animals and microorganisms. They do not concentrate in food chains and do not persist from year to year in croplands. They are detectable only rarely in food and then only in insignificant amounts.

A highly poisonous kind of dioxin called TCDD is an unavoidable contaminant in commercial supplies of 2,4,5-T and silvex. The amount present in currently produced formulations of 2,4,5-T and silvex is not enough to alter the toxicological properties of these preparations or to endanger human health or to affect plants or animals in the environment.

The phenoxy herbicides are widely used becaused they are more efficient and usually less hazardous and less injurious to the environment than alternative methods. Use of these chemicals is estimated to reduce the cost of production of the crops on which they are used by about 5% and to reduce overall agricultural production costs in the United States by about 1%. Uses in forests and nonagricultural situations provide additional savings. If the phenoxys were no longer available, the cost of food, forest products, electric power, transportation and governmental services would be higher. These costs would be borne by consumers.

INTRODUCTION

The phenoxy herbicides were discovered nearly 40 years ago, incidental to research on naturally occurring plant hormones (Peterson, 1967). As the chemical nature of plant growth substances became known, related compounds were synthesized and tested for effects on plant growth (Zimmerman and Hitchcock, 1942). Certain phenoxy acetic acids, including 2,4-D, were found to be plant growth regulators and in due course were discovered independently in the United States and Britain to be active herbicides capable of selectively killing many broad-leaved weeds in cereal grains, grasslands and coniferous forests (Bovey and Young, 1978; Nutman et al., 1945; Blackman, 1945). Further research led to the commercial use of several phenoxy herbicides, including 2,4-D, 2,4,5-T, MCPA and silvex (Loos, 1975).

Despite the more recent development of many other herbicides, the phenoxys remain major tools in vegetation management (Emmelin, 1977). We can expect continued usefulness for 2,4-D and related chemicals in the management of such resources as croplands, forests, ranges, waterways, industrial lands, public utility properties, wildlife habitats, urban parks, athletic fields and landscape plantings (National Academy of Sciences, 1968).

The phenoxy herbicides are weak acids that are only slightly soluble in water and petroleum oils (Crafts, 1961). Although the acids are the biologically active form, they are normally converted to water-soluble amines or oil-soluble esters for convenience in handling and application. These are mixed with other ingredients, such as solvents, emulsifiers, thickeners, and wetting agents, to make commercial formulations for specific uses. The amine forms are diluted with water and sprayed on foliage or injected undiluted into trees (Bovey, 1977). Esters are sprayed as oil solutions or as emulsions with water. One class of amine salts of the phenoxys is soluble in oil rather than in water. The strength of commercial formulations is expressed in terms of the equivalent content of the parent acid. However, equal acid equivalents of esters or amines of the same phenoxy herbicide are not equally active. Esters generally have greater herbicidal activity than the amine forms but are more expensive. Esters may evaporate from foliage after application, releasing fumes that can move outside the treated area and cause injury to sensitive plants elsewhere. This hazard can be reduced by the use of low-volatile (long-chain) esters, but these cost more than the high-volatile (short-chain) esters and are less effective as herbicides in some situations (Crafts, 1961). There is no single best formulation for all purposes, and this is reflected in the availability of a wide variety of commercial products for a multitude of uses. Available products include mixtures of phenoxy herbicides and mixtures of these herbicides with unrelated herbicides, fertilizers and other materials (Crafts, 1975). Mixtures of 2,4-D and 2,4,5-T are commonly employed in brush control (Crafts, 1975a).

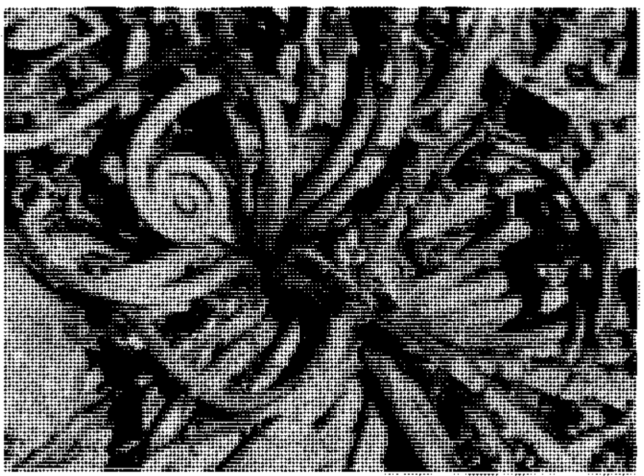
Although many phenoxy acids have some degree of herbicidal activity, most are not commercially available because of cost, limited effectiveness or other reasons. These chemicals form a family of compounds that have similar chemical and biological properties but differ in their activity on individual plants, their cost and other characteristics. The ones presently used in the United States include 2,4-D, 2,4,5-T, MCPA, silvex, 2,4-DB, MCPB, dichlorprop, mecoprop, and 2,4-DEP (Weed Science Society of America, 1974). 2,4-D is by far the predominant compound used in the United States. It is preferred to other phenoxys on the basis of cost and effectiveness in most situations. Other phenoxys find use only where they control weeds resistant to 2,4-D or where crops are less sensitive to them than to 2,4-D. In 1975, the amounts of 2,4-D, 2,4,5-T and silvex used in the United States were, respectively, 59, 6.7 and 2 million pounds (Stanford Research Institute, 1976). MCPA, 2,4-DB, dichlorprop and mecoprop have important but limited special uses (Klingman and Ashton, 1975). 2,4-DEP is a chemical closely related to 2,4-D that acts primarily through the soil (Crafts, 1975b). It is not extensively used.

Mixtures of 2,4-D and 2,4,5-T related to commercial brush killers were employed as "defoliants" in the war in Vietnam. Partisans in this conflict denounced the use of herbicides as "chemical warfare." Critics claimed that, in addition to killing plants, the materials killed people, livestock and wild animals and caused human birth defects (Whiteside, 1971). These charges have been exhaustively investigated by scientists and argued widely in the press and elsewhere. The evidence is that in Southeast Asia, as elsewhere, these chemicals have little biological activity beyond their effectiveness as herbicides (Committee on the Effects of Herbicides in Vietnam, 1974). However, it is not the purpose of this report to renew this largely political controversy. The yearly application rates in Vietnam were often 30-fold greater than commercial usage, and the concentration of the controversial dioxin contaminant in 2,4,5-T was 100- to 1,000-fold greater than it is in currently manufactured materials. Thus, dioxin application rates were 3,000 to 30,000 times greater per acre than for current applications. Therefore, the validity of claims relating to health and environmental effects in Vietnam has no relevance to the safety of current herbicide usage in the United States (Tschirley et al., 1975).

HERBICIDAL PROPERTIES

The phenoxy herbicides are absorbed by plant foliage, roots and soft stem tissue. When applied as a drench in diesel oil, they can soak through the dry bark of trees and enter living tissues by this means (Crafts, 1964). Once absorbed, the phenoxys move within the plant along the pathways that carry food and water (Crafts, 1961). They tend to accumulate in the actively growing parts of roots and stems (Crafts, 1964). The leaves and buds twist and curl, and new growths of stems and leaves are malformed. Sensitive young plants may die in a few days. Hardy shrubs and trees may succumb only after weeks or months or may survive without evident injury (Bovey, 1977).

The phenoxy herbicides appear to enter in an imperfect and uncontrolled way into the regulation of growth processes normally governed by the natural growth hormones (Ashton and Crafts, 1973). There is interference with cell division and enlargement, with food utilization and with a wide array of other vital processes. The exact mechanism of these actions is not known, and indeed the exact workings of natural plant growth regulators are equally obscure. Phenoxy herbicides are far more toxic to green plant than to animals because the kinds of materials that have growth regulating activity in plants do not act in the same way in animals.



Effect of 2,4-D on dandelion. The normally straight stems bearing the flowers are bent and curled, and the plant will soon die. Perhaps the most troublesome broad-leaved weed in lawns, dandelion is easily controlled by 2,4-D. Photograph courtesy of A. J. Turgeon, University of Illinois.

The phenoxys, in addition to their use as herbicides, also find limited use as plant growth regulators for crops (Wort, 1964). For example, they can be used to control the ripening of bananas. 2,4-D is sprayed on orange trees to increase fruit size and to prevent fruit and leaf drop (Coggins and Hield, 1968). Silvex is sprayed on apples to enhance coloring and to prevent premature fruit drop. Although popularly miscalled "defoliants," the phenoxys are, in fact, antidefoliants and act at low concentrations to prevent the shedding of leaves and fruit (Coggins and Hield, 1968). They enhance blossom retention and increase fruit set (Erickson and Brannaman, 1950). At low concentrations the phenoxys promote the rooting of cuttings and presumably could be used for this purpose in plant propagation (Leopold and Kriedemann, 1975). Although these are useful properties, the toxicity of the phenoxy herbicides to plants limits their employment as purely plant growth regulators. Ordinarily such needs are met by other hormone derivatives that are less active as herbicides and are marketed specifically for plant regulatory purposes.

Normal pin oak leaves on the left and leaves treated with 2,4-D on the right. 2,4-D causes the leaves to become elongated, twisted and curled. Photograph courtesy of Charles L. Benn, Iowa State University.

PRACTICAL USES

The phenoxy herbicides are used in land and water management wherever their particular selective properties coincide with the desired changes in vegetation. The most common uses are suppression of broad-leaved plants in the presence of grasses, conifers or certain legumes (Klingman and Ashton, 1975). Each use is governed by the known response to the herbicide of each kind of plant present. Such general rules as "broad-leaved plants are susceptible while grasses and conifers are resistant" have important exceptions, and nothing short of thorough knowledge of the response of each kind of plant under prevailing conditions has made possible the effective use of these chemicals (Klingman and Ashton, 1975).

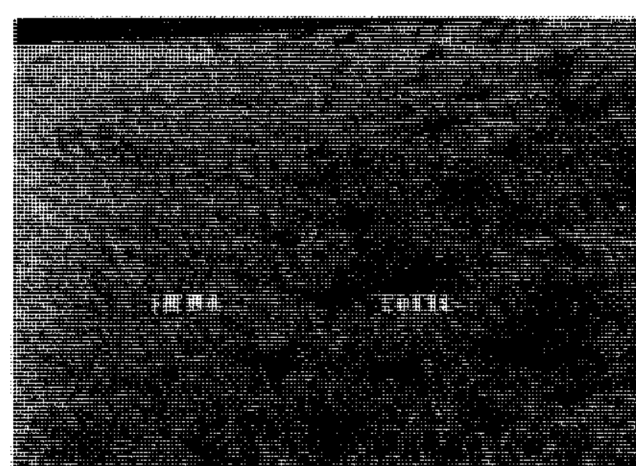
Herbicides are most useful when employed in coordination with other practices in vegetation management. The aim is to create conditions favorable to the crop, forest trees, range grasses and other preferred species and unfavorable to unwanted plants. The total set of manipulations constitutes the management system in each case. The phenoxy herbicides function in a wide variety of systems ranging from forest and wild-land management and cereal and forage production to the management of industrial and aquatic sites (Anderson, 1977). Management objectives are diverse, including primarily the production of food, forest products and other commodities and also the management of fish and game habitats, suppression of allergenic and poisonous plants, maintenance of navigable and recreational waterways and many others. Before the advent of modern herbicides, many of the tasks they now perform were not done at all or were done more laboriously and less effectively by other means.

Cropland

Four-fifths of the 72 million pounds of phenoxy herbicides used annually in the United States is applied to cropland and rangeland. In 1975, 55 million pounds of these chemicals were used on food and feed crops in the United States (Stanford Research Institute, 1976). The principal crops treated are the grains: wheat, corn, barley, oats and rice. The usual treatment is with 2,4-D at a rate of less than 1 pound per acre (United States Department of Agriculture, 1973).

The small grains are always infested to some extent with annual and perennial weeds that can be controlled by the phenoxy herbicides. If not controlled, these weeds

The effect of applying 2,4-D is shown in this North Dakota wheat field by a comparison of the field at large with the narrow strip in which wild mustard overtops the wheat due to a sprayer skip. Wheat yields are reduced about one-third by 100 wild mustard plants per square yard. Photography courtesy of John D. Nalewaja, North Dakota State University.



Milk from cattle grazed on pastures containing wild onion has a highly objectionable taste and odor. Repeated applications of 2,4-D eliminate this weed without damage to grass pastures. The area on the left has been treated with 2,4-D. The area on the right is untreated. Photograph courtesy of D. E. Davis, Auburn University.

reduce crop yield, interfere with harvesting and reduce grain quality. For example, wild garlic bulblets harvested with the wheat cause a garlic taste in flour milled from the grain, making it virtually worthless. 2,4-D is the principal herbicide used in the United States for the control of broad-leaved weeds in cereal grains. About 60 million acres of feed and food grains are treated with approximately 34 million pounds of 2,4-D annually in the United States (Stanford Research Institute, 1976). The recommended rate of application depends on the specific weed problem and crop resistance but generally ranges from 1/4 to 1 pound per acre (Crafts, 1975b; United States Department of Agriculture, 1973). Under some conditions, 2,4-D is not adequately selective in the small grains, and it is common practice in such instances to use MCPA instead. Although MCPA is appreciably more expensive than 2,4-D, about 4 million pounds of this chemical are applied to about 8 million acres of small grains annually in the United States (Stanford Research Institute, 1976; Klingman and Ashton, 1975). A substantial portion of the U.S. rice acreage also receives 2,4-D, 2,4,5-T or MCPA treatment for control of broad-leaved weeds. 2,4,5-T is often used on rice in the southern states, where curly indigo and other weeds resistant to 2,4-D and MCPA are widespread (Anonymous, 1977).

Few alternative practices are available for control of broad-leaved weeds in cereal grains. Mechanical and hand tillage following planting are hopelessly impractical. Of the other selective herbicides used for special weed problems in small grains, none can be considered as general substitutes for the phenoxys. For example, dicamba can be used to control some annual and perennial broad-leaved weeds in oats and wheat (not barley), but this material does not control weedy mustards and other important weeds (Anonymous, 1977). Moreover, dicamba is relatively toxic to small-seeded legumes and thus cannot be used in the central and eastern areas of the United States where small-seeded legumes are commonly intersown with small grains (United States Department of Agriculture, 1973). Bromoxynil controls many annual broad-leaved weeds in small grains, but it is not effective against most perennials and cannot be used in winter grains and where small-seeded legumes are intersown (United States Department of Agriculture, 1973). Present practice in some areas is to combine dicamba or bromoxynil at low rates with 2,4-D or MCPA to broaden the spectrum of weeds controlled. Dinoseb is another alternative herbicide which controls primarily annual broad-leaved weeds in small grains. Dinoseb does not move internally in plants and is thus relatively ineffective on perennials. Moreover, it is far more toxic to warm-blooded animals than are the phenoxys (Weed Science Society of America, 1974). There are essentially no alternatives to the phenoxy herbicides in rice production.

The broad-leaved weeds shown here overtopping the corn can be controlled with 2,4-D. The weeds in this field would be expected to reduce the yield of corn about 50%. Photograph courtesy of Charles L. Benn, Iowa State University.

2,4-D is used to control broad-leaved weeds in corn and sorghum. This use has decreased since the introduction of the triazines and other effective preplant and preemergence herbicides that kill not only broad-leaved plants but weedy grasses as well. However, deep-rooted perennial weeds are generally resistant to these materials, and for this reason their populations increase in the absence of periodic treatments with 2,4-D. Thus, 2,4-D continues to retain a place in corn and sorghum culture, with approximately 30 million acres of these crops being treated with 2,4-D annually (Stanford Research Institute, 1976). The rate of application ranges from 1/4 to 1/2 pound per acre. Dicamba is a partial alternative to 2,4-D; however, it does not control all species controlled by 2,4-D and is best used in mixtures with 2,4-D to extend the spectrum of weeds controlled.

Cultivation supplemented by hoeing is an alternative to 2,4-D in the production of corn and sorghum. Indeed, cultivation is still widely practiced with these crops, either alone or in combinaton with herbicides. Since cultivation cannot remove weeds occurring directly in the crop row, it must be supplemented with hand work at costs that are presently prohibitive (Stout et al., 1977). MCPB and 2,4-DB can be used for control of broad-leaved weeds in legumes (Hawf and Behrens, 1974; Shaw and Gentner, 1957). MCPB and 2,4-DB are not themselves herbicides but are precursors of the herbicides, MCPA and 2,4-D, respectively, and are converted to the active form within the plant (Wain and Smith, 1976; Wain and Wightman, 1954). They can be safely used to control certain broad-leaved weeds in green peas, soybeans, peanuts and small-seeded forage legumes because these crops have less ability to convert them to MCPA and 2,4-D than do most weeds. The total amount of MCPB and 2,4-DB used is small, but these herbicides make possible the control of certain yield-limiting weeds in important leguminous crops. In most instances, no other herbicide is equally effective for this purpose.

Alternatives to the use of 2,4-DB and MCPB in legumes are limited. Dinoseb can be used as a postemergence treatment on some small-seeded forage legumes, green peas and peanuts for control of broad-leaved annuals, but this material is of limited effectiveness on perennials and cannot be used on late-emerging weeds without risk of crop damage. Chloroxuron and bentazon are possible substitutes for postemergence control of broad-leaved annual weeds in soybeans; however, these herbicides are several times more costly than is 2,4-DB (National Academy of Sciences, 1975). Cultivation and hand weeding after planting continue to be recognized weed control practices in the larger-seeded legumes grown as row crops, but these practices have the limitations described earlier for corn and sorghum.

Phenoxy herbicides are used to control susceptible weeds in such crops as apples, asparagus, blueberries, cranberries, flax, pears, potatoes, strawberries and sugarcane. Each crop has specific requirements for weed control, including in some instances special formulations and unusual methods of application (Crafts, 1975). In orchards and vineyards the herbicide need not be truly selective since it can be applied selectively to the weeds and not to the trees and vines.

The phenoxy herbicides are also used for weed control around the farm in noncrop situations. Such uses are coordinated with preventive and cultural practices to make up efficient production systems. When the same methods are used year after year, special populations of weeds build up that are tolerant to the constant or repetitive methods employed (National Academy of Sciences, 1968).

An advantage of having a variety of herbicides and other practices is that it makes possible the alternation and rotation of weed control measures in successive years. Rotations to different herbicides or to other crops, each with its particular herbicides and cultural methods, and the use of combinations of herbicides or combinations of herbicides with other methods are recognized means of combatting weeds in croplands. Thus the phenoxys are production tools not only in the crops in which they are directly used but also in the crops that are produced in rotation with them.


Trees tend to advance into grazed grassland and suppress the grass. The scrubby oak trees on this Texas range have been killed by aerial spraying with 2,4,5-T. The grass is now making good growth and provides good grazing. Photograph courtesy of D. B. Polk, U.S. Soil Conservation Service.

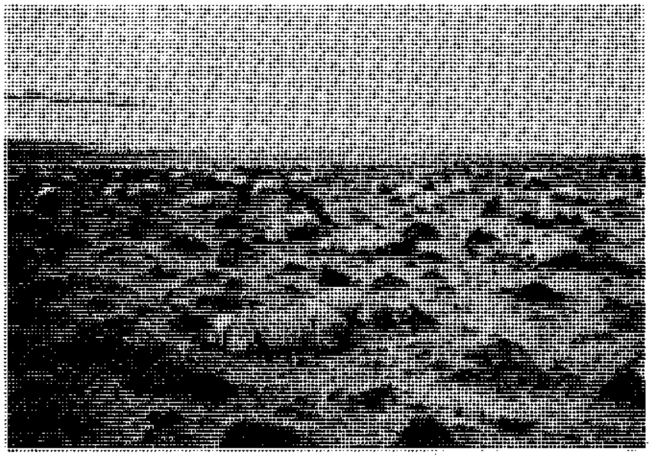
Pastures and Ranges

Pastures and ranges are lands producing grasses or other forage plants that are harvested by grazing with domesticated animals. Pastures are grazing lands that are intensively managed, often by periodic cultivation, treatment with herbicides or rotation with crops. Rangelands are less intensively managed and are often arid or rough lands little altered from their natural state.

The central problem inherent in all grazing lands is the fact that livestock consume forage plants and leave weedy plants untouched and uninjured. The result is that valuable species are suppressed while unpalatable or noxious ones remain undamaged and free to prosper under reduced competition. Thus, the very nature of grazing provides an overwhelming competitive advantage to weedy species. The advantage is so great that, in the absence of proper management, weeds come to predominate in nearly all situations, often to the virtual exclusion of forage species. These weeds, often poisonous, kill large numbers of livestock each year.

Weedy vegetation can be held in check to some extent and forage yield maintained by the proper timing and rotation of grazing and by avoiding excessive grazing (Vallentine, 1971). Pastures can be plowed and replanted when soil and slope permit. Ranges can be reseeded or seeded with improved species. Fertilizers can be applied

A dense growth of mesquite and prickly pear in South Texas. Without control of these species, the area shown is worthless for grazing. Photograph courtesy of D. B. Polk, U.S. Soil Conservation Service.



Sheep killed by consumption of halogeton. Approximately 1200 sheep died in this incident in Utah. The sheep had drifted onto a stand of halogeton, a poisonous plant that replaced the original vegetation as a result of an early practice of bringing sheep to this area each year and allowing them to graze it heavily. Consumption of poisonous plants causes the loss of an estimated 3 to 5% of the domestic livestock in the United States each year. Photograph courtesy of Lynn F. James, U.S. Department of Agriculture.

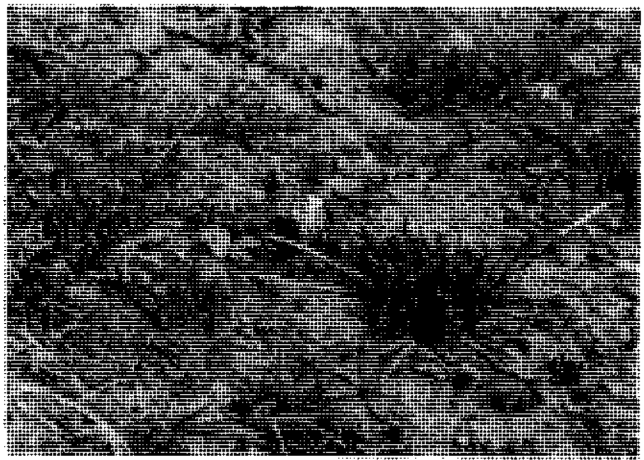
and pests controlled. Such positive measures are useful and necessary for increasing forage production; however, effective management systems must sooner or later face up to the necessity of taking direct destructive action against weeds. Important methods for controlling pasture and range weeds include chemical and mechanical methods and fire (Vallentine, 1971).

The phenoxys are the principal herbicides used on grazing lands (Way and Chancellor, 1976). Their low cost, high activity, suitability for low-volume application and ability to kill most broad-leaved plants, including woody species such as mesquite and sagebrush, without injury to grasses and certain legumes, make them widely useful in pasture and range management. As early as 1951, 500,000 acres of rangelands were treated with 2,4-D and 2,4,5-T. By 1966, over 10 million pounds of phenoxy herbicides, largely 2,4-D, were being applied annually to privately owned pastures and rangelands in the 48 contiguous states, amounting to nearly one-fourth of the total domestic consumption of phenoxy herbicides at the time. In 1975, 18 million pounds of phenoxy herbicides were applied to pastures and rangelands in the United States (Stanford Research Institute, 1976). This total included 14.7 million pounds of 2,4-D applied to about 20 million acres of land. About 2.5 million pounds of 2,4,5-T were applied to pastures and ranges, including treatment of about 1.5 million acres of rangeland for control of mesquite, a task for which this chemical is uniquely adapted (Environmental Protection Agency, 1974).

At present, most of the 2,4-D used on grazing lands is being applied to pastures. Of the 630 million acres of rangeland, only about 5.0 million acres, amounting to 0.8% of the total, are treated with phenoxy herbicides each year (Anonymous, 1976a). Pastures may be treated annually, but rangelands are treated only every 6 to 10 years. Also, woody plants on rangelands reach levels requiring treatment on only 150 to 200 million acres in the United States and are then treated only when returns justify the expenditure. Although treating rangelands with phenoxy herbicides often increases forage production several fold, the land may be so arid or otherwise unproductive that this level of increase is still not enough to yield an adequate return on treatments costing as little as $5 per acre.

Alternatives to phenoxy herbicides are more limited on rangelands than on pastures. Economic constraints on rangelands are dictated by the inherently low productivity of these lands. Drastic treatment such as bulldozing, ripping, or rootplowing followed by seeding may cost six times as much as treatment with phenoxy herbicides. These procedures destroy existing forage and disturb the soil, making it susceptible to wind and water erosion and to reinvasion by weeds. Such alternatives are attractive only on sites with high productive potential that can be revegetated quickly.

Before rangelands were managed as they are now,



Larkspur plants grazed by cattle in an area in Utah. About 25 cattle died in this incident. Larkspur is a poisonous range plant that is responsible for the death of many livestock. It is widely distributed in the mountainous areas and some plains areas of the West. Photograph courtesy of E. H. Cronin, U.S. Department of Agriculture.

One of the cattle that died as a result of grazing the larkspur in the photograph at the left. In the Wasatch Plateau of central Utah, larkspur causes more financial loss to livestock producers than do all other poisonous plants combined. Control of larkspur with herbicides greatly reduces the loss of cattle. Photograph courtesy of A. Earl Johnson, U.S. Department of Agriculture.

natural fires often were able to reduce brush and coarse weeds to levels that were in balance with forage species (Vallentine, 1971). Man has largely eliminated fire, presumably to prevent loss of forage and to reduce the danger of wildfire. This, in part, accounts for a general increase in weeds on rangelands and suggests a reevaluation of present attitudes toward fire in range management. Fire on range and pasture lands is clearly an alternative to the use of phenoxy herbicides in some situations, particularly for brushlands. The smoke resulting from range or pasture burning, the objectionable appearance of the fires and of burned-over lands, the difficulty of keeping fires from spreading and the hazards to wildlife are factors discouraging the use of burning and leading to the proliferation of laws restricting the employment of fire in range and pasture management.

Forests

Forests cover a third of the United States, or 750 million acres (Anonymous, 1973). Two-thirds of this, 500 million acres, is productive enough to be managed for commercial timber. The remainder is either too low in productivity for commercial timber or unavailable for timber production because it has been withdrawn for other uses such as water yield, grazing, wildlife or recreation.

Three-fifths of the commercial timberland (about 300 million acres) is producing forest products at less than two-thirds of capacity, due primarily to competing undesired vegetation (Walker, 1973). Over 100 million acres of this area is productive land that is supporting virtually no timber of significant value despite a history of high-value growth. These are the principal areas on which phenoxy herbicides, mostly 2,4-D, 2,4,5-T and silvex, are being used to create space in which a desired forest cover can be established (Romancier, 1965).

The purpose of the use of phenoxy herbicides in forestry, as in other enterprises, is to discriminate between desired and undesired plants (Byrnes, 1960). In some cases, defective trees or undesired species have become dominant, whereas in others there are not enough trees to form a stand because of weed, brush or vine competition (Newton, 1973). In other situations, forests fail to regenerate because habitats have become altered in ways that support destructive populations of animals (Marquis, 1975; Miller et al., 1975).

Traditional forestry methods emphasize hand-cutting for thinning and culling of forest stands (Newton, 1973). Such methods may be satisfactory and economically sound, particularly where cut material is utilized. However, high costs and the sheer magnitude of the problem on a nationwide basis make it evident that large-scale forest improvement simply cannot be achieved by manual means. Herbicides are being used increasingly as a substitute for hand-cutting.

Nearly half of America's best timberland is now occupied by low quality trees and shrubs. This picture shows the consequences of cutting the timber from a productive area in Oregon (note the stump as an indication of the size of the trees) and replanting it with Douglas fir but without controlling the competing vegetation that quickly overtopped and suppressed the replants. The small fir trees are difficult to distinguish among the brush. The value of the timber the brush prevents from developing is indicated by the fact that recent sales of timber on National Forest land in Oregon on sites similar to the one shown but before cutting have been ranging from $20,000 to $30,000 per acre. Photograph courtesy of Oregon State University Forest Research Laboratory.

Weed tree control by spraying 2,4,5-T into notches (frills) cut in the base of the tree. Photograph courtesy of Charles L. Benn, Iowa State University.

The phenoxy herbicides are used for preparation of sites for tree establishment and for selective weeding to release preferred species from competing woody plants (Byrnes, 1960; Bey et al., 1975). Herbicides are applied by aircraft, by ground broadcast sprays and by treating individual trees (Byrnes, 1960). Rates of herbicide application for both aerial and ground broadcast treatments generally range from 2 to 4 pounds of 2,4,5-T or 2,4-D/2,4,5-T mixture per acre (Bovey, 1977). Broadcast applications for conifer release are based on the greater resistance to the phenoxys of the principal conifer species than of most hardwoods (Bovey, 1977). Individual tree injections are made through spaced incisions around the trunk using about 1 milliliter of 2,4-D solution per cut (Peevey, 1975; Holt, Voeller, and Young, 1975). Limited use is also made of basal sprays and stem frills, with phenoxy herbicides being applied in oil solution to the bases of tree trunks or to cuts on the stems. Such treatments have lasting effects and usually need be used only once or twice in a 30- to 80-year forest rotation cycle. Many areas do not develop conditions requiring treatment; others, once initial conditions are corrected, should seldom need retreatment if properly managed.

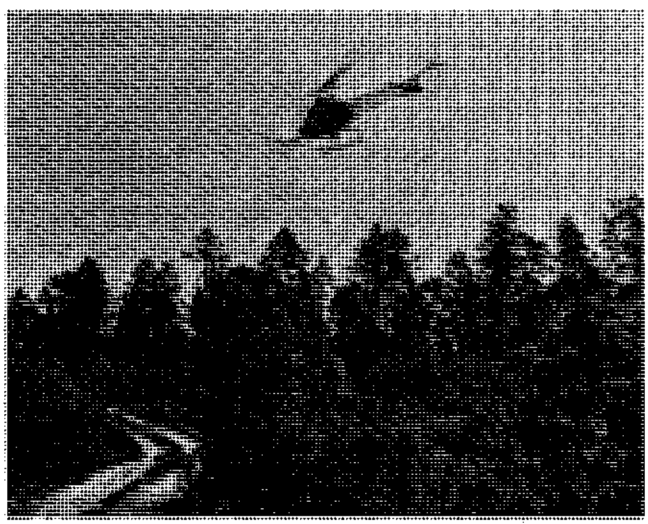
On forest land, as on cropland and rangeland, the phenoxys are used in concert with other management practices and other herbicides to secure objectives beyond the simple suppresssion of unwanted plants. There are many alternative procedures for both timber stand improvement and complete rehabilitation (Walstad, 1976; Anonymous, 1978). They entail different costs and impacts but can accomplish the same general results (Newton and Norris, 1976; Newton and Norgren, 1977; Newton, 1977). They may employ both chemical and nonchemical procedures, including the option, in some instances, to take no action at all.

Culling and thinning also may be accomplished by injecting organic arsenicals, picloram or dicamba, often with the same effect as injections of the phenoxys (Peevey, 1975; Holt, Voeller, and Young, 1975). Injection does not directly expose other trees or wildlife to the herbicide nor does it entail appreciable contamination of the general environment. However, costs generally favor use of the phenoxy herbicides either alone or in combination with picloram, often by several dollars per acre.

Site preparation may be accomplished with sprays of picloram, dicamba, amitrole, glyphosate or other herbicides in place of, or in addition to, treatments with the phenoxys. These chemicals are relatively less selective among woody species than the phenoxys, and in some instances also kill the grasses. Residues of picloram and dicamba are more persistent and active than are those of the phenoxys. Other herbicides can often be used effectively, despite a variety of technical problems, but at a cost of $10 to $40 per acre more than for site preparation based on the phenoxys. Generally, fewer technical and environmental problems are encountered with phenoxys than with substitutes that serve the same purpose (Newton, 1977). There are numerous vegetation types for which substitutes may not be used because of persistence of the chemicals in the soil or lack of effectiveness. The use of other materials is usually warranted only when there is a need to control species resistant to the phenoxys or where potential drift of the phenoxys could pose a hazard to nearby sensitive crops (Walstad, 1976).

Mechanical equipment can be used for forest weed control, but usually at costs and hazards greater than those associated with use of herbicides (Miller et al., 1975). Power saws are more costly to operate in most circumstances than are injectors. Hazards from the use of saws are great, both directly from the equipment and indirectly from falling trees (Bernstein, 1977). Exposure of workers to poisonous plants also causes injury and loss of time. Girdling requires much labor and entails a delay of a year or longer for weed trees to die and may be ineffective because of sprouting from below the girdle. Bulldozers may be used to clear land for planting, and rolling choppers can incorporate brush and woody residues into soil. Such extreme methods are costly and disruptive to the soil, and usually lead to greater erosion and sedimentation in streams (Newton and Norgren, 1977). Herbicides used in forests do not degrade water quality below accepted standards. Biologically significant concentrations of 2,4-D and 2,4,5-T do not occur in forest waters following proper applications of these chemicals (Newton and Norgen, 1977; Sheets, Rieck and Lutz, 1972).

Fire is an important cultural tool that may be used independently or in conjunction with herbicides and mechanical tools. However, objectionable smoke, concern for wildlife and the difficulties of fire control restrict the use of fire (Newton, 1977). Herbicides are often used to desiccate vegetation, so that smoke is reduced, and to allow areas to be burned when adjacent areas are green



Maximum yields of wood pulp and lumber require management procedures that suppress competing hardwoods and favor pines. Aerial application of 2,4,5-T to a developing forest in the Southeast (left) resulted 5 years later in an excellent stand of pine trees (right). Photograph courtesy of D. E. Davis, Auburn University.

Solid stands of conifers, such as this one in Oregon, provide maximum production of high quality wood and attractive scenery. Once the conifers have developed a closed canopy, they suppress competing vegetation. The young trees, however, require protection from faster growing trees, bushes, and weeds. The protection may be supplied by use of herbicides or by various manual methods. According to a recent summary prepared by Gary Blanchard of Starker Forests in Oregon, the cost of control by spraying with herbicide from a helicopter ranges from $15 to $23 per acre. The cost of manual cutting ranges from $32 to $156 per acre (some of the recent bids in Oregon's Siuslaw National Forest are said to exceed $800 per acre). The cost of safety insurance is $0.20 per acre for helicopter spraying and $16 per acre ($32 per $100 of payroll) for manual cutting. Photograph courtesy of Oregon State University Forest Research Laboratory.

and low in flammability.

The decision to make no treatment may be justified in some instances; however, such a decision is more often made through neglect than through planned action. Alterations of vegetation resulting from past malpractices are not automatically self-repairing. Trees and shrubs present on a site tend to remain dominant unless removed or killed (Newton, 1973). If forest composition is poor for any reason, it will likely remain poor. If game habitat is poor in such a stand, it will usually remain poor. In the absence of compensatory culling, each selective removal of forest products will increase the proportion of undesirable growing stock. The effect of no treatment is therefore likely to persist indefinitely and to perpetuate the degradation of stands conditioned by past and present malpractices.

Aquatic Habitats

Aquatic vegetation is present in all surface waters of reasonable quality. This plant growth constitutes the primary food production in water and thus provides the nutritional basis for all aquatic life, ranging from microorganisms to game fish and water fowl (Hynes, 1970; Bureau of Aquatic Plant Control). Under certain circumstances there is a buildup of overwhelming masses of aquatic weeds that may clog streams, lakes, reservoirs and canals, causing flooding, interfering with recreation and the flow of irrigation and drainage water, restricting navigation and impairing fish and wildlife habitats (Pennsylvania Water Resources Coordinating Committee, 1971; Bureau of Aquatic Plant Control; Timmons, 1960; Timmons and Klingman, 1959).

The growth forms of aquatic plants range from single-celled algae to floating mats of such flowering plants as alligatorweed and water hyacinth that completely cover the water surface (Hynes, 1970; Bureau of Aquatic Plant Control). Submersed plants, such as some pondweeds, are rooted in the bottom and grow beneath the water surface. Others, such as cattails and bulrushes, are rooted in the bottom in shallow water and rise above the water surface.

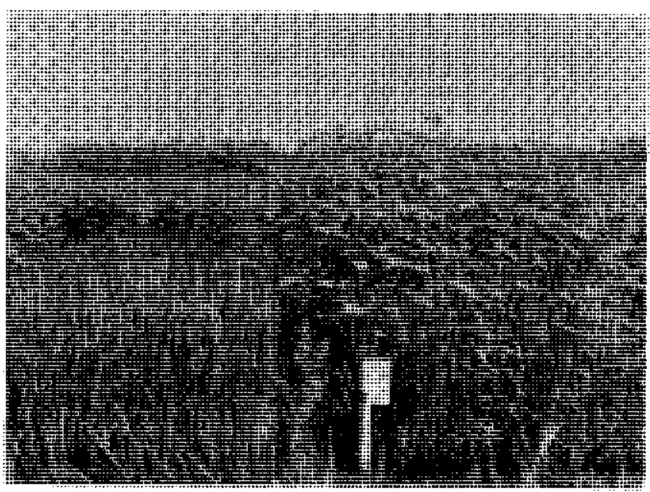
Most of the many desirable attributes of water may be served at one time or another by the judicious use of herbicides. Domestic water reservoirs are often treated on a regular basis with copper salts to suppress algae, and in other situations various chemicals, including phenoxy herbicides, are added to the water or sprayed on floating or emergent vegetation (Mullison, 1970). About 2 million pounds of 2,4-D and 1/2 million pounds of silvex are used for aquatic weed control in the United States annually (Stanford Research Institute, 1976).

2,4-D can be used at rates up to 4 pounds per acre for control of water hyacinth and other floating or emergent species (United States Department of Agriculture, 1973). 2,4-D and silvex are frequently used in the form of granules or pellets which, after being applied over the water surface, sink to the bottom and kill rooted submersed weeds. Alligatorweed is resistant to 2,4-D but may be controlled with silvex. Both 2,4-D and silvex are put in water in liquid form at 1.5 to 2 parts per million (ppm) or 5 pounds per acre foot of water for control of some weeds (United States Department of Agriculture, 1973). Bulrushes, cattails, water lilies and most shoreline and emergent weeds are controlled with an oil-water emulsion of 2,4-D esters at rates of 4 to 6 pounds per acre.

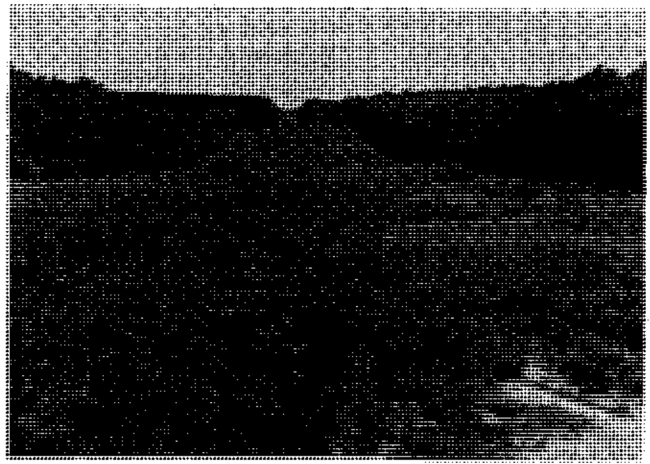
There are some alternatives to phenoxy herbicides for chemical control of aquatic weeds (Mullison, 1970). Diquat can be used to control water hyacinth, water lettuce and duckweed and submersed and floating weeds generally. Acrolein and aromatic solvents are effective for control of submersed weeds, but both are highly toxic to aquatic animals. Endothall, dichlobenil, diquat, dalapon and fenac are alternatives to the use of phenoxy herbicides for certain weeds and under some conditions. Few herbicides are registered for aquatic use. There are no suitable chemical alternatives to 2,4-D and silvex for control of many shoreline or emergent weeds.

Mechanical alternatives for aquatic weed control include underwater cutters for rooted weeds and swath cutters for floating mats. Dredging, draglining and underwater dragging of chains and other devices may be used on suitably accessible waterways (Bureau of Aquatic Plant Control). The cost of mechanical methods for control of water hyacinth ranges from $150 to $1,600 per acre compared with a chemical cost of $12 per acre for treatments with 2,4-D (Environmental Protection Agency, 1974). Costs of more than $100 per acre may be expected with the use of alternative herbicides.

An important use of phenoxy herbicides in the aquatic environment is in the production of rice. In view of the worldwide importance of this most critical food crop, the use in rice culture may eventually become the most important use of these herbicides. The uses in rice and in noncrop aquatic situations have much in common, including the existence of few economical alternative methods.



Control of hemp sesbania in rice in Arkansas with 2,4,5-T. The plot on the left was sprayed, and the plot on the right was unsprayed. The yield reduction due to the hemp sesbania in this picture was about 40%. Overall losses due to hemp sesbania in the southern rice area in the United States are estimated at 8% in yield and 4% in quality. Photograph courtesy of Roy J. Smith, Jr., U.S. Department of Agriculture.



Diverse and dense vegetation composed of grasses and other herbaceous plants and short, woody shrubs on a power-line right of way in central Pennsylvania maintained with phenoxy herbicides. Herbicides were used only twice in 20 years to control the growth of trees. Photograph courtesy of W. R. Byrnes, Purdue University.

Industrial Lands

Industrial vegetation management is directed primarily at modifying plant cover so that it does not interfere with industrial operations. Effects on the general environment and on aesthetic values must also be considered (Tillman, 1976).

Management actions range from minor tree pruning for protection of power lines and structures to the total suppression of all plants in such installations as railroad tracks, power substations and storage yards. About 11 million pounds of phenoxy herbicides are used on industrial lands annually in the United States, of which half is 2,4-D and the remainder is 2,4,5-T and silvex. Industrial areas requiring total vegetation control are usually treated with soil sterilants rather than phenoxy herbicides. Industrial lands in the United States subject to management of plant cover are in excess of 50 million acres. This total includes nearly 4 million miles of highway, 200,000 miles of railroad and about 2 million miles of overhead electric lines, of which 300,000 miles are high-capacity circuits occupying 4 million acres.

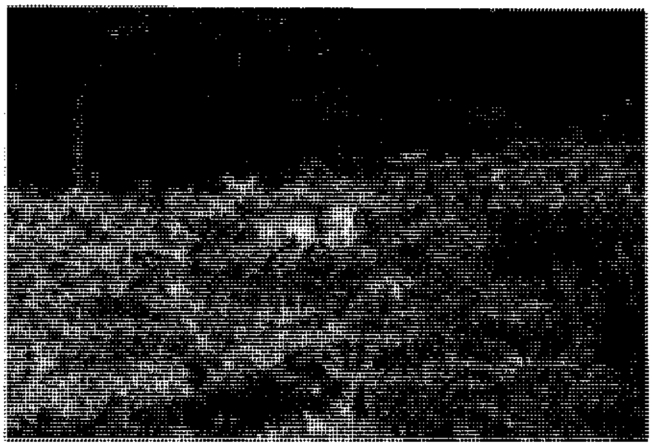
Most utility, highway and railroad rights-of-way are initially cleared by mechanical means, the cost of clearing in wooded areas varying widely with the nature of the terrain, labor costs and other factors. On power and communication line rights of way, subsequent control commonly entails the use of 2,4-D and 2,4,5-T (Bramble and Byrnes, 1972). Newly constructed lines cleared with mechanical equipment often require two herbicide applications in succession to control sprouts; subsequent treatments are needed less frequently, depending upon the aggressiveness of invading species. Maintenance operations may involve: (1) selective basal sprays of 2,4,5-T or 2,4,-D/2,4,5-T esters at rates of 12 to 16 lb per 100 gallons of oil; (2) foliage or stem-foliage sprays of 2,4,5-T or 2,4-D/2,4,5-T mixtures in water applied with ground equipment at rates of 3 to 4 lb of chemical per 100 gallons of spray mixture; and (3) aircraft applications of 2,4,5-T or 2,4-D/2,4,5-T mixtures at rates up to 12 lb per acre, often as invert emulsions or combined with a thickening agent and applied by special equipment to reduce spray drift (Barnhart, Brandt, Miller et al., 1976). Other treatments include tree injections of the kind used in forests. Silvex and dichlorprop are used as foliage sprays at rates similar to those used with other phenoxy herbicides. These compounds kill certain species not controlled by 2,4-D and 2,4,5-T, but otherwise they affect a more limited spectrum of plants.

The preferred vegetation on highway and utility rights of way is usually grass and other low vegetation (Bramble and Byrnes, 1976; Niering and Goodwin, 1974). The proper management of vegetation on roadsides is important to safety by providing adequate sight distances at curves and intersections. Moreover, tall weeds can cause hazardous snowdrifts. Before the use of phenoxys, the methods available for vegetation control on highway and utility rights of way were mowing, plowing, hand cutting and burning. 2,4-D, 2,4,5-T and other herbicides have eliminated the need for plowing, hand cutting and burning and also permit fewer mowings per year. Chemicals are particularly useful on steep slopes, wet areas and areas obstructed by guard rails and other structures and not accessible to mowing machines. The use of phenoxy herbicides on rights of way is sometimes restricted by the proximity of desirable vegetation susceptible to injury by drift.

Alternative measures for utility rights of way maintenance include such chemicals as ammonium sulfamate, picloram, amitrole, dicamba and glyphosate (Barnhart, Brandt, Miller et al., 1976). Ammonium sulfamate is effective for control of many woody plants. However, since it must be applied as high-volume sprays, it is not suited to applications by aircraft and in rough terrain that cannot be reached by heavy vehicles. Ammonium sulfamate appears to be environmentally safe for wildlife and free of residue problems. However, it kills grass and is thus not suitable for broadcast treatments where ground cover is wanted. Picloram is highly effective on many woody plants and can be applied as foliage sprays or to the soil in granular form. It is relatively persistent in the soil and must be used with due regard for this characteristic (Newton, 1967). Picloram is extremely toxic to some crop species. Amitrole, dicamba and other foliar herbicides have important uses in industrial weed control. Their selectivity patterns differ from those of the phenoxy herbicides.

By spraying with 2,4-D, highway rights of way and farm fence rows can be converted from tall, unsightly weed patches to dense stands of grass that help suppress further weed infestation. Only occasional mowing or spraying is needed to maintain this condition. Photograph courtesy of Charles L. Benn, Iowa State University.

Kudzu, a serious weed along rights of way in the Southeast, can be controlled by repeated applications of 2,4-D. The area on the left has been sprayed with 2,4-D. The area on the right is untreated. Photograph courtesy of D. E. Davis, Auburn University.



The food supply and cover conditions for deer and certain other wildlife species are more favorable in this right of way cleared for a power line in Pennsylvania than in the original uncut forest. Deer make greater use of the right of way than of equal areas in the adjacent forest. The deer in this view of an area maintained with phenoxy herbicides is feeding in a blueberry patch. Blueberries are much more abundant in the right of way than in the adjacent forest. Photograph courtesy of W. R. Byrnes, Purdue University.

Blackberry, an excellent wildlife food, with abundant fruit in a power-line right of way in central Pennsylvania. Blackberries and blueberries in this right of way are utilized by wildlife and local berry pickers. Deer browse both the berries and the stems. Photograph courtesy of W. R. Byrnes, Purdue University.

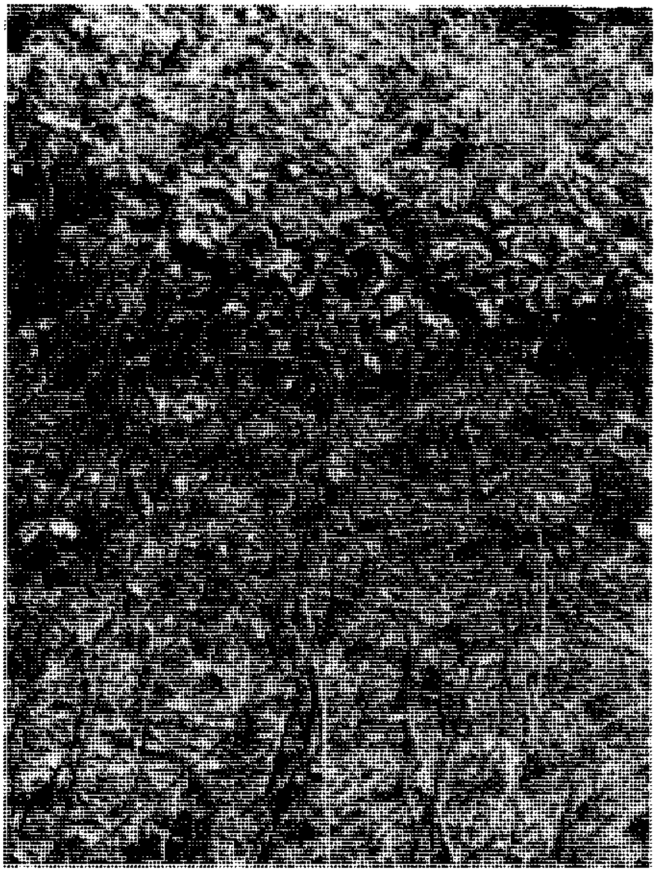
Alternative management systems on most rights of way in wooded areas are similar to those used in forestry including hand cutting, mowing and plowing or bulldozing. Terrain limitations greatly restrict the use of ground equipment as replacements for aerial applications.

Urban Lands

Urban vegetation is principally lawn and turf, supplemented with shade trees and shrubbery. The central management effort is directed toward maintaining high-quality, weed-free turf (Environmental Protection Agency, 1974). There are 15 million acres of turf in the United States, of which about one-tenth is golf courses and one-third is home lawns.

2,4-D, 2,4,5-T, silvex, MCPA and dichlorprop are used on turf to control dandelions, plantains, garlic, chickweed and other nongrass weeds. This is standard practice by greenskeepers and turf managers throughout the world. Other herbicides used in turf management include DCPA, benefin, bensulide, arsonates, siduron and others that control crabgrass and certain other annual grasses. Simazine and atrazine control many

Regrowth of woody brush composed of red maple, chestnut oak and white oak tree sprouts in a right of way cleared for a power line in Pennsylvania. The original trees were cut in the winter of 1951-1952, and the regrowth was cut in 1958 and again in 1967. This picture, taken in 1974, shows the third cycle of regrowth of sprouts. The tree sprouts were cut again in 1976. By 1978, the fourth cycle of regrowth was 8 to 10 feet tall. Hand cutting does not kill the tree roots. Photograph courtesy of W. R. Byrnes, Purdue University.



annual weeds in turf. DCPA and dicamba are effective on selected annual grasses and some phenoxy-tolerant broad-leaved weeds. Dicamba is readily absorbed by roots from soil and can injure shrubs and shade trees in and around turf areas. The use of alternative herbicides to the exclusion of phenoxy herbicides would greatly reduce the control of broad-leaved weeds, a critical aspect of turf management.

The phenoxy herbicides are also widely used in public health programs to suppress poison ivy and allergenic plants such as ragweed.

Application of 2,4-D to dormant poison ivy produced the kill shown in the foreground. Vines in the background were not treated. Poison oak and poison sumac have similar effects. In California, poisoning due to this class of plants ranks first on the list of work-related disorders. Photograph courtesy of Charles L. Benn, Iowa State University.

HAZARDS

All chemicals, including ordinary household materials and the common ingredients of foodstuffs, are under some conditions hazardous to humans and other living things (Peoples, 1975). A substance may be a fire hazard, stain clothing, be corrosive, cause the floor to be slippery when spilled, or be poisonous and cause illness or death. In poisoning, the hazard is compounded of two variables: the inherent toxicity of the chemical and the degree of exposure to it. High toxicity with little exposure presents low hazard, whereas high exposure to materials that are not highly poisonous may have serious consequences.

The toxicity of the phenoxy herbicides is known with reasonable accuracy for hundreds of species of plants and animals under a variety of conditions (Way, 1969). The levels of herbicide present in the environment as a result of normal use and under conditions representing possible misuse are also known for a wide variety of situations. These facts form the basis for the assessment of hazards resulting from the use of the phenoxy herbicides. The scientific data are extensive, comprising more than 40,000 scientific papers and technical reports over a 35-year period. The phenoxys are relatively old materials in terms of research and accumulated experience in their use. It is possible not only to assess risks projected on the basis of experimental data but also to confirm or deny these projections on the basis of hazards that have developed or failed to develop from over 35 years of extensive use throughout the world.

The phenoxy herbicides are powerful plant killers, and the principal hazards from their use are related to this fact. The hazard is almost entirely to plants. The danger is either from failures in selectivity, leading to injury of the crop or other valuable plants in the treated area, or from spray drift or the movement of herbicide vapors, leading to injury of plants outside the treated area. There is a preponderance of evidence that the phenoxy herbicides are not significantly hazardous to animal life and microorganisms under normal conditions of use and indeed under conditions of substantial misuse (Way, 1969). There may be harm or benefit to animals indirectly as a result of either adverse or favorable changes in vegetation (Borreco, Black and Hooven, 1972). However, this is a consequence of the chosen vegetation management plan and not of the means taken to accomplish it. Losses to crops due to failures in selectivity can result from overdosing due to mismeasurement of chemicals, poorly calibrated spray equipment, overlapping of spray swaths causing double coverage, weather variations that affect crop resistance, and spraying at the wrong stage of growth. Rice, for example, is susceptible to 2,4-D injury at certain stages of growth, and many normally resistant plants are subject to injury during flowering and fruiting. Conifers are less resistant to the phenoxys when in rapid growth (Anonymous, 1977a). 2,4-D injury is widely recognized by farmers and foresters throughout the world, and the means of preventing major losses are well known but, unfortunately, are not always practiced.

Spray Drift

The most serious hazard in the use of the phenoxy herbicides is drift of the chemical to nontarget vegetation during or after application (Mullison, 1970; Stewart and Gratkowski, 1976; Akesson and Yates, 1975). Phenoxy herbicides are extremely toxic to cotton and grapes (Brown et al., 1948; Clore and Bruns, 1953). Beans, tomatoes, melons and certain ornamental plants are also easily damaged (Linn et al., 1959). The hazard to nontarget crops is related to the susceptibility of the plants and their stage of development and growth (Goodman, 1953). Other factors are the distance from treated areas to susceptible plants, the amount of herbicide applied on a given day and the nature of the herbicide formulation used. The proportion of driftable small drops in the emitted spray and the height of the application (air or by ground) above the surface also affect spray drift (Gratkowski, 1976). Wind velocity and direction and the degree of turbulent mixing can greatly increase or decrease downwind transport and deposition of the spray in the susceptible crop area. Air temperature and humidity alter crop response and affect spray evaporation (Stewart and Gratkowski, 1976; Akesson and Yates, 1975; Butler et al., 1969).

The herbicide can move as spray droplets, or it can evaporate and move as vapors (Akesson and Yates, 1975). The ester forms of phenoxy herbicides can evaporate from droplets in the air or from plants and other surfaces after spraying. The vapors can then drift in the air to sensitive crops and other susceptible plants outside treated areas (Stewart and Gratkowski, 1976; Akesson and Yates, 1975). This behavior is mainly a property of the high-volatile (short-chain) esters which are seldom used today. Low-volatile (long-chain) esters are essentially free of this hazard except under conditions of very high temperatures and the close proximity of sensitive crops. Under such conditions, the amine salt formulations provide further protection against vapor movement.

Drift of herbicides as droplets can be greatly reduced by spraying the material in the form of larger and heavier droplets that tend to settle rapidly in the target area (Akesson and Yates, 1975). Droplet size can be increased by using higher spray volume, lower pressures, nozzles with larger orifices, nozzles of special design, or special systems for aircraft that give close control of droplet size (Stewart and Gratkowski, 1976; Gratkowski, 1976). Thickening agents can be added to the spray mixture to cause it to form larger drops and fewer fine particles (Stewart and Gratkowski, 1976; Akesson and Yates, 1975; Gratkowski, 1976; Gratkowski and Stewart, 1973; Butler et al., 1969).

Application machines and techniques have improved significantly in recent years. It is no longer necessary in hazardous situations to apply phenoxys with equipment and formulations not specifically designed to reduce drift. Although a larger number of small drops may be more effective, larger spray drops of 500 to 1500 microns settle rapidly and provide safer and, in the long run, more economical control in areas where drift may be a problem (Akesson and Yates, 1975).

With use of the best available technology, it is routinely possible to deposit 97 to 99% of the released spray within ordinary target areas by either aircraft or ground equipment (Akesson et al., 1971). Although such precision is not without its measure of added cost, in hazardous situations the additional expense is clearly worthwhile. Even more effective means are being developed which will permit use of phenoxy herbicides with significantly less drift than is possible with present methods.

In hazardous situations, phenoxy herbicides should be applied only when light and continuous wind is blowing away from nearby susceptible crops (Stewart and Gratkowski, 1976; Akesson and Yates, 1975). Phenoxy herbicides should not be applied in a potentially hazardous situation when a temperature inversion, or a warm layer of air, is overhead under 1500 feet elevation (Anonymous, 1977a). Absence of wind or an inversion ceiling reduce turbulent mixing or ventilation and promote a build-up of small drops and vapor in the air that can drift as a concentrated mass to sensitive crops.

A final means of protection from drift is to recognize situations that are beyond normal protective measures and to avoid spraying. When highly susceptible crops such as cotton and grapes are grown within 3 to 5 miles of large-scale operations (over 100 acres per day), crop injury may occur despite normal precautions. There are federal and often state regulations that apply to such situations (Akesson and Yates, 1975). Regulations forbid use of specified herbicides at certain times of the year and require special permits for exceptionally hazardous uses, or they may allow application only under supervision (Akesson and Yates, 1975).

The drift of phenoxy herbicides to nontarget areas is easily detected by the symptoms that appear on sensitive species. The symptoms are pronounced, and they often appear to indicate greater injury at first than is ultimately the case (Goodman, 1953). The pattern of injury of nontarget vegetation in relation to the primary treatment is ordinarily such that the source of spray drift is evident.

Toxicity

Toxicity is the degree that a substance is poisonous. It is commonly expressed as the lethal dose, or lethal concentration, to 50% of the test animals (LD_{50} or LC_{50}). Dose is commonly stated in milligrams of chemical per kilogram of body weight (mg/kg). Concentration is often expressed as parts per million (ppm) or parts per billion (ppb) of toxicant in food, water or air. The phenoxy herbicides are considered to be moderately toxic. The acute oral toxicity of a single dose of the phenoxy herbicides to mammals ranges from LD_{50} values of 100 mg/kg to 2,000 mg/kg, depending upon the test animal and the particular chemical or formulation (Whitehead and Pettigren, 1972; Drill and Hiratzka, 1953; Highman, Gaines and Schumacker, 1976; Hill and Carlisle, 1947; Rowe and Hymas, 1954; Hill, Heath, Spann et al., 1975; Lenz, 1977; Dost, 1978). The herbicides are absorbed after ingestion, transported via the plasma, concentrated in the kidneys and rapidly eliminated in the urine, largely unchanged chemically (Gehring et al., 1973; Koschier and Berndt, 1976; Clark, Palmer, Radeleff et al., 1975; St. John et al., 1964; Dost, 1978). For 2,4-D or 2,4,5-T, the acute oral LD_{50} is upwards of 300 mg/kg for rats, mice, guinea pigs, hamsters, rabbits, primates and various livestock and large game animals (Innes et al., 1969; Kutches et al., 1970). This is equivalent to doses of 1 ounce or more of chemical for a mature human male. There is evidence that the dog has lower capacity to excrete the phenoxys, and as a result these chemicals are more toxic to dogs than to other test animals (Hook et al., 1974; Hook et al., 1976; Piper et al., 1973; Drill and Hiratzka, 1953). Unlike the dog, humans excrete the phenoxy herbicides rapidly via the urine (Kohli, Khanna, Gupta et al., 1974; Gehring et al., 1973; Matsumura, 1970; Seabury, 1963).

In long-term feeding trials, test animals tolerate doses of as much as 25% to as little as 0.4% of the acute oral LD_{50} fed daily on a continuing basis without ill effects (Palmer, 1972). Signs of poisoning include loss of appetite, loss of weight, weakness, lack of coordination, alterations of the liver and other internal organs, and defective offspring in tests with sensitive species (Palmer and Radeleff, 1969; Erne, 1966). 2,4,5-T is known to be a teratogen (cause birth defects) when administered at high doses to mice under some circumstances (Wilson, 1972; Courtney et al., 1970; Wilson, 1973). The same may be true for the other phenoxys as well, since biologically active chemicals commonly can be shown to have this or other fetotoxic effects under some conditions of exposure (Wilson, 1972; Courtney et al., 1970; Wilson, 1973; Fraser, 1977; Heinonen, Stone and Shapiro, 1977). When gestating animals are poisoned by massive doses of any substance, there are usually adverse effects on the developing offspring (Wilson, 1972, 1973; Courtney et al., 1970).

The phenoxy herbicides are generally less toxic to birds than to mammals (Lutz and Lutz-Ostertag, 1972; Lutz-Ostertag and Lutz, 1974; Whitehead and Pettigren, 1972; Kenaga, 1975; Foster, 1974; Tucker et al., 1970; Pimentel, 1971). The acute oral LD_{50} for 2,4-D and 2,4,5-T for poultry, mallards, pheasants, pigeons and quail ranges from 300 to 5,000 mg/kg. The LC_{50} for these chemicals in feed for birds is upwards of 2,500 ppm and is typically greater than 5,000 ppm. The toxicity to fish is highly variable (Kenaga, 1974; Hughes and Davis, 1966; Butler, 1970; Butler, 1965). LC_{50} values range from less than 1 ppm to more than 1,000 ppm in water. These values are equivalent to treatments of 10 pounds to 10,000 pounds of phenoxy herbicides per acre in a pond 4 feet deep. Toxicity is largely associated with the ester and oil-soluble amine formulations (Newton and Norgren, 1977). The water-soluble amine salts are relatively nontoxic to fish. Oysters, crabs, mussels and a wide variety of other invertebrates are not directly affected by the phenoxy herbicides applied in lakes, ponds and estuaries for aquatic weed control (Butler, 1963; Butler, 1965). The phenoxys are essentially nontoxic to insects and related organisms and are not significantly fungicidal or bactericidal at ordinary levels of exposure (Smith and Isom, 1967; Moffet and Morton, 1975).

Residues

When the phenoxy herbicides are sprayed on vegetation, a residue of the herbicide is deposited on plant foliage, on soil, on fences, poles and structures, and often onto surface waters. Of the herbicide deposits on leaves, some is absorbed into the living tissues, often killing the plant (Audus, 1976; Kearney and Kaufman, 1975; Ashton and Crafts, 1973). The residue remaining in the tissues of dead plants is largely decomposed as plant material rots; however, some is released into the soil. The herbicide remaining in surviving plants is broken down over a period of a few days to a few weeks. Forage from pastures and ranges treated with 2,4-D, 2,4,5-T, MCPA or silvex has initial residues in and on the plant material of about 100 ppm per pound of chemical applied per acre (Morton et al., 1967). Initial residues in and on forage rarely exceed 300 ppm, and this only on sparse vegetation from the heaviest allowable rates of use on grazing lands (Clark et al., 1975; Baur et al., 1969). Forage residues decline with a half-life of 1 to 2 weeks. Thus, within 2 to 4 weeks, levels have fallen into the range of one-half to one-sixteenth of the initial value.

Since domestic and wild grazing animals tolerate up to 2,000 ppm of phenoxy herbicides continuously in feed and larger amounts for short periods, there is no hazard to animals from the residues of phenoxy herbicides ingested in the forage even from treatment of ranges and pastures at exaggerated rates (Clark et al., 1971; Clark and Palmer, 1971; Norris, Montgomery and Johnson, 1977). Detectable residues do not appear in the milk of cows consuming rations containing up to 300 ppm of 2,4,-D, MCPA or silvex and up to 30 ppm of 2,4,5-T fed continuously for 2 to 3 weeks (Clark et al., 1975; Leng, 1972; Leng, 1977). The 300-ppm level of 2,4-D, MCPA and silvex is a greater exposure than would occur normally from grazing a treated pasture. Residues of 2,4,5-T can appear in the milk of cattle that are fed forage containing 2,4,5-T in concentrations of 30 ppm or more (Clark et al., 1975). To insure against residues in milk, the Environmental Protection Agency has stipulated no grazing by dairy cattle for 7 days after treatment of pastures with 2,4-D and for 6 weeks after treatment with 2,4,5-T. Residues in meat from cattle and sheep fed phenoxy herbicides at concentrations of 100 to 2,000 ppm in the feed for 28 days before slaughter are highest in kidney and liver tissues with somewhat lower levels in muscle and fat. Residues from up to 2,000 ppm of phenoxy herbicides in the feed decline rapidly to nondetectable levels within 7 days after withdrawal except for low levels of silvex in kidney tissue from animals fed silvex and low levels of 2,4,5-trichlorophenol in liver tissue from animals fed 2,4,5-T (Clark et al., 1975; St. John et al., 1964). In monitoring programs, no residues of 2,4-D or silvex were detected by the U.S. Food and Drug Administration in 13,000 samples of milk and 12,000 samples of meat from market channels analyzed for these compounds from 1963 to 1969. Trace amounts of 2,4,5-T were found in three samples. Residues of the phenoxy herbicides are also occasionally detectable in plant products used as food, although at levels so low as to be of no toxicological concern.

Residues of the phenoxy herbicides leached into the soil are bound to some extent by soil particles and are held in the upper part of the soil. They do not leach into ground water and contaminate wells and springs, nor do they move significantly into streams or to adjacent areas from surface runoff (Lawson, 1976; Brown and Nishioka, 1967; Manigold and Schultze, 1969; National Research Council, Safe Drinking Water Committee, 1977; Newton and Norgren, 1977; Sheets, Rieck, and Lutz, 1972). However, wind or water erosion that carries major quantities of soil also transports any phenoxy herbicide residues present in the soil. The diluting effect of the soil is such that levels of the phenoxy herbicide residues in the root zone of plants are normally not sufficient to injure green plants or to affect nongreen organisms such as bacteria, fungi, worms, insects and rodents.

The phenoxys are, without exception, subject to decomposition by various microorganisms that are universally present in soils (Kaufman and Kearney, 1976). When applied to soils at typical agricultural rates, 80 to 90% of added 2,4-D is usually decomposed in 1 to 4 weeks (Weed Science Society of America, 1974). MCPA may require 6 weeks and 2,4,5-T and silvex about 3 months for essentially complete destruction (Alton and Stritzke, 1973). Thus the phenoxy herbicides do not build up in the soil, and treatments can be applied to croplands year after year without accumulation.

Detectable residues of the phenoxy herbicides do not appear in surface waters unless the chemicals are directly added to the water or fall there incidental to spraying of rice or shoreline and forest vegetation or unless the chemicals are added as a water treatment for the control of aquatic vegetation. In practice, the greatest residues in streams and lakes resulting from range and forest uses are less than 0.1 ppm (Norris and Moore, 1970; Norris, 1971; Newton and Norgren, 1977). The concentration in water from treatment of rice and the spraying of floating and emergent aquatic weeds rarely exceeds 0.1 ppm (Soderquist and Crosby, 1974). Treatments with 2,4-D equivalent to several parts per million are used to control such submersed aquatic weeds as water milfoil (Smith and Isom, 1967). These are added as slow-release granules containing phenoxy esters or water-soluble amines (Bureau of Aquatic Plant Research and Control). Surface and emergent weeds are treated by spraying. Rates and application practices are designed to keep the residues in water below the 0.1 ppm tolerance established by EPA for 2,4-D in potable water and water used for irrigation.

Residues in running water are subject to dilution through stream flow, adsorption by bottom mud and decomposition by sunlight (Newton and Norgren, 1977). The concentration in streams after forest and shoreline treatments usually falls below detectable levels in a few days. In shallow waters such as rice paddies or stagnant, swampy areas, residues are decomposed by microorganisms and by sunlight. Residues decline at about the same rate as in soils. The decomposition of the phenoxys is rapid in most water, but may be slowed under conditions of oxygen deficiency.

Dioxin

A dioxin contaminant referred to as TCDD is formed in the manufacture of the trichlorophenol used to make 2,4,5-T and silvex (Blair, 1973; Milnes, 1971). The presence and significance of this impurity first became known about 20 years ago (Higginbotham et al., 1968). 2,4,5-T formerly contained TCDD at concentrations of 1 to 70 ppm, the higher levels being sufficient to cause skin eruptions called chloracne in industrial workers (Woolson et al., 1972; Kearney et al., 1973; Poland et al., 1971; Young et al., 1976). Although it has not been feasible to eliminate this contaminant entirely, present production methods are able to reduce the dioxin level routinely to less than 0.01 ppm in commercial 2,4,5-T with occasional batches containing as much as 0.05 ppm (Fisher, 1977; McQueen et al., 1977). The average level of dioxin in present U.S. production of 2,4,5-T appears to be about 0.01 ppm (Fisher, 1977; International Agency for Research on Cancer, 1977; McQueen et al., 1977). To have reduced to a thousandth of its original content an impurity in a chemical already widely used by the public and recognized as safe would appear to be a sufficient solution of this problem. However, it has become apparent that TCDD is one of the most toxic chemicals known (Kociba et al., 1975; Blair, 1973; Rose et al., 1976; Johnson, 1971). This poses the complexity of assessing the consequences of the presence of a very small amount of a very toxic substance in mixtures sprayed into the environment.

TCDD is toxic to laboratory animals at all stages of life, and it also is a weak teratogen in mice (Neubert et al., 1973; McConnell et al., 1978; Allen et al., 1977). The acute oral LD_{50} ranges from 0.0006 mg/kg (0.6 microgram per kilogram) in male guinea pigs to 115 micrograms per kilogram in rabbits (Blair, 1973). Dogs are less sensitive to TCDD than rabbits.

Among the effects are skin damage, liver damage, hemorrhage and reduced ability to cope with disease organisms. Death from a lethal dose is often delayed several weeks (Blair, 1973; McNulty, 1977). Following ingestion by the rat, TCDD is absorbed from the gut, localized in the liver and fat, and eliminated largely via the feces but to some extent through the urine (Kociba et al., 1975; Blair, 1973; Rose et al., 1976; Piper et al., 1973; Allen et al., 1975; Kociba et al., 1978). About half of the ingested material is eliminated from the body in the first 17 days (Piper et al., 1973; Fries and Marrow, 1975).

Birth defects develop when the chemical is administered during the time of pregnancy when fetal organs are forming (Sparschu et al., 1971). The effect is directly upon the developing fetus rather than on the genetics of the mother (Emerson et al., 1971; Blair, 1973). TCDD is more of a toxicant than a teratogen (McQueen et al., 1977). It usually causes death of the fetus rather than abnormalities (McQueen et al., 1977). Because of the narrow range of dosage between the no-effect level on the fetus and the lethal effect on the mother, TCDD is classed as a weak teratogen (Fraser, 1977).

The evidence shows that TCDD is from 5,000 to 500,000 times more toxic to mammals than 2,4,5-T, depending on species. Under current standards set by the Environmental Protection Agency, the content of TCDD in commercial 2,4,5-T must be less than 1 part in 10 million parts of 2,4,5-T. In practice the content is about 1 part in 100 million (Fisher, 1977). On this basis, a single toxic dose of TCDD would be contained in from 200 to 20,000 toxic doses of 2,4,5-T, depending upon the test species. Thus, the current level of TCDD in 2,4,5-T does not contribute significantly to the toxicity of herbicidal preparations of 2,4,5-T.

For a person or animal to be poisoned with TCDD without first being poisoned with 2,4,5-T would require the existence of a mechanism in nature that would separate TCDD from 2,4,5-T, greatly concentrate it and make it accessible for consumption in food or feed. Any postulated mechanism must take into account what is known about the environmental fate of TCDD.

The amount of TCDD distributed in the United States in 2,4,5-T and silvex is probably no more than 1 ounce (28 g) annually. This material is distributed over approximately 5 million acres at the rate of 5 micrograms per acre. The most sensitive species known is the guinea pig, which has an LD_{50} of 0.6 microgram per kilogram (Johnson, 1971). If we assume that we have a grazing animal about the size of a sheep or deer (175 lb or 80 kg) and the sensitivity of a guinea pig, this animal would have to consume, without excretion, all of the treated vegetation on more than 9 acres of land to get a lethal dose. If the animal had the sensitivity of a rat, it would have to consume, without excretion, all of the treated vegetation on more than 400 acres.

TCDD falling on foliage is not absorbed appreciably by plants but is rapidly decomposed by sunlight (Crosby and Wong, 1977; Plimmer, 1974; Crosby et al., 1971). When TCDD on leaves is exposed to sunlight, most of the chemical decomposes the first day. Washing into the soil by rainfall plus additional slight losses by volatility serve further to dilute and disperse the remaining residue (Helling et al., 1973). There is evidence also that TCDD is not formed when 2,4,5-T is subject to ultraviolet radiation and that it is not formed in significant quantities from 2,4,5-T when treated vegetation is burned (Stehl and Lamparski, 1977; Langer et al., 1973).

Once in the soil, TCDD residues become firmly bound to soil particles and are not appreciably taken up by plants (Helling et al., 1973; Kearney et al., 1972; Isensee and Jones, 1971). The residues do not leach downward but remain localized in the surface soil (Kearney et al., 1973). Microbial degradation then comes into play and decomposes most of the remaining chemical to basic materials over a period of probably a year or two (Matsumura and Benezet, 1973; Stark et al., 1975).

TCDD sprayed into waters rapidly disappears, due to vapor distillation into the atmosphere and to decomposition by sunlight provided the waters contain small amounts of organic compounds (Crosby and Wong, 1977). Its low solubility in water (0.0002 ppm) causes it to migrate rapidly out of solution and to adhere to any available surface on which it may be degraded in place. When sufficient supplies of the chemical are present for a long enough time, TCDD can accumulate in algae, snails and fish at concentrations exceeding those in the ambient water (Miller et al., 1973; Isensee and Jones, 1975; Matsumura and Benezet, 1973). This property is not believed to be of practical concern, however, since herbicide spraying does not lead to a substantial amount of TCDD in the environment subject to accumulation (Newton and Snyder, 1978). Analyses reveal that accumulation in food-chain organisms is not a problem (Woolson et al., 1973; Shadoff et al., 1977). The possibility of TCDD entering the food chain has been widely investigated using methods sensitive to as little as 10 parts per trillion (ppt) (Woolson et al., 1973; Shadoff et al., 1977; Mahle et al., 1977; Newton and Snyder, 1978; Bausch and Matsumura, 1975). Amounts of TCDD sufficient to cause direct toxicity or birth defects, however, have never been found in food or water as a consequence of proper herbicide spraying.

In an Environmental Protection Agency-directed test of 85 samples of fat from cattle grazed on pastures sprayed with 2,4,5-T, one contained TCDD at a concentration of 60 ppt, two had approximately 20 ppt, five had 5 to 10 ppt (lower than the test's reliability), and the remainder had no detectable TCDD (Ross, 1976; Worthington, 1978). The significance of the positive values in this survey is questionable for various reasons including (a) inadequate information on the sources of the samples, (b) the difficulties of analyzing samples for such low concentrations of TCDD in the presence of interfering substances and (c) the failure to identify TCDD in any of the corresponding liver samples (TCDD normally accumulates in the liver concurrently with accumulation in the fat) (Newton, Norris and Witt, 1978). In any event, the average levels of TCDD found in the fat and, indeed, even the highest level, represent concentrations well below the no-effect level established by EPA (U.S. Environmental Protection Agency, 1977). In the only formal experiment designed to test the accumulation of TCDD in animals in the wild, Newton and Snyder (1978) found no detectable amounts of TCDD in tissues of mountain beaver at the end of 45 to 60 days of feeding on vegetation that had been sprayed with 2 lb of 2,4,5-T per acre at the beginning of the feeding period.

Because the general public first became aware of TCDD as a very toxic contaminant in 2,4,5-T, recent poisonings by TCDD from other sources have been improperly linked to herbicides (Whiteside, 1971). There have been several accidents involving high-level exposure of persons to TCDD (Milnes, 1971; Goldman, 1972; George, 1973). One was an incident in Missouri involving waste oil used to keep down dust in stables. The oil contained TCDD and various other toxic chemicals (Anonymous, 1976; Beale et al., 1977; Commoner and Scott, 1976; Carter et al., 1975; U.S. Environmental Protection Agency, Office of Solid Waste Management Programs, 1975). A recent and more serious incident involving TCDD occurred in Seveso, Italy (Hay, 1976; Whiteside, 1977; Wallenfel, 1977). Herbicides were not involved in either of these poisonings. The incidents involved far higher levels of exposure of man and animals to TCDD than are encountered in the field use of 2,4,5-T and serve to document the safety rather than the hazard of 2,4,5-T. In the Seveso incident, for example, TCDD was released in a village at rates per acre that were millions of times greater than those that occur from 2,4,5-T treatments (Reggiani, 1977). People continued to live in the contaminated area for about 2 weeks after the accident. A number of animals were killed by the fall-out of phenolics and possibly by other chemicals, and there were numerous cases of human chloracne. No cases of severe human illness were attributable to exposure to TCDD, however, nor was there an increased incidence of human birth defects (Reggiani, 1977).

Evaluating the hazard of TCDD in the environment poses the problem of comprehending numerical values far removed from common experience. One is likely to be so overwhelmed by the very great toxicity of TCDD that he fails to comprehend the infinitesimal levels of exposure. One must recognize also the long history of safe use of 2,4,5-T containing a thousand or more times as much TCDD as at present. The evidence indicates that the TCDD contaminant in 2,4,5-T and silvex is well below levels hazardous to humans and other organisms.

SOCIOECONOMIC FACTORS

The fact that phenoxy herbicides are widely used in a variety of situations in cropland agriculture, on range lands and pastures, on private and public forests, on watersheds, and on industrial and urban sites is ample evidence that these herbicides are efficient inputs relative to available alternatives (Barrons, 1969). If the phenoxy herbicides were not relatively efficient and inexpensive, they would not be in use (United States Forest Service, 1978).

There are alternatives to the use of phenoxy herbicides, but each would cost more to achieve the same objective (United States Forest Service, 1978; Ennis, 1971; Fox, Jenkins, Andrilenas et al., 1970; Fox, Jenkins, Holstun et al., 1971; Andrilenas, 1971). Alternatives are almost always available in production processes. The relevant questions are: (1) how much do the alternatives cost, (2) who should pay the additional economic and environmental costs, and (3) why should the low-cost method be discarded in the first place (Fox, 1971)?

This report has shown that, with proper application and with current standards of production, phenoxy herbicides do not have serious unintentional side effects. Indeed, where control of weeds or woody plants is advantageous, these herbicides usually have less harmful side effects on the environment than do alternative methods of control (Barrons, 1969).

It is clear that reduced use of the phenoxy herbicides would result in increased costs to consumers. Some producers would gain at the expense of other producers and the public, hired agricultural labor might gain marginally and nonpaid farm family labor would likely lose. There would be both short-run gains and losses followed by long-run gains and losses. The net effect would be loss. The effects of restriction on forest and industrial uses have not been analyzed in detail. However, one effect would surely be increased prices of forest products (United States Forest Service, 1978). Costs to users would be mostly increased trouble and labor (Fox, Jenkins, Holstun et al., 1971).

The costs of a possible ban on all phenoxy herbicides for agricultural uses have been estimated in terms of the reduction in net U.S. farm and ranch income that would occur if alternative means of weed control were used to maintain current levels of agricultural output (Ennis, 1971; Fox, Jenkins, Andrilenas et al., 1970; Fox, Jenkins, Holstun et al., 1971; Andrilenas, 1971). The estimates were for the late 1960s, but the general conclusions would still hold today.

The estimates show that the increased costs of alternative weed control measures would total about 1% of the farm value of all crops and about 5% of the farm value of crops actually affected. The percentages of the total increase in cost borne by individual crops would be: corn, 37; wheat, 17; rice, 3; other small grains, 10; grain sorghum, 4; pastures, 11; rangelands, 12; and other crops, 6 (Fox, Jenkins, Andrilenas et al., 1970). One cost would be an enormous increase in the man-hours of labor needed to maintain production (Fox, Jenkins, Andrilenas et al., 1970; Andrilenas, 1971). *Net* farm income would not be reduced as greatly as gross farm income since farmers would naturally make their adjustments in fields and areas where control problems are the least. Consumers would not be affected under the assumption of constant total output. The demand for farm labor would rise, and farm wages could rise — a gain to labor and a cost to farmers.

Although the assumption of constant output is useful for the purpose of estimating alternative control costs, the actual adjustments would be more complex (Fox, Jenkins, Andrilenas et al., 1970; Andrilenas, 1971). With increased production costs, farm output in the affected crops would tend to decrease (Ennis, 1971; Fox, Jenkins, Andrilenas et al., 1970). One would expect a decline of less than 5% — probably 2 to 3%. Since the products involved are price-inelastic, a decline in output would generate a more than proportional increase in price (Fox 1971). Total revenue to farmers producing the affected crops would probably rise, and net income to these same farmers probably would fall — but by less than 5%. The price of farm labor might rise slightly; the prices of products to users would rise. Since most of the effects would be in feed-grain crops, much of the rise in consumer prices would probably be felt in prices of meat (Fox, Jenkins, Andrilenas et al., 1970). Cattle feeders and range cattlemen would probably be affected more than the crop producers themselves, since crop producers would be receiving higher crop prices and could make adjustments in their cropping practices and cropping patterns that would aid in maintaining farm income.

Different areas of the country would be affected in different ways. For example, there would be a rather severe income decline in the rice producing region of Arkansas, Mississippi and Louisiana, balanced by net income increases in the rice producing areas of California where growers are less dependent upon phenoxy herbicides.

All short-run adjustments end up as increases in prices of food, lumber, paper and other commodities to consumers. The exact magnitude of long-run cost increases due to banning of a particular management technique in crop, range and forest production is difficult to forecast. New technologies are developed to cope with changing situations, and managers shift from one technique to another to meet changing needs and to get the advantages of new ways of doing things. The costs of production using phenoxy herbicides cannot be forecast in comparison with the costs of new technology that might arise in the future.

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